Transforming electrical energy systems towards sustainability in a complex world: the cases of Ontario and Costa Rica

by

Francisco Ignacio Aguilar Vargas

A thesis

presented to the University of Waterloo

in fulfilment of the

thesis requirement for the degree of

Doctor of Philosophy

in

Social and Ecological Sustainability

Waterloo, Ontario, Canada, 2023

Examining Committee Membership

The following served on the Examining Committee for this thesis. The decision of the Examining Committee is by majority vote.

External Examiner	Dr. Lina Brand Correa Assistant Professor Faculty of Environmental and Urban Change York University
Supervisor	Dr. Robert B. Gibson Professor School of Environment, Resources, and Sustainability University of Waterloo
Internal Member	Dr. Ian H. Rowlands Professor School of Environment, Resources, and Sustainability University of Waterloo
Internal-external Member	Dr. Scott Slocombe Professor Department of Geography and Environmental Studies Wilfrid Laurier University
Other Member	Dr. Mark Winfield Professor Faculty of Environmental and Urban Change York University

Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Electrical energy systems have been major contributors to sustainability-associated effects, positive and negative, and therefore are considered as key components in pursuing overall sustainability objectives. Conventional electrical energy systems have delivered essential services for human well-being and can play a key role in tackling ongoing threats including growing poverty, climate change effects, and the long-term impacts of the COVID-19 pandemic. At the same time, some participants in electrical energy systems at national and local scales have stressed that the conventional design of electrical energy systems requires change to ensure the positive contributions and to reduce socioeconomic and environmental risks. Continuing negative trends including significant contributions to climate change, rising energy costs, deepening inequities, and long-term environmental degradation, have raised concerns and prompted calls for transforming conventional electrical energy systems rapidly and safely. However, due in part to the complexity of electrical energy systems, national and local authorities have struggled to steer their systems towards delivering more consistently positive sustainability-associated effects.

Usual approaches to electrical energy system management have sought to improve efficiency, reliability and capacity to meet anticipated demand. They have seldom treated electrical energy systems as potentially important contributors to overall sustainability in principle and in practice. Doing so would entail recognizing electrical energy systems as complex systems with interlinked effects and aiming to maximize the systems' positive and transformative effects to deliver multiple, mutually reinforcing and overall sustainability gains. The research reported here considered whether and how sustainability-based assessments can be useful tools to fill this gap and advance sustainability objectives in particular plans, projects, and initiatives carried out in electrical energy systems.

To aid in responding the main research questions, this dissertation builds and proposes a sustainability-based assessment framework for electrical energy systems that is suitable for application with further specification to the context of different jurisdictions. Use of the framework is illustrated and tested through two case applications – to the electrical energy systems of Ontario and Costa Rica. Building the proposed framework involved a literature review and synthesis of three foundational bodies of knowledge: sustainability in complexity, electrical energy systems and sustainability, and transformations towards sustainability. Further specifying and applying the framework to the context of the two case studies involved carrying out document research and semi-structured interviews with key participants in the electrical energy systems of the two jurisdictions. The resulting sustainability-based assessment framework from this dissertation proposes six main criteria categories that are mutually reinforcing and emphasize minimizing trade-offs scenarios. These are divided into a set of criteria for specification and application to electrical energy system-related projects, plans, and initiatives in different regions. The proposed criteria categories are 1) Climate safety and social-ecological

integrity; 2) Intra- and inter-generational equity, accessibility, reliability, and affordability; 3) Cost-effectiveness, resource efficiency and conservation; 4) Democratic and participatory governance; 5) Precaution, modularity and resiliency; and 6) Transformation, integration of multiple positive effects, and minimization of adverse effects.

Ontario's electrical energy system has significant sustainability-related challenges to overcome. The case study has shown that there is little provincial interest in following national net-zero commitments and authorities have removed official requirements for long-term energy planning to pursue climate goals and related sustainability objectives. Rising electricity prices have also raised concerns for many years and have been accompanied by limited willingness to engage in democratic and participatory processes for public review of electrical energy system undertakings. Additionally, recent commitments to highly expensive and risky options can further aggravate long-term socioeconomic and environmental negative impacts. In the Costa Rica case, adopting technocentric approaches to electrical energy system management led to a path dependency on large hydroelectricity development. This background of development of large hydroelectricity projects, without public consultation, has also created a sustained context of tension between governments, Indigenous groups and local communities, and private actors. Since the country is expected to experience changes in natural systems' patterns including intensified periods of hurricane, storm, flood, and drought, the strong reliance on hydroelectricity has at the same time raised concerns regarding the reliability of the national electrical energy system.

Both Ontario and Costa Rica have electrical energy systems that require rapid responses to contribute more positively to sustainability, and to help to reduce and reverse ongoing social and environmental crises. The two cases are also suitably contrasting venues for specification and application of the sustainability-based assessment framework developed in this work. The findings showed that while Ontario and Costa Rica have different contextual characteristics (e.g., geographical, socioeconomic, and political), overall lessons can be learned for best designing electrical energy systems in different jurisdictions. The findings also revealed that context-specific sustainability approaches do not necessarily undermine the viability for comparing multiple cases. In fact, specification to context can support comparisons by facilitating the identification of similarities and differences that are closely tied to contextual characteristics. Overall, the study of the two cases indicates significant potential for future works that focus on the specification to context and application of sustainability-based assessments specified to electrical energy systems that seek for barriers and opportunities for unlocking transformative effects.

Three key learnings were revealed by building, specifying to context, and applying the sustainability-based assessment framework in a comparative analysis of the electrical energy systems of Ontario and Costa Rica. First, the two jurisdictions require implementation of more effective options to minimize costs in electrical energy system operations and avoid economic risks that undermine the capacity of the system to provide affordable electricity for all. Second, efforts to meet democratic and participatory governance requirements have been insufficient in Ontario and Costa Rica. Both jurisdictions need to demonstrate the capacity to respect official processes for public approval and to ensure adequate representation of different actors' interests. Particularly, Indigenous people, local communities, and other groups with limited influence need more meaningful inclusion in official decision-making. Third, the two jurisdictions would benefit from implementing strategies to identify and assess possible combinations of policy and technical pathways that could help to unlock an existing dependency on options that support system rigidity.

The core overall conclusion is that application of the proposed sustainability-based assessment framework can inform better design electrical energy systems to deliver broader sustainability-related effects and advance transformations towards sustainability. However, the framework could be further developed by including insights from more key participants in electrical energy systems. The criteria set can be honed with specification to context and application to different jurisdictions, and to more particular initiatives that reflect evolving energy scenarios. Inclusion of transformation, integration of multiple positive effects, and minimization of adverse effects as a criteria category has been helpful to recognize political contexts, promote just transitions, and emphasize the interlinked effects of applying the rest of the criteria. Since this is a new component in sustainability-based assessment frameworks, the transformation criteria category will require particular attention in future applications. Among other matters, further work in the field of electrical energy systems transformation towards sustainability should also address continuing and emerging phenomena, including adverse political trends such as right-wing populism and post-truth politics, that would maintain gaps between current practices and the steps needed for progress towards sustainability.

Generally, however, while there are many needs and opportunities for more applications of the framework and additional research into the barriers to and openings for energy system transition and transformation, the sustainability-based assessment framework proposed and tested in this dissertation research should be a useful tool for directing change in complex electrical energy systems towards broader contributions to sustainability.

Acknowledgements

This dissertation is dedicated to my mother, Dr. Lupita Vargas. This venture would not have been possible without your unconditional love and support. As a single mother, coming from a modest background, you were able to overcome every obstacle to build an incredibly successful career and raise and provide for two well-educated children. Your knowledge, relentless drive, and infinite kindness have been an inspiration to many, including your family. Thank you, mom. To quote Kevin Durant: “you are the real MVP”.

To Bob Gibson, I cannot thank you enough for everything you have done for me. I have always been grateful to have you as my supervisor. Moving to Canada to pursue a PhD, and a better quality of life, would not have been possible without all your help through the entire process. We know this was not an easy endeavour. While doing this PhD, I moved and adapted to a country where I did not know anybody, improved my reading and writing skills in English to meet high quality standards, immersed into an unfamiliar field of knowledge, had to change my research topic a couple of times, endured a global pandemic as an international student away from family and friends, lost loved ones, and went through a couple of emotional meltdowns. Your patience, guidance, constant presence, and jokes were vital to overcoming all the challenges. Thank you for giving me the opportunity and believing in me.

To Ian Rowlands, you played a key role in this achievement. Your practical viewpoints and words of encouragement helped me to find a way when I was not sure where my work was going. Thank you for your dedication and for always giving me your support during stressful times.

To my committee, Mark Winfield, Scott Slocombe, and Lina Brand Correa, thank you for your contributions to this work. Your insights enriched this dissertation and challenged me to continue evolving as a researcher.

To the people from Ontario and Costa Rica that participated in the research, thank you for the conversations and for sharing your vast knowledge on themes relevant to this dissertation and to broader issues. Your expertise has been essential to attaining the objectives of this research.

To my friends, you guys are just the best, I am grateful to have you in my life. Knowing that I could always count on you, even in the distance, has meant a lot. Thank you for always being proud of me, and for your willingness to celebrate my successes and to help me get back on my feet during my struggles. José Ramirez, Armando Coronel, Diana Briseño, and Kira Cooper, you deserve a special mention. Your devoted friendship has been invaluable during this process.

To all the excellent and dedicated scholars that inspired me to pursue this PhD, your guidance at the different stages of my academic path was essential to this accomplishment. Ana Virginia Maldonado, Adriano Ciani, and José Baltazar Andrade Guerra, thank you for your positive influence.

Funding acknowledgement

This research and the projects related to the objectives of this dissertation have been funded by the National Council of Science and Technology (CONACyT) and the Secretariat of Energy (SENER) of Mexico.

Table of contents

List of tables

List of figures

List of abbreviations

ARESEP	Autoridad Reguladora de los Servicios Públicos
CENCE	Centro Nacional de Control de Energía
CEPAL	Comisión Económica para América Latina y el Caribe
CNFL	Compañía Nacional de Fuerza y Luz
DCC	Dirección de Cambio Climático
EIA	U.S. Energy Information Administration
FAO	Food and Agriculture Organization
ICE	Instituto Costarricense de Electricidad
IEA	International Energy Agency
IESO	Independent Electricity System Operator
INEC	Instituto Nacional de Estadística y Censos
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
MINAE	Ministerio de Ambiente y Energía
NRC	National Research Council Committee on Health
NRCAN	Natural Resources Canada
OEB	Ontario Energy Board
OPA	Ontario Power Authority.
REN21	Renewable Energy Policy Network for the 21st Century
SIEPAC	Sistema de Interconexión Eléctrica de los Países de América Central
UNEP	United Nations Environment Programme
WCED	World Commission on Environment and Development
WEF	World Economic Forum

CHAPTER 1. Introduction

The complexity of our world poses relevant challenges to stopping and reversing the consequences of human practices that accumulate severe and sometimes irreversible negative effects to societies and the environment. In this regard, research has shown that pursuing sustainability in a context of complexity requires paying attention to and respecting the contextualities of specific sectors and regions of application (Gibson et al., 2017). Broadly, this thesis work seeks to contribute to the study and application of sustainability as a context-specific tool to better design and evaluate the activities of key human sectors towards attaining widely accepted goals for broader social and ecological well-being. More specifically, this study considers electrical energy systems as specific venues, with major influence on environmental functions and human lives, that are crucial to advance sustainability.

First, this chapter introduces the research context that has influenced this thesis work. This consists of a general research context that positions sustainability as a relevant field of knowledge to attain more positive effects from social and ecological interactions. Also, a more specific research context is included, focusing on electrical energy systems as key contributors to sustainability-associated effects, positive and negative. Second, based on the research context, a set of overarching research questions and objectives are developed to guide this thesis work. Third, the dissertation structure is provided with a brief overview of key topics and findings discussed in the chapters comprising the research.

1.1. Research context

The world faces risky scenarios that have challenged humanity's capacity to attain broadly accepted sustainability goals for maintaining essential social and ecological systems. For instance, research has shown that current responses to climate change are insufficient to avoid threatening effects in the upcoming decades – e.g., economic instability, extreme weather, growing social inequalities, etc. (WEF, 2022). Also, human activities with severe impacts to key socioenvironmental functions have threatened the planet's biodiversity, with around one million species facing extinction (IPBES, 2019). In addition, the impacts of the COVID-19 pandemic have already exacerbated ongoing global crises and hindered progress to the Sustainable Development Goals (Hughes et al., 2021). Some reports, for example, have projected increases in people living in extreme poverty (Dooley & Kharas, 2021), threats to food security (FAO et al., 2021), and barriers to ensure access to clean water for all (Eger et al., 2021).

In recognition of the Earth having limits to what it can safely tolerate, while at the same time having to provide for everyone inhabiting it (O'Neill et al., 2018), sustainability emerges as a desirable task. Making progress towards more sustainable futures involves transforming societal structures, common assumptions, and attitudes, as well as habitual practices (Beddoe et al., 2009). However, this is particularly challenging in our contextual reality featured by complex dynamics.

Transformation in complex systems is not fully understood yet, and changes in deeply entrenched social and ecological systems can eventually cause broader and unexpected effects, positive and negative (Folke et al., 2010; Levin et al., 2013; Walker & Salt, 2006). One example is that responses to ongoing issues that failed to broadly consider the complexity of social and ecological systems can overlook social injustices and aggravate environmental pressures (Newell & Mulvaney, 2013; Swilling & Annecke, 2012). Effective democratic and participatory governance has been highlighted as key for developing policy and long-term planning to favour sustainability in a complex world (Adger & Jordan, 2009; Lange et al., 2013; Scoones et al., 2020). However, transformative change, away from the conventional and towards more sustainable paths, is relatively a nascent area of study in need for further practical and theoretical contributions (Burch et al., 2014; O'Brien, 2012; Patterson et al., 2016). Therefore, directing transformations in complex systems to enable faster and safer responses to endangering effects for humanity and the biophysical context remains a challenge.

In a context of complexity, and in need for rapid transformation, sustainability needs to consider and respect the particular characteristics of different venues and cases of application (Bond et al., 2012), instead of looking for definitive universal prescriptions (Jacobs, 1999; Kates et al., 2005). For these purposes, sustainability-based assessment frameworks can be relevant tools to evaluate and design official plans, projects, and initiatives, to contribute more positively to sustainability goals and avoid adverse effects (Gibson, 2017). However, widely adopting sustainability-based assessment frameworks will require more successful applications in diverse sectors and more favourable policy regimes (Fonseca, 2020). This thesis work has developed a sustainability-based assessment framework for application to electrical energy systems with the purpose of contributing to more effective designs of electrical energy systems that make broad contributions to sustainability.

1.1.1. Specific research context: electrical energy systems as venues for transformation towards sustainability

Conventional electrical energy systems have existed for approximately sixty years (Teske, 2010; Rutter & Keirstead, 2012), and efforts to transform them have been attempted, with greater and lesser success, for at least forty years (e.g., Lovins, 1977). While they provide many essential services, relevant calls for change have been often related to electricity systems not being yet designed to support sustainability-associated commitments. This is especially relevant since electricity-related activities (e.g., generation, distribution, and transmission) have a direct influence in attaining (or not) desirable goals for social and ecological well-being (Nathwani & Kammen, 2019). Electrical energy systems are expected to play a key role in tackling growing poverty, threatening climate change effects, and the related exacerbating long-term effects of the COVID-19 pandemic (UN, 2020). However, the conventional design of electrical energy systems can create more severe socioeconomic and environmental risks. These include vulnerability to collapse and extremely high costs, as well as high levels of pollution, toxic waste release, and harmful emissions to the atmosphere (Li, 2005; Jeffs, 2012). More specifically, electrical energy systems have gained particular attention as key contributors to climate change (UN, 2016) and as a determining sector for better or worse climate futures (IPCC, 2022).

Directing electrical energy systems to maximize their contributions to sustainability is particularly challenging since these systems are crucial for day-to-day lives and are deeply entrenched in economies and political institutions. So far, responses to pressing issues have predominantly focused on technical solutions, while less attention has been paid to key organizational and political shortcomings (Burch, n.d.; Potvin et al, 2017). This is partly because attempts to implement new governance design options can be significantly undermined by the highly disputed nature of energy system options and transition pathways. In Canada, for example, relevant gaps have been identified in policy and application between climate commitments and the design of major infrastructure, extractive projects and associated systems, including those in the electrical power sector (Gibson et al., 2018). Overall, the urgency for rapid effective action paired with the need for gradual building of public understanding and political support is one major conundrum for electricity systems to make progress to sustainability (Delina & Sovacool, 2018).

Some researchers have identified that responses to climate change and to other critical social-ecological issues are not sufficient because decision-making has not found adequate means of overcoming the barriers to change (Beddoe et al, 2009; Etzion et al., 2017). Therefore, it is crucial to enhance institutional capacity to seriously engage in reversing imperilling effects for societies and the environment (O'Brien, 2012). Considering this, this thesis synthesizes approaches towards sustainability transformations to develop sustainability-based criteria for examining and evaluating electrical energy systems in need for change to sustainability.

1.2. Research questions and objectives

This thesis work explores efforts, barriers, and opportunities, and proposes a sustainability-based assessment framework, for the evaluation and design of electrical energy systems towards sustainability in a complex world. In general terms, the scope of the study looks for assisting to close an existing gap between decision-making and sustainability-related commitments. For this purpose, a conceptual examination that uses a lens that is normative, integrative, and specified to context is developed. This aims to contribute to enhancing broad and mutually reinforcing social-ecological benefits provided by electrical energy systems. Equally important, it might aid to shed light on what are crucial implications for lessening climate and other associated risks.

The guiding principles established by the Sustainable Development Goals emphasize that sustainability-associated issues must be tackled through means that support social and ecological well-being and just transitions (United Nations, 2015). In this thesis, Gibson et al.'s (2005) set of requirements for sustainability has been adopted in this study as an appropriate basic tool for such purposes. The requirements seek broad, mutually reinforcing, and long-lasting benefits, but the criteria to be applied must be specified for the context of application. Essentially, this approach is posited as a cohesive element to guide efforts from different participants in electrical energy systems to create multiple positive contributions to sustainability as a joint effort.

More deeply, this work aims to contribute to unravelling the conundrum of short time and long politics that electrical energy systems face. This conundrum can be broadly viewed as a wicked problem. That is, a problem that is particularly pluralistic, nebulous, multi-dimensional, non-linear, dynamic, socially-constructed, and has no definitive solutions (Rittel, 1974). The problem addressed also fits in the description of a 'super wicked problem', in which there is urgency for rapid responses, lack of institutional capacity to tackle urgent issues, and decision-making that has ignored long-term effects and prioritized short-term solutions (Levin et al., 2012). Public decision-making usually has focused on technical approaches for problem-solving, and managerial tools for directing changes that aim to solve complex problems (Weber & Khademian, 2008). However, theoretical and contextual uncertainties complicate responses that transform away from dominant practices that pose severe social and ecological risks in a timely and safe manner (Olsson et al., 2014). Since problems of this type are better addressed by transdisciplinary research (Wickson et al., 2006), attempting to expand transdisciplinary learning processes, shared knowledge, and collaboration is key in this thesis.

Overall, this thesis intends to advance knowledge on how best to plan for electrical energy systems in light of sustainability-in-complexity considerations and the urgency for rapid and transformative responses. In so doing, the research may help to build understanding on how to influence deeply entrenched systems to minimize undesirable features and accumulate multiple long-lasting positive effects to their social-ecological context. In particular, the study aims to delve into how a context-specific sustainability approach (Gibson et al., 2005) can be applied for the general design of electrical energy systems and broadly support transformations towards sustainability.

Considering the research context presented above, the following research questions were developed to guide this thesis work:

1. **What can be learned from the literature on sustainability-in-complexity, electrical energy systems and sustainability, and transformations towards sustainability about how best to specify sustainability-based assessment criteria for designing and evaluating electrical energy systems in the complex context of climate change and other pressing social and ecological issues that demand transformation?**
2. **What framework of sustainability-based assessment criteria for evaluation of existing electrical energy systems emerges from the learning in response to question 1?**
3. **What can be learned from applying this framework, with further specification for context, in case studies of two quite different jurisdictions with electrical energy systems in need of transformation? In particular, what can be learned about the utility of the framework and its specification for context, and about the barriers to**

and opportunities for transforming the electrical energy systems of the two jurisdictions?

The main objective of this thesis, in accordance with the research questions, is to study the viability of designing electrical energy systems towards meeting sustainability requirements in a context of complexity and urgency to contribute to broad positive effects. The thesis work therefore aims to strengthen the comprehension of barriers and means for steps to transforming electrical energy systems towards a sustainability path. From a practical point of view, this research can support overall electricity system planning to better consider policy-making implications for contributing to multiple long-lasting sustainability benefits. For these purposes, five specific research objectives were developed to support the main objective:

Specific research objectives:

1. Synthesizing key theoretical contributions from the literature on sustainability in complexity, electrical energy systems and sustainability, and transformations towards sustainability relevant to the elaboration of sustainability-based assessment frameworks specified to electrical energy systems.
2. Building a sustainability-based assessment framework specified to electrical energy systems that is normative, emphasizes attention to sustainability in complexity, and can be further specified for application to different jurisdictions and contexts.
3. Specifying and applying the sustainability-based assessment framework to the electrical energy systems of two different jurisdictions: Ontario and Costa Rica.
4. Analyzing and comparing the main findings from the process of building, specifying, and applying the sustainability-based assessment framework to the two case studies.
5. Identifying key lessons and directions for further research relevant to the barriers to and opportunities for transforming the electrical energy systems of the two jurisdictions towards making more positive contributions to sustainability.

1.2.1. Case application: Ontario and Costa Rica's electrical energy systems

In efforts to address the research questions and objectives, this thesis has focused on the electrical energy systems of Ontario and Costa Rica as two cases for the application of the study. Ontario and Costa Rica are two jurisdictions that, in the last thirty years, have experienced transitions in their electrical energy systems, with positive and negative sustainability-associated effects. Relevant changes in Ontario have included the adoption a new electricity market model, the closure of coal-fired power plants, the implementation of official climate policy and obligations, and the removal of relevant climate policy and other previously established planning obligations by a new government. Similarly, Costa Rica has experienced transitions like including private actors in the electricity market to some extent, focusing strongly on large hydroelectricity development, and halting new and ongoing large hydroelectricity projects due to social unrest and decreasing electricity demand.

The data used to support this study was collected through a literature review, document research, and semi-structured interviews. The literature review helped to build the theoretical foundations based on key insights from the areas of sustainability in complexity, electrical energy systems and sustainability, and directing transformations towards sustainability. The document research focused on obtaining information about official decision-making, planning, policy-making, political contexts, and other salient events in Ontario and Costa Rica (e.g., government announcements, energy plans released, approval of bills, press coverage of electricity system-related events). The semi-structured interviews were conducted with eight participants with relevant experience in the electricity system of each jurisdiction (e.g., government workers, academics, community representatives). Finally, the interviews helped to gather key information to support the document research for better understanding the contextual characteristics of Ontario and Costa Rica's electrical energy systems.

In Ontario, some promising options that can contribute to sustainability-related objectives have been incorporated to the electrical energy system, but recent provincial decisions have created challenging long-term scenarios for the social and environmental context. The closure of coal-fired power plants in 2015, for instance, motivated by poor air quality and related health issues, contributed to significant reductions in harmful emissions to the atmosphere (Harris et al., 2015). Also, compared to other provinces in Canada, Ontario has an advanced capacity for implementing tools for resource efficiency, conservation, demand response, as well as renewable energy options. However, provincial decisions that have ignored national commitments to tackle threatening climate change effects pose long-term risks. With the recent removal of relevant climate policy and long-term energy system planning requirements, Ontario now projects significant increases in harmful emissions to the atmosphere for the next decade. Additionally, Ontario's failure to attain the public approval of electrical energy system-related projects through democratic and participatory governance has contributed to social pressures and cost-related challenges.

Costa Rica's geography and recent policy context has favoured large hydroelectricity generation as a key factor for preserving a renewable electrical energy system and providing broad and affordable access to electricity. While these aspects are favourable for pursuing sustainability goals, the electrical energy system also has struggled with the lasting negative effects of project development without appropriate consideration and respect for local community needs and environmental regulations. For example, around 35 electricity system-related projects that sparked public opposition because of evident social and ecological threats have been stopped in the past two decades. This at the same time has contributed to high financial losses and tensions between key participants in the electrical energy system like local communities, government authorities, and private actors. In addition, Costa Rica's electrical energy system can be highly vulnerable to ongoing climate change effects. That is, since Costa Rica has a high dependency on hydroelectricity, changing patterns in natural resource systems threaten to reduce the reliability of the electrical energy system.

Overall, the study of the two cases draws relevant insights for future works that focus on the specification to context and application of sustainability-based assessments specified to electrical energy systems.

1.3. Thesis structure

Chapter 2 examines the conceptual and practical challenges of sustainability, and the implications of pursuing sustainability in a world of complexity. The chapter also highlights sustainability as an endeavour that should be pursued in a context-specific manner to make more significant progress towards globally embraced goals. Overall, Chapter 2 positions sustainability as a base for a practical assessment tool that can be specified and applied to diverse social and ecological contexts.

Chapter 3 explores main sustainability-related issues, as well as relevant opportunities to make positive contributions towards sustainability, associated to electrical energy systems. This chapter positions electrical energy systems as relevant venues in need for transformation to decrease climate change-associated risks and contribute to attain global sustainability goals.

Chapter 4 delves into recent literature on diverse approaches to transform complex systems towards contributing more positively to sustainability. Chapter 4 also emphasizes transitions and transformations as key components of complex systems' dynamics and human-induced change. Ultimately, this chapter provides key considerations for directing change towards sustainability in particular venues – in this case, electrical energy systems.

Chapter 5 focuses on the research design and methods used for this thesis work, including the research methods selected for the study of two specific cases: Ontario and Costa Rica. This includes the description of the case selection process and the methods used for data collection and analysis (e.g., literature review, document research, semi-structured interviews). Additionally, Chapter 5 provides the processes and steps for the specification and application of a sustainability-based assessment to the electrical energy systems of Ontario and Costa Rica.

Chapter 6 and Chapter 7 focus on the case studies of Ontario and Costa Rica's electrical energy systems. The chapters provide a background and context exploration with considerations relevant to the electrical energy systems in Ontario and Costa Rica in the past three decades. Chapters 6 and 7 also outline key findings for the specification of the sustainability-based assessment framework for electrical energy systems to the context of Ontario and Costa Rica. Based on the key findings, the sustainability-based assessment frameworks for electrical energy systems are developed with specific considerations for the contextual characteristics of the two cases. Finally, the conclusions drawn for each of the cases are presented. Both chapters include conclusions relevant to the theory, framework, and implications for the jurisdiction studied.

Chapter 8 provides an overall analysis resulting from the specification and application of the proposed sustainability-based assessment framework for electrical energy systems to Ontario and Costa Rica. The analysis includes a comparison of significant similarities and differences between the findings associated to each of the main criteria categories for the specified frameworks in the two cases. The outcomes from the analysis help to support the argument that specification does not necessarily undermine comparability and can in fact facilitate possibilities for comparison between two cases with different contextual realities.

Chapter 9 consists of the key concluding insights drawn from this thesis work. The concluding chapter provides the major findings from the study, including the learnings from the main areas of knowledge consulted for this work, learnings from specifying and applying the sustainability-based assessment framework to the case studies, implications for theory and practice, and directions for further research.

CHAPTER 2. Sustainability in complexity

Sustainability has received growing attention over the years as a field of study. For at least five decades, sustainability-related studies have recognized that the Earth has a limited capacity to recover from the negative impacts of unsustainable human practices (e.g., Meadows et al., 1972). In this regard, research has shown that usual governing approaches that prioritize economic gains over social and ecological considerations have led to the accumulation of endangering impacts to life-support systems (Rockström et al., 2009) and social foundations for human prosperity (Raworth, 2012). Recent projections have revealed in this sense that current negative social and environmental trends must be reversed rapidly to avoid irreparable disruptions to the planetary context (e.g., Hughes et al., 2021; IPBES, 2019; WEF, 2022). In this context, sustainability focuses on maintaining the Earth's capacity for providing essential life-support systems, while delivering sufficiency and the foundations for opportunity and inclusion to all (Gibson, 2006). In so doing, sustainability seeks to break continuing negative trends and maximize positive effects that can lead to more prosperous futures for everyone. One main challenge to make desirable changes, however, is that sustainability is pursued in a global context of complexity. That is, the world is made of complex social and ecological systems which dynamics are uncertain, unpredictable, non-linear, can resist or enable change, and are constantly evolving (Kay et al., 1994; Slocombe, 1993; Holling, 2001).

The first section of this chapter provides a chronological examination of sustainability concepts and history through different decades, starting from the 1960s to more recent events. The second section delves into key sustainability challenges, including ideological and structural challenges. The third section focuses on complex systems thinking and examines what is known and not known about complex systems. The fourth section explores sustainability as a context-specific approach. This section is divided into three sub-sections that address the requirements for making progress towards sustainability, Canada's experience with a new generation of sustainability-based assessments, and lessons from previous applications of sustainability-based assessments. Finally, the fifth section provides a summary of the main insights drawn from the chapter.

2.1. Sustainability concepts and history

Sustainability is an old wisdom embraced by most human cultures, for most of human history (Grober, 2012). Before industrialization and its associated ideas of progress and growth, sustainability looked different. According to Gibson and colleagues (2005, Ch. 3), sustainability before industrialization sought the continuity of societies in dynamic interactions among humans, nature, and god(s) that focused on preservation and continuity (Gibson et al., 2005, Ch. 3). Modernism, however, meant the end of old sustainability (Gibson & Collins, 2016). The modern era, marked by the rise of modern science and economics, and their union in industrialization, prompted vast scientific and engineering work focused on finding ways to understand and manipulate nature for the extraction and production of valued materials (Worster, 1992). In such a regime, the characteristics of old sustainability were rejected as barriers to growth, progress, and humanity's pursuit of satisfaction.

With modern ideas and practices expanding globally, a new stage for sustainability emerged. Critiques of modern thinking appeared publicly in the early days of the industrial era (Gibson & Collins, 2016), but the long-term, increasing signals of tainted vital systems were the most alarming. Hence, the idea of sustainability was revived in light of palpable dangers of applied modernism and industrialization. In the 1960s, growing evidence of decimated forests, contaminated streams and lakes, and damage to other associated systems sparked the creation of the United Nations Conference on the Human Environment (Johnson, 2012, Ch. 1). According to some authors, this event was a significant opening for a second coming of sustainability (Gibson et al., 2005, p. 47; Kirsch, 2010). The conference represented a first glance of main institutions of the modern era widely discussing how to maintain the Earth as a hospitable place for humanity (Ward & Dubos, 1972). In the 1970s, increasing evidence drawing attention to the limitations of modern development as an approach to ensure basic sufficiency to all raised global concerns – e.g., the post World War II development agenda failing to alleviate billions of people lacking the basics of nutrition and sanitation (Ward and Dubos, 1972). In this context, sustainability regained considerable strength with Meadows and colleagues' (1972) well-known *Limits to Growth*. According to Vos (2007, p. 335), their work "set the stage for sustainability" by creating awareness of imminent risks of losing essential life-support systems.

The most well-known version of sustainability is the one defined as sustainable development by the Brundtland Commission in the 1980s. That is, a modality of development that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1986, p. 15). Brundtland and colleagues stressed the unavoidable negative effects of poverty and deprivation to the stability of the environment and the economy. While it was an important step for sustainability, this version also spurred some concerns that increased in the early 1990s. For instance, the WCED's concept was critiqued as vague, attracting hypocrites, and fostering delusion (Gibson, 1991). Likewise, as noted in the previous section, it posed risks of being "misinterpreted, distorted, and even coopted" for personal purposes (Lélé, 1991, p. 607). The WCED's approach was also critiqued as focusing mostly on the symptoms of industrial practices, lacking discussion on fundamental "changes in beliefs, attitudes and social practices" (Robinson et al., 1990, p. 39). The Brundtland Commission's work, however, also encouraged diverse parties to embrace an idea that became increasingly meaningful. Since the unsustainability of current practices has become more obvious, and superficial change has failed to deliver sustainability, the activities that pose social and ecological risks have become less defendable (e.g., Gibson et al., 2005; Shiva, 2006).

Redclift (2005, p. 212) pointed out that discussions resulting from the Brundtland Commission's work attained at most a "superficial consensus" that allowed for "parallel but distinct discourses around sustainability" to appear. Indeed, there is evidence of numerous definitions of sustainability being crafted over the years, especially during the 1990s and early 2000s. Kirkby and others (1995) identified 70 definitions between 1974 and 1992; Holmberg, according to Mebratu (1998), argued that there were more than 80 by 1994; four years later, Hill (1998) counted 160; Parkin (2000) identified 200 by the year 2000; meanwhile, as Bonevac mentions (2010), Dobson found 300 definitions also in 2000. According to Rosenau (2003), the increase in multiple and customized views has been key to a fragmentation of societal and political perceptions, and efforts to sustainability. Hence, while it is broadly desired, "there is little agreement about what constitutes sustainability" (Vos, 2007, p. 334). As result, as White (2012, p. 213) points out, sustainability as a concept can pose many "definitional difficulties, which translate into operational difficulties".

In the mid 2000s, different works addressed the definitional challenges by emphasizing that such diversity of views on sustainability can be desirable. For instance, different authors stressed that diverse perceptions on relevant social and ecological issues can provide opportunity for global debate and continuous learning, as well as discussions related to contextual issues in different regions and sectors (Gibson et al., 2005; Kates et al., 2005; Robinson, 2004). These works remarked that there is a scientific, and probably a philosophic, consensus that sustainability may not have, and does not need, a universal definition.

Some researchers, nonetheless, have continued to seek for a better illustration of sustainability as a shared vision. Namely, sustainability as a problem-solving process has been usually seen as a balance between three interconnected circles: economy, environment and society (Flint & Danner, 2001). This is commonly known as the triple bottom line, or the three pillars of sustainable development (e.g., Elkington, 1994; Norman & MacDonald, 2004; Rogers & Ryan, 2001). However, this approach has been critiqued as often seeking a balance by addressing the three circles separately, in opposition, and often prioritising the economy over the rest (Flint, 2013). While other authors have designed variations of this version (see Gibson et al., 2005, p. 58), such interactions can be far more complex in real life than usually illustrated.

More defensible views of sustainability have increasingly required economic, social and environmental aspects to be mutually supporting in ways that establish and maintain a dynamic viability in perpetuity. For instance, Robinson and colleagues' (1990, p. 39) defined sustainability as: "the persistence over an apparently indefinite future of certain necessary and desired characteristics of the socio-political system and its natural environment". Those characteristics, they add, should have capacity for change over time, given the unpredictability of such systems' interactions. One relevant example is that some sustainability applications have more recently aimed to ensure the "resilience of desirable systems and facilitate positive transitions or transformations of problematic systems" (Gibson, 2017, p. 9).

2.2. Sustainability challenges

There are critical obstacles to overcome to advance sustainability. For instance, sustainability is a very contested concept that has multiple definitions and diverse interpretations (Bonevac, 2010; Hill, 1998; Mebratu, 1998; Parkin, 2000). In this context, sustainability can be, and has been, frequently moulded in support of personal tenets and interests that sometimes can in fact undermine efforts to sustainability (Lélé, 1991; Mebratu, 1998; Smith & Stirling, 2010). Beddoe and colleagues (2009) have highlighted in this regard that predominant worldviews, institutions, and technologies in different social sectors have not favoured the overall advancement of sustainability. Instead, official authorities have usually offered incomplete solutions to reverse harmful trends (e.g., Burch, 2019; Gibson et al., 2018; Potvin et al., 2017). In addition to this, solving sustainability problems is difficult because the complexity of social and ecological systems makes such problems too difficult for governments alone to tackle successfully (Head, 2008). In this sense, sustainability-related issues are particularly pluralistic, nebulous, multi-dimensional, non-linear, dynamic, socially constructed, and have no definitive solutions (Head, 2008; Rittel & Webber, 1973; Weber & Khademian, 2008).

One challenging aspect for sustainability is that widespread ideologies and dominant structures that are in charge of determining the direction of most human activities can hinder progress towards sustainability. Usual ideologies and structures in global decision-making are based on a widespread vision of economic growth being a synonym or prerequisite for progress and a compass for technological and societal development (Beddoe et al., 2009; Du Pisani, 2006; Worster, 1993). However, some researchers have argued that economic models that are based on unstoppable growth have built enduring barriers to broad contributions to sustainability (Costanza, 2008; Daly, 2005).

While constant economic growth is usually seen as a prerequisite for prosperity, there is evidence that it does not necessarily provide chances for long-lasting social and ecological well-being (Daly, 2006; Gowdy, 1994; Kosoy et al., 2012). For instance, Kates and colleagues (2005, p. 1) point out that essential human aspirations such as “peace, freedom, development, and the environment” have not been guaranteed (Kates et al., 2005, p. 1). In fact, many do not experience the benefits of economic growth, and the consequences can be overwhelming – e.g., insecurity, poverty and deprivation (Baghwati, 1988; Hornborg et al., 2007; Kakwani & Pernia, 2000, McNeill & McNeill, 2003; Raworth, 2012). Nonetheless, as economic growth remains the model of choice, with little attention to alternatives, it must tackle crises caused by its own flaws (Kallis, 2011).

Grober (2012, p. 13) has pointed out that, historically, when production and consumption do not increase consistently, nations have declined into social and financial crises. At the same time, most sectors often overlook the physical limits to what the planet can safely tolerate without generating adverse and irreversible effects (Meadows et al., 1972; Rockström et al., 2009). Consequently, vital systems such as fisheries, forests, and water resources are today endangered (UN, 2020). In addition, the institutions designed to solve such issues are not well-suited to address sustainability-related problems in the face of complexity (Kooiman, 2003). In fact, institutional decision-making that is not cognizant of broad social and ecological systems in a context of complexity only provides short-term responses that compromise long-term aspirations (Walker & Salt, 2006).

2.3. Complex systems thinking

This section is by no means a comprehensive, in-depth exploration of complex systems thinking. Instead, it situates sustainability in a complex world by exploring contributions from diverse streams of knowledge. These include ecosystems studies, psychology, transition management, health care, geography, biometeorology, evolutionary studies, sociology, ergonomics, ecological engineering, history, among others.

2.3.1. What is known about complex systems

Complex systems theory emerged from modern systems thinking, which has its roots in the 1920s, with contributions from the fields of biology, psychology, and ecology in the study of living systems (Capra, 1996). The different fields of study focused on examining multiple interacting dynamics and interlinked effects in systems' components to understand phenomena unfolding in whole systems (e.g., the human body). Considering this, Ludwig von Bertalanffy's (1956) work identified that there are rules across different fields of study that can be generally applied to all systems but the complex interactions among their components must be considered. This theoretical approach has been recognized in many fields as a landmark for more recent complex systems thinking (e.g., Miller, 1965; Kay & Schneider, 1994; Katz & Kahn; 1978; Loorbach, 2010; Trochim et al., 2006). By using the contributions from the study of human and ecological systems, von Bertalanffy (1956) illustrated that living systems have unique behaviours that distinguish them from non-living systems (von Bertalanffy, 1956). Essentially, these ideas are the foundations of what we know as complexity.

According to Capra (1996), understanding life is understanding that living systems are constantly changing, they are self-organising, and able to learn and self-perpetuate. This has been studied extensively through decades by different streams of knowledge. As a result, whereas complex systems are difficult to grasp, some relevant lessons have been learned. For instance, contributions from ecosystem thinkers have led to the recognition of social and ecological systems being complex and inherently linked with great influence on each other (Slocombe, 1993; Levin et al., 2012; Fischer et al., 2021). Notably, social-ecological systems can sustain themselves by changing their components indefinitely, without a preferred state (Berkes & Folke, 1998; Kay et al., 1994; Velasco, 2009). This happens, normally, through non-linear interactions that can create effects at multiple system scales (Aschoff, 1967; Dekker et al., 2013; Reyers et al., 2018; Slocombe, 1993). Then, complex systems have the capacity to select from a diversity of sub-components that emerge from such interactions, favouring the continuity of the components' life (Allen & Strathern, 2003; Jorgensen & Fath, 2004; Levin, 1999).

Complex systems can also learn from experience, and communicate to smaller and larger scales, what is desirable or negative for preserving the hospitability of the system's environment (Holling, 2001; Schlüter et al., 2019; Velasco, 2009). In this regard, some of the sub-components serve as agents to push changes towards (or to maintain) what they perceive as desirable (Cinner & Barnes, 2019; Slocombe, 1993; Tainter, 2006). Noteworthy, while system behaviour can result from the dynamic qualities and effects of system interactions, it can also be influenced unpredictably by human intent. The latter, according to different authors, is driven by unique human features that emerge in response of, and are strengthened by, experiencing their social and ecological environment, sometimes varying widely on each individual (Abson et al., 2017; Bandura, 1977; Meadows, 1999; Westley et al., 2011). The same authors stress that in the face of systems delivering negative effects, human intent can intervene and push change in entrenched systems. However, since changes may happen abruptly, unexpectedly, and unpredictably (Fischer et al., 2021; McDaniel et al., 2003; Miller, 1997), complex systems can adapt and transform in the face of disturbance, and to retain vital functions, as long as they have not been too debilitated to reorganise (Holling, 1996; Masten, 2001; Rutter, 1993; Ungar, 2008; Walker & Salt, 2006). If they have, the system is at risk of collapsing, thus losing its defining characteristics (Carpenter & Gunderson, 2001; Costanza et al., 2007; Villasante et al., 2021; Yoffee & Cowgill, 1991). Finally, different scientific fields stress that the dynamics between components can greatly vary according to the social and environmental context where the components' interactions unfold (Bonner, 2004; Dekker et al., 2013; Gibson et al., 2005; Levin et al, 2012).

2.3.2. What is not known about complex systems

Scientists agree that social-ecological systems cannot be controlled. Instead, their interactions can be managed to create favourable conditions for retaining the system's desirable functions and enhancing the positive effects they can provide to all (Fischer et al., 2021; Gunderson & Holling, 2002; Kay et al., 1994; Slocombe, 1993). However, there are vital aspects of complex systems that are not fully understood yet (and may not be fully understandable). For instance, while it is agreed that complex systems are always changing, there is still not sufficient knowledge to understand how those changes happen fundamentally (Burch et al., 2014; Preiser et al., 2018; Spang et al., 2015; Venda & Venda, 1991). Hence, there is a diversity of approaches for steering systems that have negative impacts to societies and ecosystems towards more positive effects (e.g., Abson et al., 2017; Bouchet et al., 2019; Geels, 2004; O'Brien, 2012). At the same time, since such systems may have desirable characteristics to maintain, managing complex systems to change their negative characteristics while maintaining the desirable ones is extremely difficult (Brown, 2014; Olsson et al., 2014; Walker & Salt, 2006).

While relevant advances have been made since von Bertalanffy's work, we do not fully understand yet how components' interactions unfold. So far, traditional scientific methods are mostly limited to providing short-term perspectives and they cannot anticipate to a full extent the long-term consequences (Cilliers, 2005; Reyers et al., 2019; Tainter, 2000; Ravetz, 2006; Robinson, 1982). For instance, the non-linear dynamics and unlimited capacity of complex systems to change constantly in space and time defeat the planning and modelling strategies often used in institutional decision-making (Francis, 2006; Levin et al., 2012; Preiser et al., 2018; Robinson, 1982; Velasco, 2009). In addition, systems' agents may perceive differently what is desirable for the system since they experience different realities and have different priorities.

Hence, while system agents can influence positive effects, they also have the capacity to resist overall change if it threatens their favourable individual states (Burch et al., 2014; Smith & Stirling, 2010; Voß & Bornemann, 2011). Finally, all of this happens within unclear boundaries, making it difficult to identify, categorize and study systems' components and scales (Cilliers, 2001; Metzger & Muller, 1996; Richardson & Lissack, 2001). Hence, despite key findings, complex systems thinking has an uneven acceptance – while in some areas of research it is highly influential, in others it is mostly ignored or rejected (e.g., Capra & Luisi, 2014).

2.4. Sustainability as a context-specific tool for application in a complex world

In our complex reality, sustainability cannot be presented as a definitive global prescription. In this sense, rigid sustainability approaches can create windows for undesirable applications (Jacobs, 1999). Instead, sustainability in complexity should be treated as a continuous process (Kemp, Loorbach, & Rotmans, 2007) that manages opportunity in conflicting views (Scoones et al., 2020; Sneddon et al., 2006) emerging from contextual issues (Adger et al., 2003; Gibson et al., 2005; Weaver & Rotmans, 2006). Therefore, the characteristics for desirable futures and the implications for present choices must be determined in a context-specific manner (Bond, Morrison-Saunders, & Pope, 2012; Costanza & Patten, 1995).

Context-specific sustainability can be pursued by assessing "the potential impacts of a wide range of relevant initiatives (such as legislation, regulations, policies, plans, programmes and specific projects) and their alternatives on the sustainable development of society" (Devuyst, 2000, p. 68). This endeavour entails questioning whether existing policy-making considerations define adequately whether current or proposed projects contribute to and enhance social and ecological well-being (Gibson et al., 2016; Francis, 2006; Pope et al., 2017; Winfield, 2016). For instance, enhancing the consideration, clarification and formalization of sustainability-based decision making for any proposed undertakings is crucial (Pope et al., 2017). In addition, the extremely complex nature of the world must be acknowledged in determining the contextualities of each case (Gibson, 2016).

Different scientists have focused on developing criteria for making progress towards sustainability in specific cases. For this thesis work, the literature review has identified three different types of sustainability-based assessment efforts. First, first generation sustainability-based assessment efforts that have not yet incorporated explicitly the dynamics of our complex reality. Recent examples include Horn and colleagues' (2018) sustainability assessment framework focused on the life cycle of building materials. While this approach emphasizes resource maintenance and sustained social and economic functions, it overlooks non-linearity and unpredictability of both social and ecological systems. Another example is the sustainability assessment framework for higher education institutions developed by Alshuwaikat and others (2016). In this assessment, the authors consider citizenry, public participation, conservation, creating opportunity, and long-term economic sustainability. In some instances, however, this work ignores issues of multi-scale effects, contextual considerations and the capacity of the system to resist change. Also, Fang and colleagues (2015) propose a sustainability assessment framework that integrates environmental footprint and planetary boundaries' considerations. This approach strongly favours, for instance, the consideration of environmental boundaries, multi-scale effects and scale-specific characteristics. Nevertheless, it does not provide enough emphasis on societal and economic effects and contextual issues, and the haziness of social and ecological systems' boundaries.

Second, efforts that have paid attention to complexity in sustainability assessment efforts, with greater or lesser success. Some illustrations include the works on energy systems by Gaudreau (2013), forestry by Jastremski (2017), solar photovoltaics by Moslehi and Arababadi (2016); beef cattle ranching by Santos and others (2017), and agri-food systems by Peano and colleagues (2015). These works have considered important elements retrieved from complexity thinking like emphasizing the need for specification to context, attention to multi-scale effects in the development of the criteria, and consideration of potential trade-offs that may emerge from the application of the assessment framework While these works have advanced the consideration of complexity, they also point to directions for further research in sustainability assessment-related studies. In summary, further research requires focusing on:

1) defining requirements, specified for particular sectors, that should not be overlooked in any situation; and
2) identifying contextual barriers and opportunities for transforming towards a new generation of official sustainability-based assessments.

Third, relevant approaches that have addressed the previous two points and can provide guidance in pursuing such objectives in an integrative manner (e.g., Bond et al., 2012; Dalal-Clayton & Sadler, 2014; Government of Western Australia, 2003; Hacking, 2019; Gibson, 2016). One general contribution from these works is that they focused attention on multiple criteria that address time and spatial equity in resource access and opportunities, trade-offs avoidance, governance, learning, and inclusion in decision-making.

2.4.1. Basic requirements for making progress towards sustainability

For the normative and descriptive purposes, Gibson and others' (2005) work frames the unifying outcomes of sustainability assessment experience. One relevant outcome is the identification of a set of requirements for making progress towards sustainability that should not be overlooked in any context (Table 2.1). This approach has been useful for assessing the contributions to sustainability benefits, at strategic and project levels, in diverse cases (Gibson, 2017). The set of requirements is based on many years of debates, research and practical experience on applied sustainability. As result, basic principles can now be agreed upon (or are at least difficult to challenge) when evaluating sustainability in any context (Cohen 2017; Gibson 2017; Kuzdas et al., 2016; Luederitz et al., 2013; Suprayoga et al., 2020). It must be noted, however, that the requirements are only the basic elements that need to be considered. Hence, significant contributions need to be made in each of them depending on context. Nevertheless, they can inspire processes for criteria development through further research, contextualization, learning, knowledge application, innovation, and creativity (Atlin, 2019; Jastremski, 2017). Finally, while this approach has not been fully adopted by governmental authorities, and has been described as too demanding, there has not been contestation in the scientific community about the validity of the requirements (R. B. Gibson, personal communication, June 12, 2019).

Table 2.1. Requirements for progress towards sustainability (based on Gibson et al., 2005)

Socio-ecological system integrity	Build human-ecological relations that establish and maintain the long-term integrity of socio-biophysical systems and protect the irreplaceable life support functions upon which human as well as ecological well-being depends.
Livelihood sufficiency and opportunity	Ensure that everyone and every community has enough for a decent life and opportunities to seek improvements in ways that do not compromise future generations' possibilities for sufficiency and opportunity.
Intragenerational equity	Ensure that sufficiency and effective choices for all are pursued in ways that reduce dangerous gaps in sufficiency and opportunity (and health, security, social recognition, political influence, etc.) between the rich and the poor.
Intergenerational equity	Favour present options and actions that are most likely to preserve or enhance the opportunities and capabilities of future generations to live sustainably.
Resource maintenance and efficiency	Provide a larger base for ensuring sustainable livelihoods for all while reducing threats to the long-term integrity of socio-ecological systems by reducing extractive damage, avoiding waste and cutting overall material and energy use per unit of benefit.
Social-ecological civility and democratic governance	Build the capacity, motivation and habitual inclination of individuals, communities and other collective decision-making bodies to apply sustainability principles through more open and better informed deliberations, greater attention to fostering reciprocal awareness and collective responsibility, and more integrated use of administrative, market, customary, collective and personal decision making practices.
Precaution and adaptation	Respect uncertainty, avoid even poorly understood risks of serious or irreversible damage to the foundations for sustainability, plan to learn, design for surprise and manage for adaptation.

Immediate and long-term integration	Attempt to meet all requirements for sustainability together as a set of interdependent parts, seeking mutually supportive benefits.

Nonetheless, there are recurring gaps between the theory and application. One of them is that there is little interest shown by governmental authorities in clarifying the implications of effectively attaining sustainability-related commitments (Gibson et al., 2016; Hacking, 2019; Kirsch, 2010; Yaylaci, 2015). As consequence, incomplete and insubstantial versions of sustainability assessments have been used as the normative tools for official projects in diverse contexts. In fact, authorities sometimes dismiss requirements for attaining approval of initiatives proposed for the sake of short-term, political and economic purposes (Winfield, 2016). Notably, obscure strategic processes in, for example, mining (Yaylaci, 2015), energy systems (Gaudreau, 2013), food systems (Clapp & Fuchs, 2009), and water systems (Wiek & Larson, 2012) have weakened contributions to attain overall sustainability goals.

2.4.2 Next generation sustainability-based assessments: Canada's experience

In order to effectively address the most pressing issues faced by ecological and social systems, renewed and more meaningful sustainability-based assessments can be relevant decision-making tools in the near future at strategic and project levels. However, while sustainability-based evaluations are key for maximizing positive social and ecological effects, they cannot be developed and implemented effectively if they are not supported by favourable regimes (Atlin, 2019; Fonseca, 2020; Gibson et al, 2016; Johnston, 2016). In Canada, for instance, there has been increasing consensus on the need to improve federal and regional impact assessment regimes (e.g., Fonseca, 2020; Johnston, 2016). Some authors argue, in this regard, that sustainability-based assessments need to shift away from first generation assessments – that is, impact assessments that focus mostly on mitigating adverse environmental effects (Gibson et al., 2005, Ch. 2). Instead, bigger efforts to embrace complexity and deliver more positive and mutually reinforcing effects to societal well-being and environmental health are needed (Gibson et al., 2016). However, despite decades of experience and some relevant successes, impact assessment that follow formal regimes are still significantly flawed and rarely designed to deliver broad, desirable long-lasting effects in an increasingly complex world (Johnston, 2016).

While project-level impact assessments can provide essential benefits – identifying the need, purpose, alternatives and potential cumulative effects of individual undertakings – its project-centred scope is nevertheless limited (Doelle, 2012). Broader policy-making that enables mutually reinforcing interactions among projects and programmes is needed (Carver et al., 2012). In this sense, developing impact assessments at strategic levels (e.g., policies, plans and programmes) is essential for integrating objectives at multiple jurisdictional levels. However, strategic environmental assessment processes tend to be debilitated by strong resistance from vested, often powerful, interests and by a poor understanding of sustainability-in-complexity (Croal et al., 2010). In addition, shortcuts taken in favour of "faster, easier and cheaper approvals" have spurred conflict and delayed effective action (Gibson et al., 2016, p. 252). Most jurisdictions, as a result, have often overlooked elements that enhance governance capabilities for sustainability – such as participation, collaboration and learning (Doelle and Sinclair, 2010). This has undermined impact assessments' overall transparency, legitimacy and fairness, diminishing the prospects of both rapid and effective decision-making to endangering issues (Winfield, 2016). Findings pointing at significant deficiencies, lack of commitment, and signs of stagnation have led to a need of rethinking governmental decision-making approaches (Johnston, 2016).

A meaningful pursuit of sustainability requires assessment undertakings to focus on maximizing positive contributions to the social, economic and biophysical context through legal and policy tools. However, this needs to be done in ways that at the same time are "more integrated, farsighted, open, efficient, credible and defensible, and most importantly, more likely to bring consistent delivery of lasting benefits from strategic initiatives" (Benevides et al., 2009, p. 30). Notably, the Canadian *Impact Assessment Act* passed in 2019 is an initial effort to shift from conventional impact assessment towards a contributions-to-sustainability-based assessment (Government of Canada, 2019). While this initiative is still incomplete and timid in implementation guidance and practice, it has potential for an initial step to the emergence of sustainability-based assessments (Gibson, 2020).

2.4.3. Lessons from previous applications of sustainability-based assessments

Some works in the literature have done relevant contributions to advancing complexity thinking for a new generation of sustainability-based assessment efforts. In this regard, sustainability-based assessment frameworks inspired by Gibson and colleagues' (2005) thinking have been applied to various undertakings in diverse contexts. These works have emphasized the integration of complexity to sustainability assessment endeavours. As a result, applications of the framework have yielded unique lessons and significant contributions to the literature and to the enhancement of further applications. Table 2.2 illustrates some key insights collected from the various cases. These works have drawn deeper and richer conclusions than shown in the table. For the purposes of this research, however, the table focuses on displaying lessons relevant to future applications, perhaps paving the way to more ambitious goals.

Table 2.2. Insights from previous applications of sustainability-based assessment guided by Gibson et al.'s (2005) approach

Authors	**Context**	**Insights**
Atlin, 2019	Mining in Northern Ontario, Canada	Sustainability-based assessment can aid in identifying deeply rooted issues such as cumulative and legacy effects, as well as alternatives to tackle them more effectively

Berggren, 2018	Decision-making in the Colorado River Basin, USA	Stakeholder participation, transparency and fairness are key for effective decision-making towards sustainability Focusing on improving decision-making processes may greatly favour better specification and applications
Brundiers & Eakin, 2018	Post-disaster windows of opportunities for change towards sustainability (multiple locations)	The application of the framework shed light on contextual factors that affect disaster-to-sustainability transitions The framework should have the flexibility to incorporate already existing as well as future theoretical and empirical contributions for application While every case will be different, requiring contextualisation and specification work, experience from application in diverse contexts will help in advancing towards sustainability-based assessment regimes
Cohen, 2017	Systematic review of urban sustainability assessment literature	Future research will need to establish guiding principles (limited to five), build goal-oriented assessment frameworks under these principles, and test the frameworks with empirical assessment studies Sustainability-based assessment can aid in bridging gaps between the disjointed literature in urban sustainability assessment
Doelle, 2017	Assessment of a proposed hydroelectric power Project in Labrador, Canada	Applications can be significantly hindered by lack of clarity in policy, and by unfamiliarity with the sustainability-based assessment approach Processes of contextualisation and application are not extremely complicated, but special attention has to be directed to trade-offs resolution and lasting effects in clear and transparent ways

Gaudreau, 2013	Energy systems in Barbados, Brazil and Senegal	There are considerable difficulties in qualitative assessments without more quantitative indicators The framework has great potential to be applied in many diverse situations
Gibson, 2011	Application of a contribution to sustainability test by the Joint Review Panel for the Canadian Mackenzie Gas Project	Sustainability-based assessments must be further elaborated and demonstrate their contributions to particular assessments The government's mostly negative response to the framework's recommendations points to an even larger challenge. How can we design and undertake sustainability-based assessments so that they are more effectively influential? The Mackenzie Panel's work stands as Canada's most fully developed contribution to the pursuit for sustainability-based assessment regimes. Especially, it helped greatly to identify issues and propose options related to cumulative and legacy effects, equity and multi-scale impacts
Jastremski, 2017	Forestry in Quebec, Canada	Addressing agency and power of main actors involved is a major challenge
Kuzdas et al., 2016	Sustainability assessment of alternative water governance regimes for Guanacaste Province, Costa Rica	The framework helped in clarifying sustainability priorities for water governance in the community Since communities cannot suddenly disconnect from larger-scales' unsustainability without experiencing dangerous effects, gradual transition and multi-scale alignment is necessary
Lamorgese & Geneletti, 2013	Analysis of Italian urban planning	The specification of the framework can effectively spark contributions to the requirements in application It can aid in clarifying strategies for attaining sustainability-related commitments, but clarifying equity concerns in light of plurality needs further research

Luederitz et al., 2013	Guiding principles for sustainable urban neighborhood development	Further contributions are needed to improve overall sustainability requirements for neighborhoods, and for associated sectors relevant to the sustainability of urban neighborhoods The authors propose a roadmap for developing comprehensive and sufficient overall principles (or requirements) for sustainability: 1) Complement the integrated principle set, 2) develop a sufficient principle set, 3) evaluate the impacts of the sufficient principle set, and 4) apply and evaluate the sufficient principle set The framework has the potential to bridging gaps between cultures, disciplines, and between science and society to foster sustainability in and of urban areas
Partidário, 2017	Energy-, marine-, and urban planning-related cases in Portugal	Sustainability-based assessments benefit greatly from strategic thinking in planning processes Building trust and collaboration is crucial for maximizing sustainability gains Strategic assessments can, to some extent, inform project-level assessments
Shah & Gibson, 2013	Large dam development in India	Qualitative and quantitative indicators may be needed for deciding among options and monitoring longer-term effects The specified framework can be developed for further application in other similar cases It can inform policy making for future project-level assessments
Stuart et al., 2014	Municipal planning in Ontario, Canada	Special attention must be given to policy contextualities in the specification and application processes The framework revealed a need for better policy alignment at multi-jurisdictional levels and helped in identifying multi-scale limitations

		Planning must be flexible and modular to favour mutually reinforcing interactions
Suprayoga et al., 2020	Systematic review of indicators to assess the sustainability of road infrastructure projects	Precaution and adaptation, and intergenerational equity need particular attention as they are difficult to represent through criteria and indicators More empirical and theoretical contributions to sustainability-based assessments are needed, not only to improve the frameworks, but also to identify processual and contextual barriers and opportunities
Talukder and Hipel, 2020	Sustainability diagnosis of trans-boundary water governance in the Great Lakes basin	The experience from application can inform a basis to formulate, upgrade, or coordinate existing and future trans-boundary water resources management Developing a set of requirements and criteria towards context-specific sustainability can help in understanding the implications of more effective bilateral water governance
Winfield et al., 2010	Electricity planning in Ontario, Canada	Sustainability-based assessment has the capacity to cover contextual sustainability requirements and issues as equally important; To aid in best planning for avoiding trade-offs; and To contribute positively, and fairly to interlinked social, ecological, economic and technological spheres

The table shows that some of the insights overlap directly or indirectly (e.g., Gaudreau, 2014; Shah & Gibson, 2011), but more important is that most appear to be complementary (e.g., Lamorgese & Geneletti, 2013; Luederitz et al., 2013; Partidário, 2017). As previously mentioned, the experience from past applications of context-specific, sustainability-based assessments creates opportunity for advancing knowledge. These insights, therefore, need particular attention in future applications if new regimes of sustainability-based assessments are to emerge and be established.

2.5. Summary of key lessons

Sections 2.1 and 2.2 provided lessons relevant to pursuing sustainability in a complex world. For instance, the literature has shown that making progress towards sustainability entails facing difficult conceptual, practical, ideological and structural challenges. To summarize:

- There is little agreement on what sustainability means, and that can be positive. Multiple visions of sustainability have been developed for decades, and some of them emerged to favour personal interests. Because of this, there has been some distrust and opposition towards the concept and practical efforts. However, having multiple perspectives on sustainability also create opportunity for debate, discussion, and continuous learning. Diverse approaches can provide relevant insights for more effective applications in particular contexts.
- New visions of sustainability must consider the complexity of our world. Sustainability cannot be attained only by providing means for the social, ecological, and economic pillars to solve their own related issues. These three are inherently interconnected – whatever happens in one, affects the others, positively or negatively. In this context, avoiding trade-offs is an essential (and very challenging) task. This entails that sustainability must be approached as a moving target, rather than a fixed one. Therefore, rigid conceptualizations and prescriptions to sustainability are not effective.
- We must emphasize planning for ever-changing systems full of uncertainty and unpredictability. Complex systems are self-organising, and they can learn and change, based on experience. Hence, searching for solutions by recreating past system dynamics, and predicting future ones, from the present is ineffective. In this sense, inclusive and transparent deliberation is crucial since there may be many different perceptions on what desirable characteristics for a system are. Also, multi-scale effects must be a key aspect in planning and decision making for social and ecological sustainability. This includes consideration of both time and spatial scales.
- Complex systems have the capacity to absorb impacts and retain their main functions. However, this capacity is limited. While complex systems have the capacity to learn and adapt over time, we do not know exactly how much these systems can safely tolerate before they collapse and change their defining characteristics. Also, while it is not possible to control complex systems, we can learn, manage, and communicate to identify overall emerging barriers and opportunities for advancing sustainability in a world of complexity.
- Sustainability-related problems and the likely effects of response options are too difficult to fully understand in a context of complexity. The problems that sustainability aims to solve are hard to identify, we do not know the extent of their impacts, and they do not have straightforward, neither definitive solutions. Accordingly, they cannot be tackled by one entity alone (e.g., the local, provincial or national government). Precautionary approaches (favouring low-risk options, reversibility, etc.) are therefore appropriate. One key consideration in this regard is that sustainability does not mean achieving and

maintaining a preferred fixed state. Instead, it means making continuous positive contributions to the sustainability of systems' dynamics and the benefits they can provide.

- Sustainability contributions must be fair, broad, and mutually reinforcing. Over-assertion of one main component over the others can debilitate the whole system, putting it at risk of irreparable consequences, including collapse. Therefore, relevant actors must be a relevant part of broad sustainability efforts since they can either help to push them forward or undermine them.
- Many approaches to sustainability-based assessment still fail to explicitly recognize complexity. Some sustainability-based assessments in usual policy-making regimes show evidence of an insufficient regard for complexity – e.g., hazy boundaries, varied perceptions on what is desirable, multi-scale effects in time and space, agency and power, and planning for unpredictability and surprise. In this sense, a new generation of sustainability-based assessment that better deal with the complexity of our world entails moving towards new regime shifts. Some key changes include paying particular attention to 1) delivering broad and maximum contributions to social and ecological well-being, 2) designing policy-making that enables mutually reinforcing interactions between jurisdictions and projects, 3) fostering more transparent, participative, collaborative, inclusive and democratic processes, and 4) providing multiple, long-lasting benefits.

Finally, previous applications of sustainability-based assessments in the scientific literature have provided key insights that must be considered in future studies and applications. The insights are related to the potential of the sustainability assessment framework to be further developed and applied to more diverse contexts. At the same time, specification and application does not have to be very difficult, but special attention must be given to decisions on trade-offs, equity and cumulative and legacy effects. Moreover, conflicting agency and power is a major challenge to be addressed. Sustainability-based assessments, overall, can be useful tool to maximize sustainability gains in collaborative, inclusive, democratic, transparent, and fair ways. While more experience is necessary, past applications of context-specific sustainability-based assessments have delivered promising lessons for future research.

The next chapter (Electrical energy systems and sustainability) will link the key lessons of sustainability in complexity to electrical energy systems. More specifically, the chapter will examine electrical energy systems as main providers of essential services for social and ecological well-being, and as key contributors of adverse effects that have aggravated social and ecological issues.

CHAPTER 3. Electrical energy systems and sustainability

This chapter aims to position electrical energy systems as crucial components for increasing overall, positive sustainability effects. The first section argues that energy systems need change due to key sustainability challenges that are relevant to electrical energy systems. More specifically, this section identifies the main sustainability, complexity and electrical energy systems aspects in the literature that need particular consideration for specification of evaluation criteria for electrical energy systems. In the second section, Lovins' energy paths are adopted as a lens to examine more recent thinking on electrical energy systems' issues. Recent literatures relevant to energy paths are studied in five main themes: 1) renewable energy; 2) decentralization and diversification; 3) energy justice and democracy; 4) modularity, flexibility and resiliency; and 5) conservation and efficiency. The third section aims to distinguish a) *sustainability of the electricity system* from b) *electrical energy systems contributing to sustainability*, and the latter objective is posited as the foundation for a desirable approach for electricity systems' design. Finally, an initial sustainability-based assessment framework specified to electrical energy systems is proposed in the fourth section. The assessment criteria categories are based on the incorporation of basic sustainability-based assessment requirements, electrical energy system specification factors and contributions from previous sustainability assessment work. Moreover, the sustainability requirements of specification and integration and trade-off rules are discussed as further stages of analysis.

3.1. Energy systems and change

Energy and sustainability are intrinsically linked in complex ways. For instance, while energy systems are vital to basic human aspirations, they also contribute to the most pressing social and ecological issues worldwide (Casillas & Kammen, 2010; Dinçer & Bicer, 2020, Ch. 1; IEA, 2019a; Novakovic & Nasiri, 2015, p. 19; Santoyo-Castelazo & Azapagic, 2014). In this regard, the UN (2016) has remarked that, "energy is central to nearly every major challenge and opportunity the world faces today. Be it for jobs, security, climate change, food production or increasing incomes, access to energy for all is essential". Therefore, energy systems are critical category of complex systems in need of change towards sustainability.

3.1.1. Sustainability challenges of energy systems

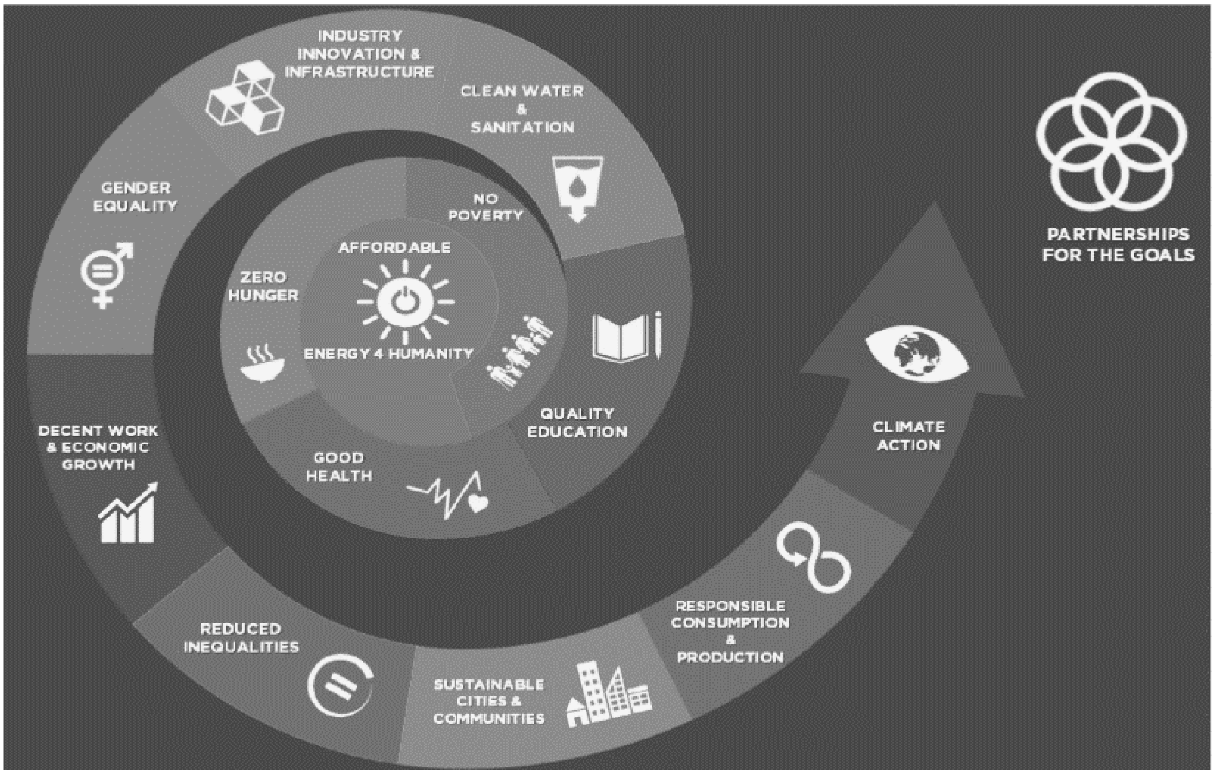
Energy systems have had, and continue to have, significant positive and adverse effects for the integrity of social and ecological systems. For instance, while providing essential services and improving quality of life for many (UNEP, 2019), energy systems also have boosted threatening effects for all – e.g., negative climate change-associated effects (Akella et al., 2009; Holland et al., 2019; Kim, 2007). Energy systems play a vital role in ensuring safe planetary conditions or irreversibly surpassing Earth's biophysical boundaries (Rockström et al., 2009) and in supporting or undermining required foundations for societal well-being (Raworth, 2012). Moreover, current irreversible effects pose bigger concerns for the future, and energy systems' role in overall well-being is expected to be equally or more important, for better and/or worse (e.g., UN, 2020).

Maximizing energy systems' contributions to sustainability is essential to provide multiple positive effects that are mutually reinforcing to the broader social and ecological well-being. The UN's (2016) Sustainable Development Goal 7 (affordable and clean energy), for example, has highlighted that energy systems must attain key sustainability-related targets by 2030 to avoid severe irreversible social and ecological impacts:

1. Ensure universal access to affordable, reliable and modern energy services.
2. Increase substantially the share of renewable energy in the global energy mix.
3. Double the global rate of improvement in energy efficiency.
4. Enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology, and promote investment in energy infrastructure and clean energy technology.
5. Expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries, in particular least developed countries, small island developing States, and land-locked developing countries, in accordance with their respective programmes of support.

In this regard, Nathwani and Kammen (2019) have emphasized that ensuring universal access to clean, affordable, and reliable household cooking facilities and electricity provides multiple positive contributions to all the Sustainable Development Goals (Fig 3.1). Similarly, other authors have identified energy-related sustainability goals as key to advance ecosystems integrity, opportunities for better health care and education, economic development, and equity benefits (Balachandra, 2011; Battacharyya, 2012; Nayan Yadava & Sinha, 2019; Serwaa Mensah et al., 2014). For instance, maximizing energy systems' contributions to sustainability can play a key role in tackling the undermining effects of the COVID-19 global pandemic that have exacerbated ongoing global crises – e.g., expected increases of billions of people in poverty and associated climate change effects (UN, 2020).

Figure 3.1. Nathwani and Kammen's (2019, p. 1781) illustration of energy access as a multiplier of the Sustainable Development Goals



Conversely, failure to maximize positive contributions to sustainability and reverse negative trends can result in severe and irreversible effects to global and local socioecological contexts. Some reports, for example, have shown that energy systems are major contributors of greenhouse gas and other harmful emissions that aggravate climate change. Roughly, two-thirds of global greenhouse gases in the atmosphere have been emitted by energy system activities (UN, 2016). In fact, the number of emissions has been increasing continuously despite global commitments to tackle threatening climate change-associated effects (IEA, 2019b; UNEP, 2019). A recent report published by the United Nations Environment Programme (UNEP, 2019) showed that energy systems emission increases averaged 1.5% yearly in the last decade, setting a historic record of 55.3 GtCO2e in total emissions in 2018. Also in 2018, energy systems' yearly emissions average increased 2%, with a record of 37.5 GtCO2 per year (UNEP, 2019).

One key consideration is that the increasing demand for natural resources for energy system purposes (e.g., metals, non-metallic minerals, fossil fuels, biomass, water, land) has been one major contributor to climate change and other severe negative effects (IPBES, 2019; Oberle et al., 2019). For instance, studies have shown that energy systems' operations for resource extraction have been key to global increases in the average of material demand per capita – from 7.4 tonnes per capita in 1970, to 12.2 tonnes per capita in 2017 (Oberle et al., 2019). At the same time, damages to ecosystems and releases of harmful substances to the environment associated to the increasing extraction of natural resources have posed, and already caused, severe irreversible impacts – e.g., poor air quality has caused millions of deaths (UN, 2020), and roughly one million flora and fauna species face extinction (IPBES, 2019).

Another key challenge is that official actions proposed to increasing energy systems' contributions to sustainability have usually emphasized technical and other narrow focuses on reducing carbon emissions over equally relevant equity considerations (Healy & Barry, 2017; Jenkins, 2018; Jones et al., 2015). For instance, different authors have drawn attention to the unfair distribution of environmental and economic risks and benefits of electricity-related activities (Healy & Barry, 2017; Jones et al., 2015; LaBelle, 2017; Sovacool et al., 2017; Stadler et al., 2018). That is, there is a significant disproportion between the global use of natural resources as fuel for human activities and the economic revenue of some regions over others (e.g., Tukker et al., 2014; UNEP, 2019). Also, while considerable progress has been made, energy systems have continued to fail in providing access to reliable electricity to almost one billion people disadvantaged by such a disparity (IEA, 2022; UNEP, 2019). This means, according to Jones and colleagues (2015, p. 149), almost one billion people struggling with "fewer educational opportunities, less access to fertile land and other natural resources, poorer health, negligible political representation, limited economic opportunities, and inadequate access to health services".

Energy systems need to be better governed through democratic and participatory processes to deal with unavoidable and unexpected needs for system change towards sustainability. Hiremath and colleagues (2007), for instance, have stressed that effective democratic and participatory governance processes are vital to tackle the unfair distribution of risks and benefits provided by energy systems, especially in remote and urban areas. One major problem, however, is that energy policy- and decision-making responses usually are inclined, and too often willing, to overlook crucial requirements for democratic and participatory governance (Alstone et al., 2015; Walker & Cass, 2007; Kuzemko et al., 2016; Miller & Richter, 2014, p. 76; Sovacool et al., 2017). According to different authors, this has undermined energy systems' capacity to facilitate the collective action and integration knowledge necessary for better understanding and tackling energy-related and broader sustainability issues (Baldwin et al., 2018; De Pascali et al., 2020; Goldthau, 2014; Stirling, 2014). Similarly, other authors have pointed out that while having long periods of life, energy systems have a low adaptive capacity to foster and integrate innovative knowledge and promising technological advances in support of mitigating adverse effects (Mitchell, 2016; Papaefthymiou & Dragoon, 2016; Shah, 2020; Lund et al., 2015). As a result, energy system projects that are usually approved without appropriate assessment, consultation or consideration of societal and environmental impacts, have created lasting negative effects (e.g., social conflict, public health issues, and extremely high costs and financial losses) (Winfield, 2016).

3.1.2. Characteristics of conventional electrical energy systems

Conventional designs for electrical energy systems have been predominant for approximately seventy years (Teske, 2010, Rutter & Keirstead, 2012). Electrical energy systems are subcomponents of energy systems that focus on the generation, transmission, and distribution of electricity services, and have enough generation capacity to provide electricity for entire regions (Government of Canada, 2020). To do so, conventional electrical energy systems are powered majorly by oil, coal, and/or natural gas (Oberle et al., 2019), and some are supported by major nuclear or hydropower generation facilities and/or make use of renewable energy to a lesser extent (IEA, 2019a).

Since they power the most essential services for human prosperity (e.g., health, food, education, transportation, etc.) (UN, 2016), electrical energy systems have a long-recognized vital responsibility of ensuring accessible, reliable, affordable, and acceptable electricity for all, at all times (Kruyt et al., 2009). Additionally, electrical energy systems have been approached globally as a key matter for national security. That is, the supply of reliable electricity is essential to ensure energy security, including self-sufficiency and capacity to respond to threats and unexpected events, in different dimensions – e.g., geopolitical, economic, political and technological (Aslantürk & Kıprızlı, 2020; Dźwigol et al., 2019; Kiriyama & Kajikawa, 2014). Therefore, some large electrical energy systems are designed to generate and distribute over hundreds of billions of kilowatts of electricity per year (Conca, 2017).

This context has positioned electricity and its associated sectors as key actors in nations' economies. In 2018, for instance, the Canadian energy sector generated more than 132 billion Canadian dollars in exports (exporting 9% of its total electricity production), contributed 230 billion to the nominal gross domestic product (almost 4 billion from electricity directly), and had averaged almost 17 billion in governmental revenue annually in the previous five years (Natural Resources Canada, 2019). In the same year, the Canadian electrical energy system created almost 820 thousand jobs, including more than 4 thousand directly from electricity services (Natural Resources Canada, 2019). Electrical energy systems

3.1.3. Key issues of electrical energy systems

The conventional designs of electrical energy systems have also contributed to key sustainability-related issues, and some foundational system characteristics have been critiqued for more than forty years as relevant contributors to severe socioecological and economic risks (e.g., Lovins, 1976). Recently, some relevant critiques have included that electrical energy systems' dependence on extracting, burning, and wasting highly polluting, non-renewable resources in massive quantities (Ghassemi et al., 2004; UNEP, 2019), has caused serious health issues, societal unrest, and costing billions of dollars in damages (Brown et al., 2017). Two relevant examples include Ontario, Canada, with 660 premature deaths and 1100 emergency room visits per year by 2007 (Jones, 2007), and the United States, with USD $62 billion in health-related damages from electricity generation in 2005 (NRC, 2010).

Electrical energy systems' operations have also been critiqued as significantly inefficient and expensive. Recent reports have shown that 8 percent of the electricity generated globally in 2014 were lost in transmission and distribution operations (The World Bank, 2018) – according to the bp Statistical Report of World Energy (2022), 24049.8 TWh were generated globally that year. As an illustration, in 2012, 290 TWh of electricity (which is equivalent to the total electricity consumed by Mexico and Peru in 2013) were lost in global generation, transmission and distribution processes (Jiménez et al., 2014). In terms of provision costs, the construction of large generation facilities can cost billions. For instance, the installation of around 10,500 MW of generation capacity only by natural gas in the United States, in 2017, had construction costs of 920 USD/kW (EIA, 2019) – this accounts for approximately USD $9.6 billion. Another example is the estimated USD $30 billion in building costs for 4,800 MW capacity in the proposed El Dabaa Nuclear Power Plant in Egypt (NRi, 2018).

Different authors have pointed out that another problematic characteristic of conventional electrical energy systems is that systems' design and planning options are often based on monitoring and forecasting to anticipate future demand and supply needs (Ghalehkhondabi et al., 2017; Robinson, 1982; Singh et al., 2013). This normally consists of projecting trends of rising energy demand and planning for meeting the anticipated new demand through additional generation (Dreborg, 1996; Robinson, 1982; Svenfelt et al., 2011). Some authors have pointed out that this practice naturally prolongs existing rising trends – e.g., increasing conventional electricity generation to cover the rising demand also entails increasing the adverse social and ecological and climate effects (Dreborg, 1996; Robinson, 1982; Svenfelt et al., 2011). In addition, planning for meeting anticipated demand can sometimes disregard the consideration of cheaper and more efficient options (Lovins, 2018). In short, planning approaches that are based on forecasting demand have been critiqued as only partly useful in a complex world (Craig et al., 2002; Schot et al., 2016), and the need for a more proactive supply and demand response seems more evident (Anderson, 2001; Bibri, 2018; Schot et al., 2016; Sharmina, 2017; Wächter et al., 2012).

Demand response options have been considered as key in efforts from governmental and independent organizations to promote scenarios that do not necessarily rely on continuing trends in rising electricity demand (e.g., Canada Energy Regulator, 2021; IEA, 2021; IRENA, 2020). Instead, these works have used scenario planning as a tool to better manage electricity demand and take steps towards more desirable futures for electrical energy systems. Demand response options including smart grids, peak-load management and consumer engagement, for instance, can maximize the system's overall positive effects and reduce costs (Anastopoulou et al., 2017; Lazowski et al., 2018; Rowlands, 2008; Villa-Arrieta & Sumper, 2019). Demand response options have also gained attention as a promising response to concerns regarding high peak-load demand – electricity that is consumed during times of the day when there is higher demand and it is more costly to generate (e.g., Anastopoulou et al., 2017; Bartram et al., 2010; Pop et al., 2017).

Finally, electrical energy systems are usually planned centrally, in terms of management and physical design. In this regard, authors have long recognized that techno-centric management has created a systematic over-assertion of technical leadership and economic priorities, tending to ignore basic foundations for human well-being (e.g., Brisbois, 2020; Golubchikov & Deda, 2012; Laird, 1990). At the same time, centrally-planned electricity system structures have higher vulnerability to natural disasters, resource shortage, terrorist attacks, market volatility, and manipulation, with potential for extremely high damage (explosion of generators, spills, multi-scale failure, economic crises, etc.) (Cowie, 2006; Farrell et al., 2004; Gatto & Busato, 2020; Yergin, 2006; Winzer, 2012).

3.2. Energy paths approaches – past and present

In 1976, Amory Lovins coined the term "hard paths" to describe the conventional design of energy systems (Lovins, 1976). The term reflects the characteristics of large electricity generation systems that are rigid to change, vulnerable to collapse, dependent on highly polluting and finite resources, inefficient in demand and supply management, and governed techno-centrically (Lovins, 1976). In contrast, he proposed and advocated for "soft paths" as a more desirable design option for electrical energy systems. That is, designing systems that are more flexible to incorporate options for dealing with unavoidable change, more resilient to disruption, fueled by diverse and cleaner renewable sources, matching supply with quantity and quality needs, and governed democratically and with more distributed power in decision-making (Lovins, 1976).

According to some authors, the hard and soft paths approach was highly discussed and polarizing in energy policy debates when it was published (Dunlap & Olsen, 1984; Robinson, 1982) and drew the attention of different academic, governmental and industrial experts (Robinson, 1982). Some advocates of more conventional energy systems argued that soft paths as a compass for policy design was an unrealistic and unrepresentative approach (Nash, 1979; Rossin, 1980; Weber, 1979; Yulish, 1977). Other relevant concerns included that ruling out fossil fuels and nuclear power would be socially and economically unfeasible (Parisi, 1977). According to Patterson (1999, p. 138), the political debates stirred by the energy paths vision stagnated, and at the end of the twentieth century the conventional design for energy systems mostly remained as the path chosen. Other authors have pointed out that, lack of diffusion, lack of government interest in the idea of soft paths, active opposition from incumbent actors, and institutional barriers to changing energy paths favoured hard paths as a predominant approach for the design of electrical energy systems (MacDonald, 2012; Newman & Brooks, 2004). Overall, the energy paths debates have shed light on the vulnerabilities of energy systems and have been crucial in opening avenues for the consideration of human and ecological dimensions in energy policy making (e.g., Morrison & Lodwick, 1981; Rosa et al., 1988; Stern & Gardner, 1981).

While there are additional perspectives in more recent debates (see section 3.2.1 below), the continuing presence of hard paths and their contributions to negative social and ecological effects should not be overlooked. The case studies selected for this thesis work – Ontario and Costa Rica – are two examples of electrical energy systems designed with hard path characteristics (see Chapters 6 and 7). In Ontario, the electrical energy system is powered by large, centralized, and expensive generation plants (e.g., nuclear, hydro, and gas). Additionally, despite concerns for long-term risks, the province has recently invested billions to maintain nuclear power as a key actor in the electricity mix (Financial Accountability Office of Ontario, 2017). Costa Rica's electrical energy system, while powered almost entirely by renewable energy, has relied on large hydroelectricity projects that can be rigid to change, techno-centrically managed, costly, socially and ecologically disruptive, and with limited capacity to match end-user needs (García-Sánchez & Avendaño-Leadem, 2018; Gutiérrez & Villalobos, 2020). While national authorities have committed to manage the electrical energy system more democratically, after years of social tensions, community representatives have emphasized that community interests are still often misrepresented in official decisions (e.g., Comisión en Defensa de los Ríos Convento y Sonador, 2016).

3.2.1. Recent literature relevant to energy paths

Electrical energy system discussions in past decades could have not foreseen the extent of urgency in current climate conditions and the associated issues, or the scope of current technological advances. Nonetheless, the 'soft or hard paths' discussions have been foundational for more recent ways of thinking about electrical energy systems design. Existing 'hard path' system designs, for instance, continued to receive critiques for being vulnerable to collapse, and as expensive, polluting, wasteful, and highly carbon emitting (Jeffs, 2012; Li, 2005; Patterson, 2007). Also, 'soft paths' design options have been often discussed as sustainability-contributing design options – e.g., incorporating renewable energy, options for creating diverse livelihood opportunities, efficiency in end-use, conservation and demand response tools, systems' capacity for resilience, decentralization, and others. (e.g., Boyle, Everett, & Ramage, 2003; Dukert, 2009; International Institute for Applied System Analysis, 2012; Jeffs, 2012).

Lovins' (1976) soft path characteristics have gained attention in more recent electrical energy system design-related discussions. The literature review of more recent works relevant to energy paths have helped to identify and categorize five key themes based on the analysis presented in this section. The five key themes identified are: 1) renewable energy; 2) decentralization and diversification; 3) energy justice and democracy; 4) modularity, flexibility and resiliency; and 5) conservation and efficiency. These five key themes respect and incorporate more recent knowledge relevant to Lovins' work. Ultimately, the five key themes aim to inform each other and shed light on key considerations for designing electrical energy systems that make more positive contributions to sustainability.

Renewable energy

Some recent scientific works have supported electrical energy systems designs being powered by renewable energy. Some authors have pointed out that the development and diffusion of renewable energy technologies can be key in mitigating and reversing climate change, insofar they are designed in consideration of sustainability in complexity (Hernandez et al., 2014; Hodbod & Adger, 2014; Lilliestram & Hargen, 2016). This involves pursuing low carbon goals while ensuring ecological responsibility and fairness towards the more vulnerable through participative decision-making processes (Akella et al., 2009; Burke & Stephens, 2016;

Mittlefehldt; 2018; Raman, 2013; Sovacool & Valentine, 2011). In this regard, different countries have acknowledged the diffusion and diversification of renewable energy as a desirable component in the system, and have committed and published official plans to attain a renewable electrical energy system (e.g., MINAE, 2015; Scottish Government, 2020; Swedish Institute, 2021).

Evidence has shown that renewable energy such as solar and wind power can be attained affordably, reliably, safely and at a relatively fast pace (Bataille et al., 2015; Kroposki et al., 2017; The Pembina Institute, 2013). However, political influence is a key factor in either widely adopting renewable energy or maintaining reliance on fossil fuels and nuclear energy. On this subject, different authors have focused on understanding and proposing alternatives to improve political processes towards maximizing the potential benefits of renewable energy (e.g., Adachi & Rowlands, 2010; Sequeira & Santos, 2018; Pinker et al., 2020; Tzankova, 2020; Yi & Feiock, 2014).

Some key concerns of adopting renewable energy-based systems are related to inter- and intra-generational affordability, vulnerability to price volatility, and compatibility to market incorporation models (Csereklyei et al., 2019; Do & Hoffman, 2019; Seme et al., 2018; Gürtler & Paulsen, 2018). Additionally, some researchers have focused on studying how to best manage the unpredictable and intermittent nature of renewable energy resources (Pratama et al., 2017; Sharma & Balachandra, 2018; Sun et al., 2016).

Decentralization and diversification

Decentralization of power and infrastructure, and diversification of sources have been proposed in recent works as relevant options for increasing energy systems' contributions to positive social and environmental effects. Some authors have pointed out that decentralized electricity systems can provide opportunity for more diverse and renewable sources of electric power in just ways (Alstone et al., 2015; De Pascali et al., 2020; Lilliestram & Hargen, 2016; Pascale, 2017). Also, due to their modular design, decentralized systems have been identified as less vulnerable to full system failures. Decentralized electrical energy system designs can isolate failures into small units, avoiding escalation to larger system failure, and increasing the capacity for faster and secure recovery (Alanne & Saari, 2006; O'Brien & Hope, 2010; Ton & Smith, 2012). This diminishes the severe risks of failure caused by a variety of threats (e.g., extreme weather, spills, accidents or operator errors). Accordingly, decentralized energy infrastructure can be a less attractive target for terrorist attacks (Farrell et al., 2004). According to some authors, decentralized systems can also support participative and democratic governance and decision-making towards more equitable futures (Baldwin et al., 2018; Goldthau et al., 2014; Katre & Tozzi, 2018). Additionally, decentralized electrical energy systems have been studied as more effective designs than conventional centralized ones in reducing the overall number of people without access to reliable, affordable, and clean electricity (Alstone et al., 2015; Hiremath et al., 2007; Sovacool & Valentine, 2011). Furthermore, some experts have studied decentralization as a design option with the potential to foster more positive social-ecological interactions and mitigate their negative impacts (De Pascali et al., 2020; Imbault et al., 2017; Walker & Cass, 2007).

While Lovins described soft and hard paths as mutually exclusive, recent studies mention the potential of including some large capacity plants due to their power to maintain stability and reliability in times of transition (e.g., Alstone et al., 2015; Kubli & Ulli-Beer, 2016; McKenna, 2018; Schmeck, 2016). At the same time, the literature suggest that new digital technologies introduce new options for electricity system management that include better central management of diverse and sometimes intermittent decentralized energy sources (Lund et al., 2015; Mitchell, 2016; Papaefthymiou & Dragoon, 2016; Shah, 2020). Finally, experts stress that the socioecological dynamics and effects, as well as market incorporation, policy and strategies, of decentralisation need to be studied in more detail (Kainiemi et al., 2019; Kubli & Ulli-Beer, 2017; McKenna; 2018; Mengelkamp et al., 2018).

Energy justice and democracy

Energy justice has been usually divided into three core components: distributional justice, recognition justice, and procedural justice (Jenkins et al, 2016; McCauley et al., 2013; Williams & Doyon, 2019). Distributional justice examines locations in the world where energy injustices happen (e.g., geographically unfair distribution of risks and benefits from energy-related operations) and focuses on how to solve them (e.g., Liljenfeldt & Pettersson, 2017; Mueller & Brooks, 2020; Yenneti & Day, 2016). Recognition justice focuses on emphasizing that energy-related operations often affect unfairly some disadvantaged groups in society – often ethnic minorities, Indigenous groups, and poor communities – and seeks for better representation and participation of such groups in decision-making processes (Carnegie, 2017). Procedural justice focuses on identifying whether there is fairness in decision-making processes for the implementation of plans or projects and what processes are needed to ensure fairness (Simcock, 2016; Walker & Baxter, 2017). In this regard, some researchers have emphasized conventional energy systems' role in social injustice. Some works recognize that global pressing issues must be tackled by more evenly distributed, democratic and just designs of energy governance (Angel, 2016; Burke & Stephens, 2018; Fairchild & Weinrub, 2017; Goldthau, 2014; Kuzemko et al., 2016). Nonetheless, while there is expert consensus on the positive effects of energy democracy and justice, they have been repeatedly undermined by political and economic interests (Lilliestram & Hanger, 2016; Rogge & Reichard, 2016; Williams & Sovacool, 2020; Winfield, 2016). For example, different authors have stressed how deliberately ignoring democratic processes to favour vested interests can hinder energy sovereignty and citizenship, gender and race equality, and sufficiency for all (e.g., Carnegie, 2017; Healy & Barry, 2017; Lieu et al., 2020; Mittlefehldt, 2018; Schelly et al., 2020).

Modularity, flexibility and resiliency

Lovins envisioned energy system managers as having the capacity to modify their components considering uncertainty and unpredictability, less severe consequences in failure, and a greater ability to recover from disruption. Comparatively, more recent works have studied these aspects in recognition of electricity systems' fragility and vulnerability to collapse. For instance, authors stress that systems should be designed to have greater modularity. That is, the ability to decompose electricity systems' components into smaller parts that can be recombined for diverse purposes (Creutzig et al., 2019; Drauz et al., 2018; Shah, 2020). Some experts have found that the development of modular technologies can greatly enhance the prospects for integration of electricity obtained from diverse sources in a safe, effective, and efficient manner (Lund et al., 2015; Mitchell, 2016; Papaefthymiou & Dragoon, 2016). Others have explained that modular designs can significantly lessen the severity of consequences of natural disasters, accidents and other threats to system integrity (Lujano-Rojas et al., 2019; Rocchetta & Patelli, 2018; Shen et al., 2019). In this subject, researchers have drawn attention to the importance of ensuring electricity systems' resilience capacity in anticipation of possible disturbances and in light of looming threats (Aldarajee et al., 2020; Jesse et al., 2019; Lin & Bie, 2016; Molyneaux et al., 2016; Wiese, 2016). Resilience as known in engineering disciplines is not the same as the resilience in terms of social-ecological systems' dynamics mentioned in Chapter 2. That is, whereas engineering resilience means being able to return to a fixed safe state, social-ecological resilience sees systems as not having a preferred state and therefore being in constant change while still needing to maintain their core structures and functions (Jesse et al., 2019; Molyneaux et al., 2016)

Conservation and efficiency

In his work, Lovins (1976) called for more efficiently designed systems, pointing out that conventional electricity systems as being wasteful, particularly in generating more electricity that needed and in using high quality electrical energy for low quality energy needs. More recently, Lovins (2018) and other experts have identified conservation and efficiency in their different applications (e.g., buildings, mobility, industry) as essential in reversing overall systems' negative trends (Chu et al., 2016; Dunlop, 2019; Gahm et al., 2016; Li & Tao, 2017; Lin et al., 2018). They have placed special emphasis on options for energy storage and conservation and demand management for electricity systems of the future.

Energy storage as a design option has gained attention due to its multiple applications, its potential to address the problem of renewable energy intermittency and to improve end-user management (e.g., Gissey et al., 2019; Taljegard, 2019; Timmons et al., 2020). The same authors point out, however, that widespread development and deployment of energy storage options are limited by cost-effectiveness concerns. In response, conservation and demand management have been recently studied as technical components and policy options to diminish resource use, waste, and consequent costs (Chan et al., 2017; Creutzig et al., 2016; Fahrioglu, 2016; Kantor et al., 2017; Shin et al., 2019). However, experts stress that energy storage advocates need to further address the potential sustainability-related impacts of mainstream use (e.g., toxic waste and extraction of materials) (Acar et al., 2019; Arbazbadeh et al., 2017; Guo et al., 2020; Hwang et al., 2017; Ren & Ren, 2017).

Ultimately, some relevant sustainability-contributing characteristics in both hard paths- and soft paths-based electrical energy system designs can be identified from the examination of energy paths approaches presented above. Therefore, while hard and soft paths have been usually approached as mutually exclusive, this work suggests that electrical energy system designs may be more beneficial as a hybrid of both path-based designs. Table 3.1 summarizes the identified positive hard and soft path characteristics and presents them as design options that can contribute positively to sustainability-related objectives for electrical energy systems.

Table 3.1. Sustainability-contributing system design characteristics for electrical energy systems

Hard paths-based	**Soft paths-based**
• Essential for multiple human well-being services • Generate enough electricity to power entire regions • Contribute greatly to regional economic revenue • Provide jobs and livelihood opportunity from electricity services	• Modular and flexible, and resilient to overall system failure • Renewable source-powered • More capable to match quantity and quality to end-user needs • Promote democratic and participatory management for more equal livelihood opportunities

3.3. Energy sustainability and electrical energy systems

Energy sustainability can be considered as providing as much energy as "can be provided without adverse effect on the earth's biosphere" (Tester et al., 2005, p. 4). However, it is now widely accepted that electrical energy systems cannot be considered as sustainable "unless they are also affordable, reliable, adequate to needs, and achievable in whatever timeframe is available" (Dukert, 2009, p. 185) and contribute to progress towards lasting livelihood opportunities, intra and inter-generational equity, and other sustainability objectives. Recent literature has shown two main approaches for the study and application of sustainability and energy systems. This section identifies and distinguishes between 1) the *sustainability of the electricity system* and 2) the *electrical energy system's contributions to sustainability* and proposes the latter as more desirable for electricity systems' design purposes.

3.3.1. Sustainability of the electricity system

The first approach consists in the study of energy sustainability (also often referred to as sustainable energy) as the combination of components and alternative design options at different levels for the *sustainability of the electricity system* (e.g., Roinioti & Koroneos, 2019; Sharma & Balachandra, 2015; Sun et al., 2016; Tziogas et al., 2019). Mostly, such works aim to determine the most feasible combinations of system components for less environmentally harmful and more socially beneficial electricity systems that still deliver universal basic aspirations (e.g., reliable, accessible, safe and affordable electricity generation and provision). Alternatively, some have proposed frameworks for the optimization of system's economic, environmental and societal sustainability parameters (e.g., Cunha, 2015; Khan, 2020; Pratama et al., 2017; Santoyo-Castelazo & Azapagic, 2014; Sharma & Balachandra, 2018). In general, these studies fail to recognize electrical energy systems as complex systems with interlinked effects that are better understood and assessed through mutually reinforcing and broad sustainability criteria. The existing literature on electricity planning that does address complexity, with greater or lesser success (e.g., Mqadi et al., 2018; Moghaddam et al., 2011; Nock et al., 2020), pays insufficient attention to the full suite of implications for sustainability. In this sense, these studies use modelling to develop electricity scenarios with more positive sustainability indicators but require more comprehensive sustainability assessments that feed the full range of effective sustainability-based criteria to such visionings.

One example of this approach is Roinioti & Koroneos' (2019) work on life cycle sustainability assessment of the Greek electrical energy system. In their work, the authors developed sustainability indicators divided into three separate types of indicators (social, ecological, and economic) that aim to determine the combinations of technical options that can provide more benefits in relation to units of electricity generated (e.g., lowest global warming potential per kilowatt per hour, lower capital cost per kilowatt per hour, or job-years per tera-watt per hour). In short, this work approaches the sustainability of the electricity system as a commodity that needs to be sustained while meeting social, ecological, and economic considerations separately.

3.3.2. Electrical energy systems contributing to sustainability

Electrical energy systems have been seldom examined as important contributors to overall sustainability in principle and in practice. Such studies would need to view electrical energy systems through an inherent lens of sustainability in complexity (see Chapter 2). As Hodbod and Adger (2014) remark, energy systems possess characteristics of vulnerability, uncertainty, resilience and capacity for constant change, cross-scale dynamics, and threshold behavior. For this purpose, *electrical energy systems contributing to sustainability* entails maximizing systems' positive effects towards delivery of multiple, mutually reinforcing and overall sustainability gains. Indeed, attaining electrical energy systems that contribute to sustainability entails also attaining energy sustainability. However, while doing so, electrical energy systems should protect life-support systems, promote local acceptance and understanding, facilitate citizenship and employment, reduce health issues, foster equity in opportunity, emphasize justice, design with precaution and flexibility, and address the vulnerability of the most disadvantaged (see Chapter 2). In other words, reversing socio-economic and biophysical trajectories that have exacerbated overall social-ecological risks, requires designing sustainability-based electrical energy systems, instead of focusing only on the sustainability of the energy system.

The approaches discussed in the sub-section below are examples of works that focus on electrical energy systems contributing to sustainability. One relevant example is Doelle's (2017) work on the Lower Churchill Panel Review for the environmental assessment of a proposed hydroelectricity generation plant in Labrador, Canada. The work aimed to develop sustainability-based assessment criteria to evaluate the environmental assessment process carried out for the hydroelectricity project, and to better inform the resulting recommendations from the Panel and future electrical energy system-related decisions. Generally, the criteria were developed in consideration of the specific context characteristics of the case and focus on informing options for generating maximum positive effects that are mutually reinforcing to each other and avoiding adverse effects. In contrast with Roinioti and Koroneos' approach (see above), this work embraces sustainability in complexity in the final criteria by explicitly recognizing the potential interlinked effects between the ecological, social, cultural, and economic effects emerging from the hydroelectricity project. Also, while aiming to facilitate broader and mutually reinforcing contributions to sustainability, Doelle's work also pays attention to the potential trade-off effects that can emerge from the interlinked sustainability-related effects stemming from the application of the criteria. In other words, this work approaches electrical energy systems contributing to sustainability to maximize the positive effects of the services that electricity provides.

3.3.3. Sustainability-based assessment of electrical energy systems

As shown above, some previous works have adopted a sustainability-based assessment approach to evaluate electrical energy system operations. Particularly, different authors (see below) have adopted Gibson and colleagues' (2005) approach for specifying and applying sustainability-based assessment criteria to electrical energy system-related projects and plans in different contexts. These works have emphasized the suitability of Gibson and colleagues' (2005) approach for application to electrical energy systems, and their contributions to knowledge can help this thesis work objectives by using them as a compass to generate further contributions to the development and application of sustainability-based assessment frameworks. The following are examples of key insights from previous applications of sustainability-based assessments to electrical energy system-related operations:

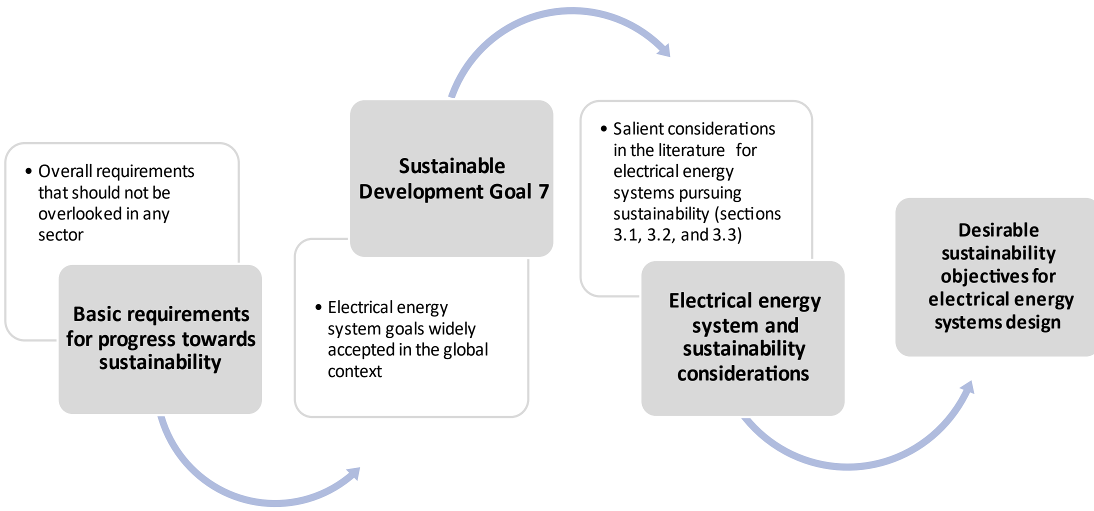
Winfield and colleagues (2010) studied the Ontario Power Authority's integrated power system plan, applying a sustainability-based assessment framework. The authors found that the plan lacked attention to maximizing "the achievable contributions from conservation and demand management, low-impact renewable sources of supply and high-efficiency and high-value uses of natural gas, while accelerating the phase out of coal-fired generation and minimizing or eliminating the role of nuclear generation over the 20-year life of the plan" (Winfield et al., 2010, p. 4124). Gibson's (2011) application of a sustainability-based assessment to a natural gas pipeline project in Canada's Northwest Territories provided key lessons relevant to avoiding the accumulation of negative effects – e.g., cumulative impacts on the biophysical environment, cumulative impacts on the human environment, equity impacts, legacy and bridging, cumulative impacts management and preparedness. Doelle (2017) applied a sustainability-based assessment lens to evaluate the proposal for a hydroelectric power plant project in Labrador, Canada. The author found significant barriers to an effective application of the framework. These were related to unfamiliarity with sustainability assessment and information gaps at different levels of application. Therefore, while the study provided relevant insights on applying a sustainability-based assessment framework, it could not offer deeper insights to electrical energy systems design. Finally, Partidário (2017) assessed the strategic investment options for a transmission grid expansion project in Portugal. Coupled with eight sustainability criteria, the author integrated strategic thinking for specification and identified three crucial decision factors (energy, fauna and land use effects). According to the author, the main criteria proposed had good public acceptance, but the scope of the plan was strongly limited by governmental requirements that did not cover broader contributions to sustainability (Partidário, 2017).

The scope of this thesis work is more ambitious in the sense that it seeks to develop a sustainability-based assessment framework with a set of criteria that can be specified and applied to the context of different plans, projects, and initiatives, in different jurisdictions. However, paired with previous applications in other projects and sectors, their contributions to knowledge reviewed in the works below can be foundational to the goal of building and specifying a sustainability-based assessment framework for application this thesis work's case studies. In other words, their contributions to knowledge can be used as a compass that incorporates key lessons learned from past applications and the incorporation of more recent knowledge for future sustainability-based assessment works focused on electrical energy systems.

3.3.4. Desirable objectives for electrical energy systems design

While Chapter 2 has delved into the overall requirements for progress towards sustainability in a world of complexity, this chapter has examined system design characteristics that can maximize electrical energy systems' contributions to accelerating such progress. Subsequently, this section provides a set of desirable objectives specific to designing electrical energy systems in a context of urgency for faster and more positive contributions to sustainability. The process for the elaboration of the objectives is illustrated below in Figure 3.2. First, Gibson and colleagues' (2005) basic requirements for progress towards sustainability were adopted as a set of guiding principles that should not be overlooked in any sustainability-oriented efforts, in any sector. As discussed in Chapter 2, the validity of adopting Gibson and colleagues' approach to can be justified by the valuable contributions to sustainability-based assessments that emerged from previous applications (see section 2.4). Also, as discussed in section 3.3, the basic requirements for progress towards sustainability have a precedent of being adopted and specified to the context of different electrical energy system-related efforts in different jurisdictions. Second, while it is presented within section 3.1, Sustainable Development Goal 7 received particular attention in this process since it contributes a set of sustainability goals for electrical energy systems widely accepted in the global context. In this process, Sustainable Development Goal 7 provides an overarching element to examine electrical energy systems through a sustainability lens. Third, sections 3.1, 3.2, and 3.3, provide main lessons on electrical energy systems' governance and technology design options to help tackle key sustainability challenges and make more positive contributions towards overall sustainability.

Figure 3.2. Process for developing desirable sustainability objectives for electrical energy systems



Generally, the objectives identified below summarize main insights from this chapter's analysis that suggest widely desirable objectives for electrical energy systems design that must be ensured in efforts to change towards making more positive contributions to sustainability. The seven desirable sustainability objectives for electrical energy systems design drawn from the literature review are:

1. Providing accessible, reliable, and affordable electrical energy services for all
2. Reducing and reversing greenhouse gas emissions and climate change
3. Protecting social-ecological integrity
4. Increasing the system's capacity for the development, deployment and integration of diverse renewable-sourced energy.
5. Maximizing system's efficiency, cost-effectiveness and conservation and demand response capacity
6. Enhancing capacity for democratic and participatory governance processes
7. Supporting design options that minimize vulnerability and maximize recovery capacity to potential threats (e.g., natural disasters, accidents, system malfunctions, terrorist attacks, etc.)

This work proposes that these objectives should be pursued in any electrical energy system designs to enhance the capacity of the system to reversing negative trends that contribute greatly to social and ecological crises. While hard and soft energy paths design characteristics were originally thought of as mutually exclusive approaches, the seven objectives combine and promote desirable effects that can and have been generated by both electrical energy system design approaches. Finally, the desirable objectives can be used to develop tools for application to evaluate the design of more specific electrical energy system plans, projects, and initiatives in different regions (see section 3.4 below).

3.4. Initial sustainability-based assessment framework for electrical energy systems

This section develops a list of five criteria categories specified to electrical energy systems in consideration of relevant insights resulting from the analysis in this chapter, paired with relevant insights from Chapter 2 (see below). Developing the list of criteria is an initial step in the specification of a sustainability-based assessment framework for electrical energy systems. First, Gibson and colleagues' (2005) set of basic requirements for progress towards sustainability was used as a foundation for the elaboration of the sustainability-based assessment framework (see Chapter 2). Then, relevant themes examined in this chapter were used as specification factors for the design of electrical energy systems that make more positive contributions to sustainability. The specification factors considered include key characteristics (section 3.1.2) and issues of electrical energy systems (section 3.1.3), key themes in recent energy paths discussions (section 3.2.1), design options relevant to sustainability objectives for electrical energy systems (see Section 3.3.4), and desirable objectives for electrical energy system design (section 3.3.4). As a result, five sustainability-based assessment criteria categories specified to electrical energy systems were defined through the synthesis of all the aspects analyzed above:

1. Climate safety and social-ecological integrity
2. Intra- and inter-generational equity, accessibility, reliability, and affordability
3. Cost-effectiveness, resource efficiency and conservation
4. Democratic and participatory governance
5. Precaution, modularity and resiliency

Ultimately, the reviewed contributions from previous assessments of electrical energy systems (e.g., Gibson 2011; Doelle, 2017; Winfield et al., 2010) were applied in addition for the selection of criteria categories and key considerations comprising the initial framework. These works were complemented by previous sustainability assessment-related literature and provided key insights for the initial framework. In short, the proposed set of criteria categories is expected to be applicable to review of any electrical energy system and it should not be overlooked in any electricity-system related endeavours. Additionally, the number of criteria categories was based on evidence that argues for no more than five concise criteria for effective sustainability assessment undertakings (Cohen, 2017; Redclift, 2005; Robinson, 2004).

3.4.1 Generic sustainability-based assessment criteria categories specified to electrical energy systems

The five criteria categories proposed above integrate consideration of the sustainability-based assessment requirements and the considerations discussed above in section 3.4. A description of this integration in each criteria category is provided below. The five categories are denominated as "C" (e.g., C1, C2, C3…). Furthermore, five key considerations are presented in each category. These key considerations are comprehensive of the main concerns in the relevant categories and are foundational for the elaboration of the criteria. However, the considerations must be polished into a more detailed set of criteria and need to be specified to particular contexts of application (e.g., particular jurisdictions, electrical energy systems, and socio-ecological conditions). In addition to the initial framework, the sustainability requirements of immediate and long-term integration and attention to trade-off rules are included and discussed afterwards. In this work, these are part of a second-stage analysis, but they must be considered in early stages of elaboration of the framework.

C1. Climate safety and social-ecological integrity

This criteria category incorporates the sustainability requirement of social-ecological system integrity. C1 draws attention to the broad concerns related to greenhouse gas emissions and climate change, and to risks of irreversibly crossing biophysical system boundaries. These concerns are related to identified threats to the biodiversity, ecological integrity, and human well-being including air quality, toxic waste, resource extraction, and animal and plant species extinction. Moreover, C1 stresses that systems' mitigation and adaptation capacity must be maximized to tackle the already unavoidable adverse social and ecological impacts associated with climate change. Therefore, this category addresses the overall electrical energy system goal of protecting social-ecological system integrity. To that effect, C1 supports design options to preserve main system characteristics that contribute to lasting socio-economic well-being and generate positive social-ecological system dynamics and effects. Finally, design options must support the reduction of environmental and climate stress and the rehabilitation of biophysical systems.

C2. Intra- and inter-generational equity, accessibility, reliability, and affordability

This criteria category incorporates three sustainability requirements: a) livelihood sufficiency and opportunity; b) intra-generational equity; and c) inter-generational equity. C2 addresses the objective of ensuring universal access to safe, reliable, and affordable electricity. By doing so, it requires for a more equal distribution of benefits and risks among present and future generations, regions, gender, race, Indigenous/non-Indigenous people, poor and rich, and marginalised groups. Particularly, C2 stresses the need for technical and policy options that maximize system capacity to provide electricity access and power essential human services for poor and remote areas. Therefore, decision-making must ensure technical viability by supporting options that deliver system reliability, resilience, safety, adaptive capacity, ease of repair, etc. C2 favours design options that promote energy access for all by providing stability/reliability (e.g., eliminating intermittency) and ensuring technical viability always. Design options must also pay attention to market volatility considerations and incorporate strategies to ensure economic viability – e.g., capital and operating costs, and consideration of risks – in the short and long terms. Additionally, C2 focuses on ensuring that electrical energy system design options address energy poverty and promote distributional justice of risks and benefits in the present. That is, current and new options must avoid the creation of negative effects, and ensure the fair provision of positive effects to already disadvantaged social groups, and in particular geographical areas. Finally, C2 favours options for direct and indirect employment opportunities that are well paid, long lasting, conveniently located and otherwise accessible, fulfilling/challenging, etc.

C3. Cost-effectiveness, resource efficiency and conservation
This criteria category incorporates the sustainability requirement of resource maintenance and efficiency. C3 addresses two broadly accepted goals for electrical energy systems: a) increasing the system's capacity for the development, deployment and integration of diverse renewable-sourced energy; and b) maximizing system's efficiency, cost-effectiveness, and conservation and demand management capacity. To that effect, C3 favours electrical energy systems powered by renewable sources, considering the identified benefits they can provide in terms of climate change mitigation, energy access, and affordability. At the same time, this category recognizes fossil fuel dependency and its large contributions to resource depletion. However, C3 also recognizes renewables energy's associated challenges regarding cost/effectiveness, price, and market incorporation. Equally important, C3 favours the potential for greater efficiency and cost-effectiveness benefits – usually hindered by poor system design. This entails minimizing provision costs and socio-ecological costs, predominantly caused by life-cycle losses in generation and delivery activities. At the same time, C3 supports systems' capacity to preserve and enhance natural (and other meaningful) resources that are essential for community well-being. Therefore, technical options that favour both renewable-sourced power and greater efficiency, conservation and demand management capacity to match electricity quality and quantity to end-user needs (e.g., storage, smart grid technologies, Nega-Watt options) are preferred.

C4. Democratic and participatory governance
This criteria category incorporates the sustainability requirement of socio-ecological civility and democratic governance. C4 includes the need for effective policy making that clarifies the implications of attaining climate and broader sustainability-associated objectives, collective action, appropriately open consideration and consultation, and integration of diverse sources of knowledge necessary to tackle urgent complex issues. C4 addresses the overall electrical energy systems' accepted goal of enhancing the capacity for democratic and participatory governance processes. To that effect, C4 draws attention to concerns regarding vested interests being favoured over democratic processes and appropriate consultation. Furthermore, this criteria category facilitates explicit recognition of the political barriers embedded in electrical energy systems, as well as the opportunities for overcoming such barriers. Like C2, this category

favours design options that foster citizenship, and gender and race equality in representation. However, it also emphasizes consultation, representation, and inclusion of vulnerable groups, and to the interests of future generations that cannot be directly represented. Particularly, the category requires specific attention to the inclusion of Indigenous people in official decision-making, recognizing that Indigenous rights and interests are often misrepresented in electrical energy system operations. At the same time, C4 requires for a higher understanding and other system capacities for justly transitioning, opening windows of opportunity, and mobilizing key actors' influence for positive change. Finally, C4 recognizes the need for clarifying the policy implications of attaining climate and associated social-ecological objectives.

C5. Precaution, modularity and resiliency
This criteria category incorporates the sustainability requirement of precaution and adaptation. C5 addresses the broadly accepted objective of supporting design options that minimize vulnerability and maximize recovery capacity to potential threats (e.g., natural disasters, accidents, system malfunctions, terrorist attacks, etc.). Therefore, this category emphasizes prudent and precautionary approaches in consideration of unpredictability and incomplete understanding on complex dynamics. C5 also addresses the limited adaptive capacity of conventional electrical energy systems to deal with surprise and unavoidable change and vulnerability to collapse. At the same time, C5 recognizes needs for policy initiatives to develop new system design options and to incorporate them to the electricity market, and for attention to associated social-ecological effects (e.g., social-ecological effects of decentralized systems). Finally, preferable design options must avoid or minimize social-ecological and economic risks and promote modular technologies and strategies that enhance adaptation and resilience capacity.

Table 3.2. Initial framework for sustainability-based assessment specified to electrical energy systems

Climate safety and social-ecological integrity
Requirement: ▪ *Social-ecological system integrity*: Build human-ecological relations to establish and maintain the long-term integrity of socio-biophysical systems and protect the irreplaceable life support functions upon which human as well as ecological well-being depends Objectives: ▪ Reducing and reversing greenhouse gas emissions and climate change ▪ Protecting social-ecological integrity

Key considerations:

- Reducing harmful emissions to the atmosphere, including carbon and other substances that aggravate global warming
- Mitigating and adapting to already unavoidable social and ecological effects associated with climate change
- Enhancing human health by maximising air quality, reducing toxic waste and ensuring safe management in all life-cycle processes
- Minimizing threats to the biodiversity and ecological integrity, including toxic substances, resource depletion, animal and plant species extinction and pollution in all life-cycle processes
- Preserving main system characteristics that contribute to lasting socio-economic well-being and generate positive social-ecological system dynamics and effects

Intra- and inter-generational equity, accessibility, reliability, and affordability

Requirements:

- *Livelihood sufficiency and opportunity*: Ensure that everyone and every community has enough for a decent life and that everyone has opportunities to seek improvements in ways that do not compromise future generations' possibilities for sufficiency and opportunity
- *Intra-generational equity*: Ensure that sufficiency and effective choices for all are pursued in ways that reduce dangerous gaps in sufficiency and opportunity (and health, security, social recognition, political influence, etc.) between the rich and the poor
- *Inter-generational equity*: Favour present options and actions that are most likely to preserve or enhance the opportunities and capabilities of future generations to live sustainably

Objective:

- Providing accessible, reliable, and affordable electrical energy services for all

Key considerations:

- Favouring direct and indirect employment opportunities that are well paid, long lasting, conveniently located and otherwise accessible, fulfilling/challenging, etc.
- Promoting distributional justice related to the benefits and risks of electrical energy system operations and addressing energy poverty by avoiding the creation of negative effects, and ensuring the fair provision of positive effects among present and future generations across regions, gender, race, Indigenous/non-Indigenous people, poor and rich, and marginalized groups

- Favouring technical and policy options that maximize system capacity to provide electricity access and power essential human services for poor and remote areas
- Ensuring technical viability (e.g., reliability, resilience, safety, adaptive capacity, ease of repair, etc.)
- Ensuring economic viability (e.g., capital and operating costs, and risks in the short and long term, in comparison with other design options available)

Cost-effectiveness, resource efficiency and conservation

Requirement:

- *Resource maintenance and efficiency*: Provide a larger base for ensuring sustainable livelihoods for al while reducing threats to the long-term integrity of socio-ecological systems by reducing extractive damage, avoiding waste and cutting overall material and energy use per unit of benefit

Objectives:

- Increasing the system's capacity for the development, deployment and integration of diverse renewable-sourced energy.
- Maximizing system's efficiency, cost-effectiveness and conservation and demand response capacity

Key considerations:

- Increasing capacity for development and integration of reliable and affordable renewable-sourced energies that reduce negative climate change effects.
- Decreasing reliance on fossil fuels
- Enhancing technical demand management capacity to match electricity quality and quantity to end-user needs (e.g., storage, smart grid technologies, demand response options)
- Preserving and enhancing natural (and other meaningful) resources that are essential for community well-being
- Minimizing provision costs and socio-ecological costs, predominantly caused by life-cycle losses in generation and delivery activities

Democratic and participatory governance

Requirement:

- *Socio-ecological civility and democratic governance*: Build the capacity, motivation and habitual inclination of individuals, communities and other collective decision making bodies to apply sustainability requirements through more open and better informed deliberations, greater attention to fostering reciprocal awareness and collective responsibility, and more integrated use of administrative, market, customary and personal decision making practices

Objective:

- Enhancing capacity for democratic and participatory governance processes

Key considerations:

- Maximizing capacity for democratic and participatory deliberation that facilitates public consultation and acceptance through explicit and transparent processes
- Building favourable conditions for open and informed discussion with integration of experts, stakeholders, vulnerable groups and local knowledge, and ensuring particular attention to adequate representation of Indigenous peoples' rights and interests in decision-making
- Recognizing and addressing political barriers embedded in electrical energy systems that undermine democratic and participatory governance (e.g., powerful political and economic interests)
- Enhancing understanding and other capacities for just transitioning, opening windows of opportunity, and mobilizing key actors' influence for positive change
- Favouring policy-making design that clarifies the implications of attaining climate and associated social-ecological objectives

Precaution, modularity and resiliency

Requirement:

- *Precaution and adaptation*: Respect uncertainty, avoid even poorly understood risks of serious or irreversible damage to the foundations for sustainability, plan to learn, design for surprise and manage for adaptation

Objective:

- Supporting design options that minimize vulnerability and maximize recovery capacity to potential threats (e.g., natural disasters, accidents, system malfunctions, terrorist attacks, etc.)

Key considerations:

- Favouring prudent and precautionary decision-making in consideration of unpredictability and incomplete understanding on complex dynamics

- Supporting design options that minimize vulnerability and maximize recovery capacity to potential threats (e.g., natural disasters, accidents, system malfunctions, terrorist attacks, etc.)
- Favouring technology with high adaptive capacity for modifications over time, as well as design options for greater system compatibility
- Minimizing social, economic and biophysical risks in planning and decision-making for electrical energy systems of the future
- Avoiding planning and decision-making that increase path dependency (e.g., capital intensive, massive long-term projects with low capacity for modifications over time)

3.4.2. Specification and integration

The sustainability-based assessment criteria for electrical energy systems will need to be further specified for application to particular systems/contexts. The further specification will allow the research to explore unique scenarios and further implications for application in any jurisdiction. To this end, analysis of documents on particular cases will shed light on regional contextual realities (e.g., economic, political, geographical, social, etc.) that are likely to influence the viability of options for decision-making. However, the application of the criteria in all categories needs to deal with not only effects and implications at the system level (inside the focal system), but also the overlapping effects and implications at smaller and larger scales (outside the focal system).

Furthermore, effectively applying the criteria entails addressing dynamic elements that are interlinked in various, and probably unexpected ways – any action undertaken in any component should be expected to spur effects that can reach all system components. Therefore, the application process, for any specific region, has to go through an integration stage. This process will help to identify potential interactive effects among the effects identified under each category and criterion. Integration will thus be crucial for enabling positive, mutually supportive effects, dealing with uncertainty, and reducing risk of undesirable events.

Adopting an integrative lens to analyze individual and collective effects should provide key elements for an overall comparative evaluation of the power system options (e.g., identifying particular and overall pros and cons). This will help to recognize and engage with emerging needs for decision-making regarding trade-offs. For this purpose, a set of considerations and rules (Gibson et al., 2005) can aid in deciding how trade-offs could be mitigated and/or avoided (e.g., by adjusting or combining some options, or finding new ones).

3.4.3. Trade-off rules

As discussed in Chapter 2, sustainability-based assessments must pay particular attention to identifying and evaluating trade-offs emerging from contextual considerations. For the purposes of this thesis, evaluating trade-offs is part of a second-stage analysis, but it still requires overall consideration in early stages of the framework elaboration. Accordingly, the initial framework specified to electrical energy systems must reflect the overall sustainability objective of reducing/eliminating trade-offs (Gibson et al., 2005). For such purposes (and in line with the rationale provided in Chapter 2), Gibson et al.'s general trade-off rules will be used as a tool for further specification and application of the framework (Table 3.3).

Table 3.3. Gibson et al.'s generic trade-off rules

Maximum net gains	Any acceptable trade-off or set of trade-offs must deliver net progress towards meeting the requirements for sustainability; it must seek mutually reinforcing, cumulative and lasting contributions, and must favour achievement of the most positive feasible overall result, while avoiding significant adverse effects.
Burden of argument on trade-off proponent	Trade-off compromises that involve acceptance of adverse effects in sustainability-related areas are undesirable unless proven (or reasonably established) otherwise; the burden of justification falls on the proponent of the trade-off.
Avoidance of significant adverse effects	No trade-off that involves a significant adverse effect on any sustainability requirement area (for example, any effect that might undermine the integrity of a viable socio-ecological system) can be justified unless the alternative is acceptance of an even more significant adverse effect. Generally, then, no compromise or trade-off is acceptable if it entails further decline or risk of decline in a major area of existing concern (for example, as set out in official international, national or other sustainability strategies or accords, or as identified in open public processes at the local level), or if it endangers prospects for resolving problems properly identified as global, national and/or local priorities. Similarly, no trade-off is acceptable if it deepens problems in any requirement area (integrity, equity, etc.) where further decline in the existing situation may imperil the long-term viability of the whole, even if compensations of other kinds, or in other places are offered (for example, if inequities are already deep, there may be no ecological rehabilitation or efficiency compensation for introduction of significantly greater inequities). No enhancement can be permitted as an acceptable trade-off against incomplete mitigation of significant adverse effects if stronger mitigation efforts are feasible.
Protection of the future	No displacement of a significant adverse effect from the present to the future can be justified unless the alternative is displacement of an even more significant negative effect from the present to the future.

Explicit justification	All trade-offs must be accompanied by an explicit justification based on openly identified, context specific priorities as well as the sustainability decision criteria and the general trade-off rules. Justifications will be assisted by the presence of clarifying guides (sustainability policies, priority statements, plans based on analyses of existing stresses and desirable futures, guides to the evaluation of 'significance', etc.) that have been developed in processes as open and participative as those expected for sustainability assessments.
Open process	Proposed compromises and trade-offs must be addressed and justified through processes that include open and effective involvement of all stakeholders. Relevant stakeholders include those representing sustainability-relevant positions (for example, community elders speaking for future generations) as well as those directly affected. While application of specialized expertise and technical tools can be very helpful, the decisions to be made are essentially and unavoidably value-laden and a public role is crucial.

Trade-off rules are essential in ensuring open attention to, and facilitating resolution of, important moral/ethical impasses in decision-making. Gibson and colleagues (2005), for instance, point out that it is unrealistic to expect options that deliver only positive contributions to all the categories of sustainability considerations. In addition, our capacity to identify the needs of future generations, and to ensure that present decisions provide benefits that are long-lasting in time, is very limited in reality (Norton, 2005). Therefore, sustainability-based assessments aim to avoid/eliminate trade-offs in light of such considerations, leaving trade-off implementation as a last resort (Winfield et al., 2010). To that effect, the trade-off rules shown in Table 3.3 will aid in the identification and evaluation of proposed trade-offs, as well as finding options to reducing/eliminating them.

3.5. Key implications of complexity for electrical energy systems and sustainability

Complex systems thinking suggests that achieving electrical energy systems that make broad positive contributions to sustainability and minimize negative effects to human and environmental well-being requires considering the complexity of the world. This entails acknowledging electrical energy systems as complex socio-ecological systems, made of complex dynamics and interactions. Based on the discussion on complex systems thinking presented in Chapter 2, this section focuses on broadly identifying key implications of complexity for electrical energy systems and sustainability.

Acknowledging electrical energy systems as complex social-ecological systems entails recognizing that they are in constant change, without an ultimate end state. Therefore, electrical energy system planning should favour the capacity of the system for modification over time (e.g., promoting flexibility to incorporate emerging policy and technical options in the global energy landscape). This is a key consideration since facilitating the incorporation of system components that allow the overall system to adapt to changing contexts can enhance capacities to recognize and respond to unpredictable challenges (e.g., unexpected climate change effects). In this sense, this also entails building pathways to unlock path dependency on usual hard path options that have low capacity for modifications over time.

Another key implication is that electrical energy system operations must consider multi-scale effects that influence system dynamics at different levels, including in other social-ecological systems. As mentioned earlier, electrical energy systems are key to sustainability aspirations since their interacting components can produce relevant effects, positive and negative, to essential foundations for human well-being and life-support systems. For instance, electrical energy system dynamics are key to the operations of adjacent human sectors such as food, water, education, health, transportation, among others. Similarly, electrical energy system management must recognize that dynamics within and among different jurisdictional levels have defining effects on overall system functions. For example, decision-making at different jurisdictional levels (e.g., local, national, global) can help to facilitate or undermine the overall capacity of electrical energy systems to deliver positive sustainability effects.

As complex systems, electrical energy systems need capacities for both resilience and transformation. That is, such systems must be able to maintain key characteristics in the face of disturbances, and to change components and dynamics at different scales, in order to preserve functions and capacities to deliver services that are vital to the overall system. In other words, it must be possible to transform electrical energy systems while preserving essential characteristics. This is key for sustainability since it means that electrical energy systems have the capacity to change towards reducing and reversing their threatening effects (e.g., harmful emissions to the atmosphere and deepening inequalities) while maintaining their existing positive contributions (e.g., capacity to power essential human services). However, since the negative effects have already contributed to severe crises that threaten the planetary capacity to preserve social and ecological systems' integrity, human intervention is needed to direct system change rapidly and safely. This entails implementing effective governance for electrical energy systems to move to more sustainable pathways and recognizing key points to intervene in the system to elicit desirable change.

According to complex systems thinking, while it is possible to transform electrical energy systems, steering change while maintaining desirable characteristics is very difficult. Complex systems' components are interlinked through non-linear dynamics that are not fully understood, and the long-term effects resulting from their interactions can be unpredictable. This suggests, as noted in Chapter 2, that conventional long-term planning methods (e.g., forecasting and modelling) are insufficient for pursuing electrical energy systems that make broad contributions to sustainability. It is possible, however, to focus on favouring contextual system interactions that accumulate desirable sustainability effects. In this sense, complex systems thinking suggests that respecting electrical energy systems' contextual characteristics is key to maximizing broad and mutually reinforcing contributions to sustainability.

Finally, since complex systems thinking has an uneven acceptance in diverse areas of knowledge, the idea of recognizing electrical energy systems as complex social-ecological systems may be unevenly accepted in different sectors and by different actors. Therefore, further research works that approach electrical energy systems as complex systems will be needed to attain better understanding and wider acceptance of the key implications of complexity for electrical energy systems and sustainability.

3.6. Summary of relevant insights

This chapter has analyzed electrical energy systems as key components in global and local aspirations to make positive contributions to overall sustainability. In so doing, the sections in this chapter have examined electrical energy systems as key contributors of both negative and positive sustainability-related effects. Ultimately, the chapter has proposed five generic sustainability-based assessment criteria categories specified to electrical energy systems. In summary, the following relevant insights have been drawn from this chapter:

- Energy systems' operations, including those in electrical energy systems, can contribute greatly to both positive and negative overall effects for social and ecological well-being. Therefore, designing electrical energy systems to maximize positive sustainability-contributing effects is key to tackle ongoing global crises and advance overall sustainability.
- Conventional electrical energy systems have contributed greatly to key sustainability-related issues. Some of the most relevant issues related to conventional designs of electrical energy system include reliance on extraction and consumption of non-renewable resources in massive quantities, inefficient and costly operations and projects, ineffective planning strategies to reverse negative trends, and techno-centric management.
- While they have contributed to severe negative social and ecological effects, electrical energy systems have also provided positive sustainability-associated effects that should be maintained in new system designs. For instance, electrical energy system designs can provide essential services for human well-being, generate enough electricity to power entire regions, contribute greatly to regional economic revenue, and provide jobs and livelihood opportunity from electricity services.
- Recent contributions to Lovins' (1976) hard and soft energy paths approach highlight five key themes that have gained attention and need to be considered in efforts to best design electrical energy systems to make more positive contributions to sustainability. The five key themes are: 1) renewable energy, 2) decentralization and diversification, 3) energy justice and democracy, 4) modularity, flexibility and resiliency, and 5) conservation and efficiency. The analysis in this chapter suggests that in the current context of urgency for change, a hybrid of hard and soft path design options might be desirable.

- The literature relevant to electrical energy systems and sustainability is often divided into two general approaches that are important to distinguish: sustainability of the electricity system and electrical energy systems contributing to sustainability.
- Five sustainability-based assessment criteria categories specified to electrical energy systems have been developed in consideration of relevant insights from this chapter and Chapter 2. The initial five criteria categories proposed are: 1) climate safety and social-ecological integrity, 2) accessibility, reliability, affordability, and equity in livelihood opportunity, 3) cost-effectiveness, resource efficiency and conservation, 4) democratic and participatory governance, and 5) precaution, modularity and resiliency. Additionally, each criteria category includes five key considerations for developing more specific assessment criteria.

Chapter 4 (Directing transformations towards sustainability) examines relevant approaches to transforming systems towards sustainability in a world of complexity, and in a global context that requires urgent change to avoid irreversible negative social and ecological effects. Chapter 4 also studies electrical energy systems as relevant venues for transformation, and as systems experiencing transitions that need to be managed justly to avoid contributing undesirable effects. Ultimately, Chapter 4 develops a sixth criteria category for the proposed sustainability-based assessment framework for electrical energy systems.

CHAPTER 4. Directing transformations towards sustainability

Overall planetary systems are in need of profound changes. As noted in previous chapters, there is broad consensus on the need to rectify negative social-ecological interactions and the overwhelming threats they pose (e.g., degradation and loss of valued human and biophysical systems). Given this urgency, transformations towards sustainability have great relevance as an area of thought and practice. However, one major challenge for sustainability undertakings is the need for directing transformations of undesirable systems while building resilience to preserve desirable system characteristics (Folke et al., 2020). This chapter focuses on transformation as a process in complex systems, which can happen naturally or by human intent, that can be directed away from unsustainable dynamics, and towards delivering more positive sustainability-related effects (e.g., Geels & Schot, 2007; Gibson et al., 2005; Meadows, 1999, Westley et al., 2011). In so doing, the chapter also explores the role and dynamics of transformations in protecting what is valuable and paying special attention to the interests of the most vulnerable.

This chapter is divided in four parts, each of them involving significant and challenging requirements for directing transformations. The first part provides a recent context on transformational thinking and sustainability. Here, it is argued that understanding the roles of transition and transformation in complex systems can be beneficial for moving towards sustainability. Transformations, moreover, are illustrated as an accumulation of positive transformative effects that pushes the systems into new structures and functions. The second part posits the governance challenges of transformation efforts as a key issue to address in designing systems towards sustainability. These challenges are largely related to power dynamics and agency exerted by different and competing interests involved in decision-making processes – this is often referred to in the literature as “the politics of transformations”. Additionally, just transitions studies are explored to emphasize the role of transformations in protecting what is valuable and paying special attention to the interests of the most vulnerable in the face of change. Hence, seven design options to maximize transformative opportunities for governing transformations towards sustainability are identified. The third part recognizes the need to delineate policy pathways as a main challenge for directing transformations. This part emphasizes the need to establish clear and well-founded policies to guide transformations towards sustainability. For these purposes, scenario planning and backcasting are highlighted as more effective tools, instead of commonly used forecasting methods. Finally, the fourth part proposes an additional main criteria category for incorporation to the sustainability-based assessment framework specified to electrical energy systems. This criteria category is created in consideration and synthesis of the main themes recognized in the literature on transformations towards sustainability. Incorporating the main criteria category is important to address explicitly the challenges of directing, motivating and removing barriers to human-induced change in sustainability efforts. However, it is necessary to ensure that the main criteria category provides compatible and mutually reinforcing positive effects to the other five.

4.1. Transformational thinking and sustainability

Transformations in the sense of human-induced redirection of systems towards sustainability have been defined from diverse perspectives. Many authors have recently provided conceptualizations building on earlier relevant contributions to transformations towards sustainability as a field of study. Some examples include:

- Mendizabal and colleagues (2018, p. 413) have defined transformation as “a process which results in a change in the biophysical, social or economic dimensions of a system from one form, function or location to another (the change can be reversible)”.
- Alternatively, Patterson and others (2016, p. 2) define it as “fundamental changes in structural, functional, relational, and cognitive aspects of socio-technical-ecological systems that lead to new patterns of interactions and outcomes”.
- From Folke and colleagues’ (2020, p. 34) perspective, “transformation implies fundamentally rewiring the system, its structure, functions, feedbacks, and properties”.
- According to the United Nations Research Institute for Social Development (UNRISD, 2016, p. 32), “transformation requires attacking the root causes that generate and reproduce economic, social, political and environmental problems and inequities, not merely their symptoms”.

Transformations towards sustainability, therefore, entail changes in the most fundamental and deeply rooted components and dynamics of social and ecological systems. However, as discussed in Chapter 2, social and ecological systems have resilience capacity to maintain relevant system components in changing environments. This is problematic when the system has developed entrenched dynamics that accumulate detrimental effects to human well-being and the biophysical context, increasing the need for transformation (Ngonghala et al., 2014; Yang et al., 2019). In this regard, directing systems to reverse negative effects and make consistent contributions to positive sustainability-related effects has been increasingly acknowledged as a political, rather than only technical, challenge. That is, relevant discussions have focused on the need to overcome socio-political barriers (e.g., power and agency of conflicting interests), as well as encouraging, directing and motivating steps to desirable change (Folke et al., 2020; Förster et al., 2020; Luederitz et al., 2017; Roberts & Geels, 2019). According to experts, our current inability to do so has greatly contributed to risky biophysical scenarios for Earth systems and humanity (e.g., IPBES, 2019; IPCC, 2018).

Costanza and colleagues (2007) have stressed that, historically, failure to understand fundamental issues and to make necessary changes has caused social-environmental crises that ended in the collapse of past civilizations. Therefore, sustainability as a transformative approach emphasizes the risks of current trajectories and provides normative considerations for desirable human-induced change (Burns, 2012; Kates et al., 2012; O’Brien, 2012). For instance, authors have studied transformations towards sustainability of essential sectors such as energy systems (e.g., Child & Breyer, 2017), water systems (e.g., Fuenfschilling & Truffer, 2016), food systems (e.g., Nelson & Phillips, 2018), urban systems (e.g., Wiek et al., 2015), as well as in climate change responses at various scales (e.g., Pelling et al., 2015) and the creation of fulfilling green jobs (e.g., Poschen, 2017). However, since transformative change towards sustainable paths is still a relatively new area of study, important questions need to be addressed in further depth (Burch et al., 2014; O'Brien, 2012; Patterson et al., 2016). Namely, authors have raised doubts on how transformations happen, and on how transformational processes in change-resistant systems should be carried out (Feola, 2015; Olsson et al., 2015; Scoones et al., 2018).

4.1.1. The diversity of transformations towards sustainability

Disciplinary efforts to understand human-induced change have been usually competing rather than integrative. For instance, transformations have been often approached as deep and sudden or small and incremental. The main conflicting standpoints during the French Revolution period provide a useful illustration: Edmund Burke's (1790) 'conventional' or 'traditional' thinking proposed that preserving the inherited sociopolitical traditions of any given society would provide overall stability while novel methods and radical change posed unaffordable risks. Burke argued for changes that were gradual, cautious, and not largely disruptive to predominant structures (Burke, 1790). In contrast, Thomas Paine's revolutionary thinking favoured profound changes in societal-political structures that were foundationally and/or systematically flawed (Nelson, 2007). According to Paine, such flaws are likely to have overwhelming consequences for societies in the long term, and future generations would need to bear the burdens of past generations' mistakes (Nelson, 2007). From this perspective, marginal adjustments are ineffective when the foundations of a system are cracked, and fundamental change is therefore necessary.

This section shows how complex systems thinking explains that transformation, in more detail, happens as a combination of both perspectives. That is, the cumulative effects of small changes can lead to transforming into quite different socio-economic system structures and functions (Atlin & Gibson, 2017; Diefenderfer et al., 2016; Folke et al., 2020). At the same time, this discussion recognizes severe threats to social foundations and the potential irreversible damages to the environment as part of our current contextual reality, and accordingly fast and deep responses in theory and practice are urgent (Kates et al., 2015; O'Brien, 2012; Roggema et al., 2012; Schulz & Siriwardane, 2015).

Currently, perceptions on how to change towards sustainability are more diverse. For instance, the highly adopted categorization of the main literatures on transforming towards sustainability by Patterson and colleagues (2016), the authors identify four "prominent conceptual approaches to transformations in the global sustainability literature" (Patterson et al., 2016, p. 5): transitions approaches, social-ecological transformations, sustainability pathways and transformative adaptation (see Table 4.1). According to Scoones and others (2020), these approaches have been identified as overlapping and mutually reinforcing in the sense that they can make important contributions to each other (see Figure 4.2). Also, all the approaches acknowledge transformations being pushed by the cumulative effects of multiple system interactions.

Table 4.1. Main conceptual approaches to transformations towards sustainability based on Patterson et al. (2016)

Transition approaches	These refer to socio-technical transitions and transition management approaches. Socio-technical systems can be defined as those consisting of "(networks of) actors (individuals, firms, and other organizations, collective actors) and institutions (societal and technical norms, regulations, standards of good practice), as well as material artifacts and knowledge" (Markard, et al., 2012). These elements interplay for a functional society, and technology is an essential tool to fulfill these vital functions (Geels, 2004). Therefore, a socio-technical transition is a set of processes that stimulate important shifts in socio-technical systems – normally, as means to pursue sustainability (Kemp, René & Loorbach, 2005; Smith & Stirling, 2010; Truffer et al., 2008; Verbong & Geels, 2010; Shove & Walker, 2007).
Social-ecological transformations	This approach posits change as an induced process of self-organization. One of its main intellectual contributions is resilience thinking – focusing on the capacity of a system to absorb shocks while maintaining systems' core structure and functions (Walker & Salt, 2006). Resilience, however, can be problematic when the system's established function, structure and/or feedbacks are undesirable (Kaika, 2017; Méndez et al., 2019). In this case, fundamental system change is necessary. Therefore, authors recognize transformability as a key systems' feature and relevant component of resilience thinking (Brown, 2014; Bobar & Winder, 2017; Olsson et al., 2014). In this approach, transformation occurs when pressures for change at a system's thresholds can be stimulated to a point where a new system function appears and establishes (Chapin, 2010; Walker et al., 2004).
Sustainability pathways	Sustainability pathways is an encompassing, cross-disciplinary approach that seeks mutual benefits of environmental health, fostering human rights and poverty reduction (Leach et al., 2007). This approach studies the patterns of change in systems by looking at past events, current trajectories and future scenarios through a sustainability lens, while paying attention to disputed alternative pathways (Beland Lindahl et al., 2016). Sustainability pathways approach adopts complementary approaches and is oriented to the search for social and environmental justice and poverty alleviation (Scoones et al., 2015; Smith et al., 2016). At the same time, sustainability pathways recognizes local knowledge and experience as essential for pushing bottom-up, profound and progressive social change (Johnston et al., 2020; Leach, et al., 2012; Stirling, 2014a).
Transformative adaptation	Transformative adaptation stems from studies on adaptation to climate change – that is, the search for actions to anticipate and cope with distress provoked by climate change-associated effects (Pelling, 2011). Adaptation to climate change as a field of study refers to "changes in processes, practices, and structure to

	moderate potential damages or to benefit from opportunities associated with climate change" (Smit et al., 2001, p. 879). Alternatively, transformative adaptation addresses climate vulnerability and risks from their roots. It entails efforts to fundamentally alter structures that have common operations that accelerate adverse environmental change (O'Brien, 2012; Pelling et al., 2015; Schulz & Siriwardane, 2015). Broadly, this approach recognizes that adaptation as a decision-making method has limits, and transformation is necessary instead when disturbances are too dangerous to be addressed through adaptation alone (Coloff et al., 2017; Kates et al., 2012).

Scoones and colleagues (2020) have recognized the previous works and have synthesized the salient literature into three main approaches to understanding and advancing transformations. Notably, the authors recognize that their work particularly focuses on "human drivers of transformations" – or human-induced change (Scoones et al., 2020, p. 66). The three main approaches are:

1. ***Structural change:*** refers to fundamental changes in the way production and consumption are governed, organized and practiced by societies;
2. ***Systemic change:*** refers to intentional change targeted at the interdependencies of specific institutions, technologies and constellations of actors in order to steer complex systems towards normative goals; and
3. ***Enabling change:*** focuses on fostering the human agency, values and capacities necessary to manage uncertainty, act collectively, identify and enact pathways to desired futures.

These perspectives embrace complexity, including the essential idea that transformations usually happen through multiple small transitions at different scales (e.g., Dorninger et al., 2020; Pereira et al., 2015). Therefore, as illustrated below, it is important to underscore the role of transitions and transformations in complex systems' dynamics.

4.1.2. Sustainability transitions and transformations in complexity

Literatures that focus specifically on change towards sustainability through transition and transformation as a scientific approach have shed light on important challenges. For instance, experts have debated how to best answer the key questions: how do we determine the defining characteristics of a system and decide on how and what to change? How do we know when fundamental change is in fact happening? How do we assess if we are going in the right direction? And who are the main actors to elicit change? (Burch, 2017; Brown et al., 2013; Patterson et al., 2016; Scoones et al., 2020). At the same time, there is a persisting fragmentation of approaches to human-induced change – particularly transitions and transformations – in works addressing social and ecological change (e.g., Blowers, 1987; Burawoy, 2001; Hölscher et al., 2018; Laughlin, 1981; Mazmanian & Kraft, 2009). This fragmentation of approaches coupled with a lack of understanding of transformations have delayed the innovation and integration of knowledge necessary to build development paths towards sustainability (Dale et al., 2018).

The following discussion uses a complex systems lens to explore the crucial role of transitions and transformations in multi-level system dynamics in consideration of the questions raised above. To this end, transition and transformations are seen as overlapping parts of the same vital system process, both being essential in the pursuit of sustainability. Their differences, therefore, are not considered significant enough to establish the two as different fields of study. Ultimately, this section aims to advance the understanding on how multiple transitions with incremental effects can lead to systems' transformations.

Multi-level system dynamics

In their work on complex social-ecological systems, Kay and Schneider (1994) used music to illustrate how ecosystems' complex behaviour should be approached. In general terms, the authors explained that complex systems' behaviour is "like a large musical piece such as a symphony, which is also dynamic and not predictable and yet includes a sense of flow, of connection between what has been played and what is still to come, the repetition of recognizable themes and a general sense of orderly progression" (p. 55). This analogy can be expanded by examining music (in extremely simple terms) through the incorporation of more contributions on complex systems thinking. Specifically, it can aim in drawing the role of transitions and transformations in multi-level system dynamics.

A musical piece (e.g., a song) observed as a system has different sub-components (e.g., instruments, bars (beats per second)) and multiple interacting levels or sub-systems (e.g., chords, notes) that define main components of the song (e.g., harmony, tempo). In this song, hence, there are multiple transitions occurring at different levels (e.g., from one chord to another, from one note to another) through the interaction of multiple sub-components (Keating & Katina, 2019; Sjöstedt, 2019; Zheng et al., 2017). A basic illustration of this process is Gunderson and Holling's (2002) widely adopted approach on adaptive cycles. From this point of view, the process of continuous transitions is called "adaptive cycle", and the multi-level interactions are identified as a "panarchy" (Figure 4.1). However, it is also possible to play the same piece with different instruments (or sub-components), modify a few notes (or sub-systems), change the harmony and tempo (or system components), and still be able to identify it as the same song (or patterns and structures) (Schaaf et al., 2011). In such case, while multiple transitions are happening, the system remains the same. In other words, it has not been transformed (Walker et al., 2004).

Adaptive Cycle **Panarchy**

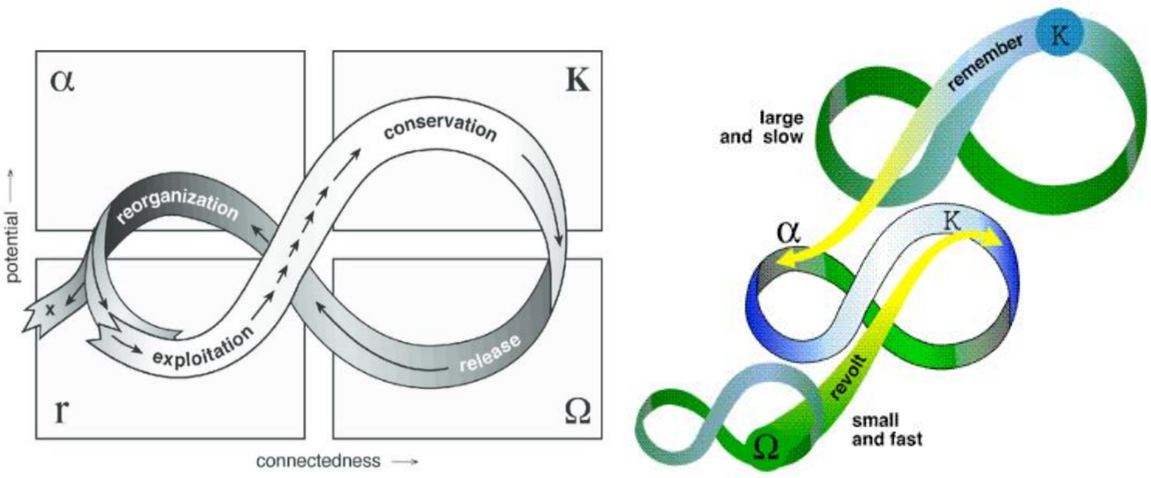


Figure 4.1. Illustration of adaptive cycle and panarchy based on Gunderson & Holling's (2002).

Resilience and transformation

Nonetheless, systems do have the ability to transform into new ones (Ibarra et al., 2020; Olsson et al., 2014; Young, 2017). For instance, as Kay and Schneider (1994) point out, a musical piece can be changed to a different one via silence. That is, a note or chord can be silenced to then play a different one. However, this also means the end – or collapse, in parallel with Ravetz (2006) – of the note or chord. If all notes and chords collapse to start a different song, this means the first song ended. Another way of transforming is by transitioning through an accumulation of effects, resulting from diverse multi-scale transition dynamics, that push system thresholds to new functions and structures (e.g., Folke et al., 2020; Ibarra et al., 2020; Méndez et al., 2019). In musical terms, it is possible to choose from a wide array of combinations of, for instance, instruments and bars, notes and chords, and harmony and tempo that transform into new songs without abrupt silence. In musical pieces, many notes and chords can be played and silenced repeatedly, and the integrity of each song can be preserved as they transition and transform into new songs. In other words, while some smaller-scale components are disrupted, the continuity between and among systems prevails (e.g., Hochrainer-Stigler et al., 2020; Walker & Salt, 2006). Table 4.2, shown below, illustrates these dynamics.

Table 4.2. The role of transition and transformation in complex systems' behavior illustrated through Kay and Schneider's (1994) music analogy

If:	***Then:***	***Also:***
S [system = song]	a. Transformation: change from one S into a new S.	The combination of interacting SC/IB – which dynamics affect multiple SS/CN interactions – define the MC/HT of the

SS/CN [sub-systems = chords, notes] MC/HT [main components = harmony, tempo] SC/IB [sub-components = instruments (referring to the sound that each instrument produce, not the physical instrument), bars (beats per segment)]	b. Transition: modifying SC/IB at SS/CN levels, without changing the MC/HT of S. c. Transition leading to transformation: the strategic selection of SC/IB to progressively change MC/HT, at SS/CN levels, into a new S.	system. Each SS/CN level, at the same time, having their own combinations of interacting SC/IB.

Based on the previous insights, it is possible to identify five key aspects relevant to transitions and transformations' roles in complex systems' thinking. The key aspects are developed as follows:

- *It is possible to have transition without transformation*, as it is possible to change instruments, introduce or remove a few notes, modify tempo and still be playing the same song.
- *It is possible to transform without transition*, as it is possible to change a song by stopping it (silence) and then playing an entirely different one.
- *Transition without transforming* means that the system and its main components, or defining characteristics, remain the same.
- *Transforming without transition* means the end of one system (set of structures and functions) to start a new one (different set of structures and functions).
- *Transforming through transitioning* means an accumulation of effects interacting at multiple scales that pushes systems to cross thresholds into new structures and functions.

It is important to remark that transformations usually happen through the latter option, and that these are more desirable for sustainability purposes. Evidently, the most threatening scenarios discussed in the sustainability literature are the result of the negative cumulative effects of multiple small transitions (Beckett et al., 2020; Jones, 2016; Österlin, 2020; Sutherland et al., 2016). Therefore, it is possible to argue that sustainability-in-complexity can be better attained by the implementation of multiple and mutually reinforcing sustainability-contributing packages that feed systems with positive effects towards more desirable systems.

Uncertainty and unpredictability

Kay and Schneider (1994) also hint that, if the only goal is to sustain the music, it would be possible to create a musical piece in which chords transition to an ending that, at the same time, transitions and transforms into the beginning of the piece. That way, it could be repeated continuously. In fact, some components could be replaced when desired and the same musical piece can be sustained. However, considering the analysis in Chapter 2, while it is possible to compose musical pieces that may sound very complicated, random and chaotic, they cannot be considered as complex. The dynamics happening in music follow linear interactions that can be depicted, for instance, in sheet music. Indeed, as Kay and Schneider pointed out, there are cases where music is improvised. However, the number of note variations and chord progressions available is limited, and they can be anticipated to a degree through harmony and harmonic progression (F. Zebadúa, personal communication, July 20, 2020). In contrast, complexity thinking explains that, in a complex piece, the musical structure would be composed by notes that are constantly and at least to some extent unpredictably shifting (Vigni, 2020; Moore et al., 2018). These notes may suddenly sound different from how they used to sound and create new chords, until eventually becoming a whole different sound experience. In other words, given the ever-changing and unpredictable interaction of notes and chords (and other songs), replicating the first composed musical piece is much more complicated, if not impossible. This, naturally, coupled with many more contextual factors involved at many more scales (see Chapter 2).

Key arguments

While recognizing that this is a very over-simplified illustration of all the interactions and elements that may be involved, useful insights can still be developed from this analogy through a complexity thinking lens that focuses attention particularly on transition and transformation. For example:

- Transitions and transformations are constantly happening in complex systems (change is the norm rather than the exception).
- Transformations can be envisioned through milestones, or desirable characteristics, that help in defining and strengthening the main components of a new system.
- Transitions can foster and provide positive effects for the new system to appear, through effectively allocating contributions to the system defining characteristics.
- The characteristics of the system must allow for both continuous transitions and transformations. This will enhance the system's capacity for resilience, sustainability, and emergence.
- Such characteristics will vary depending on scale and context.
- Transitions and transformations are very difficult to manage.

Following this logic, transition is often perceived as a process, and transformation as an outcome (Child & Breyer, 2017). As others have already stressed, however, it is important to remark that while transition and transformation are not synonymous (as shown in Table 4.2), they should be considered as part of a same process in complex systems' change (Child & Breyer, 2017; Hölscher et al., 2018; Mendizabal et al., 2018). This includes the smaller incremental changes and the large, seemingly abrupt, fundamental changes. In other words, the differences between transitions and transformations in the literature do not matter enough to separate them for scientific purposes and encourage more consistency in word selection. Therefore, transition and transformation should be considered as two words that different authors use in different ways to study the multiple phenomena happening in socio-ecological systems' change (Child & Breyer, 2017; Stirling, 2014a). Finally, while this conclusion is not unique, the analysis through a complex systems lens provides relevant contributions in the pursuit of sustainability.

This analysis proposes that transformation can (and should, for sustainability purposes), happen as a series of small transitions in a positive direction to gradually build the conditions for desirable transformation. Particularly, these transitions could be pursued as mutually reinforcing packages of positive feedbacks. As mentioned above, some transitions go in a direction that indeed leads to a progressive change of the main components of the system and can lead to a fundamental change. In this case, the fundamental change of what is identified as the main components of the system is what may determine the transformation. For electrical energy systems and transition or transformation, the core question may not be what the defining characteristics of the system are, but what characteristics of the system are relevant for specific concerns – in this case, positive effects on prospects for sustainability. This thesis' examination of electrical energy systems is centred on that concern and is supported by decades of developing theory. Namely, the key characteristics as identified by Amory Lovins and more recent studies reflect a similar preferred option – system characteristics and associated sub-components and interrelations that seem likely to have significant potential implications for positive effects on prospects for sustainability. Ultimately, embracing this thinking can provide important insights for transitioning and transforming towards sustainability:

1. Understanding the role of transitions and transformations makes it possible to better identify whether and how well the sustainability-related characteristics of a particular system are aligned with delivering positive contributions.
2. The key system characteristics identified for sustainability purposes can guide the type of changes needed for more consistently positive contributions, including:
    a. the key characteristics, desirable and undesirable, that affect a system's prospects for moving towards sustainability.
    b. the key existing system characteristics that need to be retained and strengthened for sustainability.
    c. the key desirable characteristics that the system now lacks and that should be sought through transitions and system transformation.
3. In dynamic socio-ecological systems there is no sustainability end state and therefore no final transformative achievement.
4. However, it is possible to draw general and specific component maps that indicate the direction and effects of ongoing changes related to the identified key characteristics, determine what more could be achieved, and practice appropriate precaution in uncertainty.

5. While some changes can happen more or less separately and incrementally and self-organize into a better overall system, it might be better, even necessary, to design and push the changes as a package of mutually linked and supporting initiatives, again with precaution.

4.2. Governance challenges of transforming towards sustainability

Recently, governance issues have been identified as some of the strongest roadblocks for human-induced transformations towards sustainability since they can inhibit transitions or encourage undesirable transformations. Governance issues are usually related to the power dynamics and agency exerted by different and competing interests involved in decision-making processes (e.g., Avelino et al., 2016; Blythe et al., 2018; Patterson et al., 2016; Schulz & Siriwardane, 2015). Recent literature refers to such governance challenges as "politics of transitions/transformations" (e.g., Avelino et al., 2016; Healy & Barry, 2017; Scoones et al., 2020). In this sense, politics can be considered as "all the activities of co-operation and conflict, within and between societies, whereby the human species goes about organising the use, production and distribution of human, natural and other resources in the production and reproduction of its biological and social life" (Leftwich, 1983/2010, p. 11).

Experts have identified that responses to some of the most critical social-ecological issues (e.g., climate change) have been stymied because decision-making has not found adequate means of overcoming these challenges (Avelino et al., 2016; Beddoe et al., 2009; Etzion et al., 2017). Notably, powerful actors in the system and the most dependent people and organizations in it (which are usual participants in decision-making processes) can use their influence to maintain system characteristics that benefit personal interests (Olsson et al., 2017; Méndez et al., 2019; Voß & Bornemann, 2011). In this regard, authors have recently focused on identifying the negative effects of governance issues in efforts to transform towards sustainability (Abson et al., 2017). For example, Blythe and colleagues (2016) recognize how transformational discourse and practice can be used as means for less transformative effects. As a result, the authors identified five latent risks that can further aggravate serious social and ecological issues:

Risk 1: Transformation discourse risks shifting the burden of response onto vulnerable parties.
Risk 2: Transformation discourse may be used to justify business-as-usual.
Risk 3: Transformation discourse pays insufficient attention to social differentiation.
Risk 4: Transformation discourse can exclude the possibility of non-transformation or resistance.
Risk 5: Insufficient treatment of power and politics threatens the legitimacy of transformation discourse.

In response, Scoones and colleagues (2020) argue that meaningful transformation efforts towards sustainability require the complementarity and mutually reinforcing effects of the diverse, often competing, approaches transformation. The authors point out that attaining positive complementarity effects entails the consideration of three action principles:

1. ***Taking diverse knowledges seriously*** – facilitating meaningful processes for co-creation of knowledge from diverse sources;
2. ***Accepting a plurality of pathways*** – adopting forms of deliberation that consider all contending options as well as the backgrounds and interests of the participants involved; and
3. ***Embracing the political nature of transformations*** – governing challenges of confronting views, interests and forms of incumbent power.

Figure 4.2 illustrates the overall components discussed by Scoones and colleagues. Firstly, it includes the three main approaches to sustainability-oriented transformations (structural, systemic, enabling) and the three action principles to support complementary transformative effects (diverse knowledge, plurality, politics). Secondly, the arrows represent the complementarity effects from the diversity of approaches. Essentially, addressing diverse knowledge, plurality and politics will facilitate the emergence of opportunities for making positive contributions towards desirable change. And thirdly, the outline circle represents a complementary lens necessary to examine transformations towards sustainability. This lens reminds us that contributions to desirable change produced in each component have implications and mutually reinforcing effects for the others.

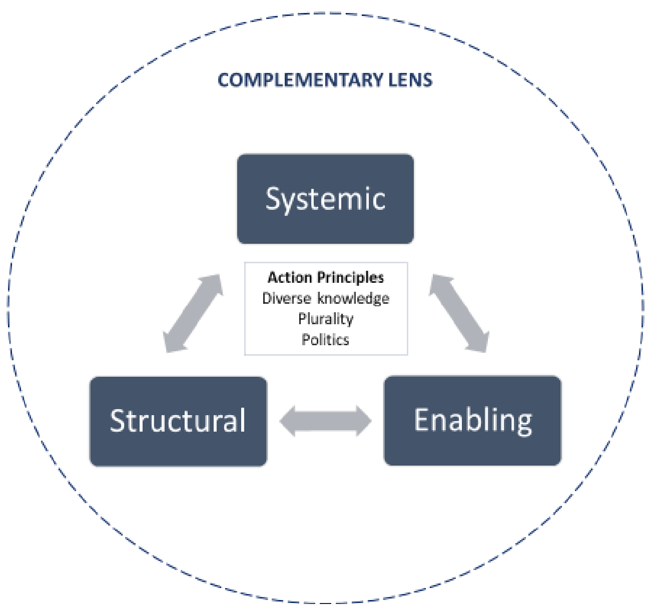


Figure 4.2. Overall components of human-induced transformations towards sustainability based on Scoones and colleagues' (2020) approach

4.2.1. Opportunities for governing transformations towards sustainability

Many authors have agreed on the perception that systems have certain characteristics and interacting components that play major roles in defining the behaviour of the overall system.

Particularly relevant works focus on characteristics for positive effects on prospects for sustainability: Lovins' (1976) soft energy paths characteristics, Meadows' (1999) system's leverage points, Gibson and colleagues' (2005) requirements for progress towards sustainability, Geels and Schot's (2007) multi-level perspective for socio-technical transitions, Westley and others' (2011) tipping points towards sustainability, Burch and colleagues' (2014) enabling policy conditions for transformative change, among others. The same authors stress, however, that human-induced change of system components involves highly disputed processes and conflict. In response, research into governing for sustainability has provided insights relevant to tackling political issues that undermine human-induced change towards desirable futures (Berkes, 2017; Dale et al., 2018; Kuzemko et al., 2016). In this regard, as discussed below, experts have identified the need for enhanced capacities of participatory and democratic governance.

Participatory and democratic governance has historically been the exception rather than the norm (Fahrmeir, 2020). However, it has also shown to be a more resilient form of governing, with a higher capacity to support sustainability contributions, compared to centric models of governing (Fahrmeir, 2020). Experts have agreed that good governance for sustainability can provide effective responses to the most imperiling planetary issues by integrating knowledge co-produced by the diverse array of sectors and actors in society (Adger et al., 2009; Biermann, 2012; Dale et al., 2018; Lockwood, 2010; Meadowcroft, 2007). Notably, attributes of "good" governance include "participation, representation, deliberation, accountability, empowerment, social justice, and organizational features such as being multilayered and polycentric" (Lebel et al., 2006, p. 2) However, good governance can be undermined by ignoring the politics of governance processes (Temper et al., 2017). In other words, participants possess their own "entrenched beliefs, conflicting values, competing interests, unequal resources, and complex social relations" (Geels et al., 2017, p. 463), and governance challenges are therefore inevitable.

Therefore, governance capacity in diverse jurisdictions can and should be strengthened to tackle such challenges and maximize the benefits of democratic and participatory processes. Otherwise, low participatory and democratic governance capacity can block the positive effects of meaningful responses and delay efforts to tackle the most urgent problems for global societies (Dryzek & Stevenson, 2011; Galaz et al., 2012; Voß & Bornemann, 2011). For example, experts agree that there is a frequent inability and/or unwillingness of governance bodies to explicitly engage with the politics of alleviating social and environmental issues (Berkes, 2017; Eriksen et al., 2014; Geels et al., 2017). Failure to overcome such limitations has prompted misaligned policy making between governmental scales and undermined the application of proven governance strategies for positive change (Dale et al., 2018; Winfield, 2016). In this sense, distribution of power – defined by Avelino and Rotmans (2011, p. 798) as "the capacity of actors to mobilize resources to realize a certain goal" – is a key related element to address. Power, and the relationships among power-exerting agents, can influence decision- and policy-making processes significantly, often towards negative socio-ecological effects (Bulkeley et al., 2015;

Stirling, 2014b). In fact, recent works argue that deceptive transformative discourses can be willfully used by influential actors to impede transformation (Abson et al., 2017; Blythe et al., 2018; Schulz & Siriwardane, 2015). Some authors, hence, stress the need to find design options that provide opportunities for directing power dynamics, agency, culture and collaborative learning towards positive development paths (Berkes, 2017; Bulkeley et al., 2015; Geels et al., 2017).

4.2.2. Just transitions

Some authors that adopt the idea of multiple transitions happening at different scales with cumulative effects that usually lead to more significant changes (or transformations) in the overall system have identified that these processes can also pose threats for valued and desirable elements for human well-being (Henry et al., 2020; Mayer, 2018). In this sense, there has been recognition that transitions occurring in diverse societal sectors, while also having positive outcomes, have spurred endangering effects for social and biophysical contexts (Healy & Barry, 2017). Markedly, the fast pace, severity and wide spreading of such effects have been identified to aggravate climate change and its socio-ecological impacts, which are more severely experienced by disadvantaged groups (Heffron & McCauley, 2018). At the same time, attempts to transition towards more ecologically positive effects have often overlooked the adverse effects to those that have been and are more likely to be affected by transitions at a global scale (Jenkins et al., 2020; Stevis & Felli, 2020). Therefore, experts have studied just transitions as an approach to "draw attention to the equity and justice challenges associated with efforts to steer society towards a more ecologically sustainable path" (Snell, 2018, p. 550). According to Rosemberg (2010, p. 141), just transition studies can capture "the complexity of the transition towards a low-carbon and climate-resilient economy, highlighting public policy needs and aiming to maximize benefits and minimize hardships for workers and their communities in this transformation".

'Jobs vs. environment' concerns

The transitions and transformations required for progress towards sustainability will likely create adverse effects for those who depend the most on the systems that are being transformed. This has been largely manifested through labour and other community movements globally prompted by concerns related to job security and economic well-being in light of ongoing transitions (Cha, 2020). Experts have highlighted, more specifically, broad concerns about climate and other environmental-related policies boosting socio-economic costs – e.g., loss of well-paid and long-lasting jobs, loss of opportunities for economic benefits (Mayer, 2018). Such issues have created a misalignment of interests between official environmental and socio-economic considerations, as well as mistrust from labour advocates towards environmental (often climate) policy (Healy & Barry, 2017). This is frequently described as a 'jobs vs environment' problem – social-economic welfare movements and environmental goals perceived as opposing. Consequently, these tensions hinder the widespread community acceptance and engagement to policy pathways' design for sustainability (Heffron & McCauley, 2018; White, 2020).

Approaches to just transitions aim to respond to these issues by ensuring that not any particular community or group experiences the burdens of sustainability-oriented transitions and transformations unfairly (Jenkins et al., 2020; Winkler, 2020). Some experts, for example, have focused on finding and implementing favourable conditions for policy-making that provide support options to the most likely affected (e.g., retraining, relocation, and pension protection) (Haggerty et al., 2018; Pollin & Callaci, 2016). However, researchers have found that policy-making tools and methods often prioritize technical and economic approaches, overlooking basic justice dimensions – e.g., distributional (fair distribution of benefits and risks), procedural (inclusion in decision-making processes) and recognition (consideration of interests and vulnerabilities of marginalised groups) (Hurlbert & Rainer, 2018; Winkler, 2020). Hence, experts have remarked the importance of involving affected groups in discussions and planning processes for transitioning systems and ensuring participatory decision-making (Galgóczi, 2020; Goddard & Farrelly, 2018; White, 2020).

Just transitions and electrical energy systems

Recently, electrical energy systems and their associated operations have become relevant venues for studying just transitions around the world (e.g., Cha, 2020; Goddard & Farrelly 2018; Swennenhuis et al., 2020; Swilling et al., 2016). There are a few evident reasons for this growing interest. Mayer (2018) recognizes that different electrical energy systems have experienced significant changes in relatively short periods of time. For instance, predominant socio-technical regimes supporting fossil fuels for powering basic human needs, and as a main source of economic income, have exacerbated climate change and its imperiling effects (Pearse et al., 2013). Newell and Mulvaney (2013, p. 452), in addition, have argued that in such socio-political context "the interests of elites and powerful actors are more often than not misaligned with the energy needs and environmental vulnerabilities of the world's poorest people". Hence, electrical energy systems have faced increasing public scrutiny to operate with low carbon emissions in just ways (Snell, 2018).

Usually, electrical energy systems have sought to attain environmental targets through low-carbon policies and decision-making that incorporates renewable energy technologies, as well as efficiency and conservation tools (see Chapter 3). However, narrowly focused low-carbon strategies have led to major decisions without appropriate consideration to socio-economic costs and valued resources and have created energy justice concerns. On this matter, Galgóczi (2020, p. 368) points out that "the transition to a (net) zero carbon economy by 2050 means a fundamental revision of our linear, extractive and fossil fuel-based growth model with major effects on jobs, livelihoods, working conditions, skills and employment prospects". Failure to do so has affected disadvantaged groups with job losses, economic burdens and conflicts caused by closures of coal plants and mines mandated for the benefit of climate safety (Healy & Barry, 2017; Mayer, 2018). Additionally, as Henry and colleagues (2020, p. 1) mention, recent events such as the 2020 oil price war and the COVID-19 pandemic "have accelerated job losses in other parts of the energy sector, especially in oil and gas".

Authors studying just transitions for electrical energy systems have therefore emphasized the need to adopt more comprehensive approaches to justice in energy transitions. For instance, different authors have studied electrical energy systems as contributors to injustices related to distributing risks and benefits unfairly to different areas of the world, creating effects that impact disadvantaged groups more severely, and avoiding official requirements to accelerate decision-making processes in favour of short-term political and economic interests (see section 3.2.1). In this regard, Delina and Sovacool (2018, p. 4) identified five salient decision-making considerations that are essential for pursuing just transitions in electrical energy system undertakings:

1. The selection of sustainable energy systems that would empower those with less in life and address inequality, deprivation, and poverty;
2. the design of fair, just, and non-paternalistic technology, financing, and capacity transfer;
3. the assurance that resources that are environmentally benign, culturally respectful, and offer more benefits than risks are given premium in decision-making;
4. the design of decision-making processes such that the processes account for social justice and the sustainability of resources for future generations; and
5. the assurance of fair distribution of the costs and benefits.

Experts have recently highlighted the role of enhanced governance capacities in addressing injustices and inequality in energy transitions. Research has shown that decision-making considerations like the ones developed by Delina and Sovacool are more likely to be attained collaboratively, through democratic and participatory governance processes (Evans & Phelan, 2016; Goddard & Farrelly, 2018; White, 2020). This entails the inclusion of labour movements, unions, community initiatives and disadvantaged groups in electrical energy systems' planning. At the same time, just transitions require for knowledge contributions to create socio-political regimes favourable for widespread acceptance and to align environmental policies with distributional and procedural justice foundations (Healy & Barry, 2017; White, 2020). Finally, just transitions are more likely to be attained if they are addressed and communicated as complex endeavours – that is, changes happening as a result of multiple, multi-scalar interactions, instead of linear causalities (Mayer, 2018). Therefore, just transitioning is considered for the purposes of this dissertation as a key aspect for governing transformations towards sustainability. Moreover, it is proposed that the incorporation of just transitions considerations to the framework specified to electrical energy systems can be beneficial to addressing some of the salient challenges for just transitions.

4.2.3. Design options to maximize transformative opportunities for governing towards sustainability

Table 4.3 shows recent studies on governing transformations towards sustainability that provide relevant examples of system design options to generate opportunities for positive effects. Broadly, the examples in Table 4.3 have focused on transforming current systems towards sustainability-based systems. However, one overlapping feature in these recent works is that they address the complex dynamics of governance. More specifically, these studies seek to identify governance attributes and tools that increase potential to create opportunities for inducing transformation towards sustainability.

Table 4.3. Examples of studies on governance options that provide opportunities for transforming towards sustainability

Author(s)	Design options	Main lessons
Burch et al., 2019; Romero-Lankao et al., 2018; Urbinatti et al., 2020	Collaboration and multi-scale alignment	Authors have stressed that policy-making in multiple jurisdictions needs to be aligned in support of social and technical innovation and co-production of knowledge
Gibson, 2017; Hacking, 2019; Kanie et al., 2020	Sustainability-contributing packages	Transformations towards sustainability are better designed and pursued at several scales through initiatives aiming to deliver packages of multiple, mutually reinforcing gains
Fahemeir, 2020; Geels et al., 2017; Stirling, 2015	Complex systems lens	Authors stress the need to examine governance through a lens that perceives advancement of change as non-linear, disruptive and multiple disputed processes
Feindt & Weiland, 2018; Kirwan et al., 2017; Takaes, 2020	Reflexivity	Governance institutions must be able to self-examine the political dynamics within their own efforts to pursue sustainability

Berkes et al., 2017; Folke et al., 2020; Fuenfschilling & Truffer, 2016; Schulz & Siriwardane, 2015; Patterson et al., 2016	Agency and power focus	Governing change for sustainability requires stronger efforts to clarify the power imbalances involved in transformations – that is, internalizing the social and ecological risks that power and politics can create. At the same time, governing change in and of complex systems must consider and find opportunity in the system participants' capacity to push or resist change
Armstrong & Kamienieki, 2017; Chaffin et al., 2016; Sharma-Wallace et al., 2018; Yasmin et al., 2020	Adaptiveness	Policy options need adaptive capacity to respond to emerging, often unexpected problems and to move away from the unavoidable, irreversible effects of crossing planetary boundaries
Kuzemko et al., 2016; Luederitz et al., 2017; McCrory et al., 2020; Scoones, 2016	Specification to context	While needing to consider broad scenarios, governing towards sustainability-contributing systems requires a deep immersion into specific contexts. That is, research must not only reveal the contextual characteristics of individual cases, but also connect them to broader levels and structural issues – e.g., "patterns of social differentiation and distribution and so class formation, gender hierarchies, and racial and ethnic discrimination…" (Scoones, 2016, p. 309).

These works are relevant to this thesis work since they provide a map of governance design options that have been identified as key in previous works on governing transformations towards sustainability. Ultimately, the main insights provide governance considerations that can be implemented to sustainability-based assessment frameworks that promote transformations as an important criteria category (see section 4.4).

4.3. Policy pathways – Futures studies for clarifying policy-making implications of transforming towards sustainability

Futures studies is an essential aspect in human activity and its role has been increasingly recognized in designing systems for sustainability (Mulvihil & Kramkowski, 2010; Robinson, 1990; Wiek & Iwaniek, 2014). Therefore, the importance of studying humans' limited ability and common unwillingness to deal with issues of the future has been long recognized (e.g., Bell, 1997; Schwartz, 1991). Currently, there are deeply rooted obstacles for designing desirable systems of the future. Notably, experts have claimed the need to understand that "the future is not what it used to be" (Inayatullah, 2018, p. 15). In other words, it has been acknowledged that our perception of the future changes constantly with time in accordance with our contextual realities (Masini, 2006; Son, 2015). Accordingly, many authors agree that current future thinking commonly overprioritizes and rewards short-term effects, while the once prioritized long-term human-oriented effects are often overlooked (Godet, 2010; Robin & Steffen, 2008; Son, 2015). As a consequence, modern societies and their institutions have often preferred to rely on tools that provide an illusion of certainty for immediate answers, rather than to find appropriate ways to deal with uncertainty (Bindé, 2000; Elahi, 2011). This further undermines the prospects for attaining desirable futures. As Innerarity (2012, p. 5) has observed:

> "…the enemies of the future are the people who conceive of it without taking its complexity seriously, those who handle it thoughtlessly (either because they view it as a mere continuation or because they mortgage it recklessly), those who plan it without respecting its opaqueness, but also those who comfortably accept the supposed natural progression of things".

These obstacles have undermining effects for making progress towards sustainability. For instance, authorities have shown little interest in clarifying the policy and decision-making implications of transforming towards sustainability (Gibson et al., 2018). At the same time, the official processes for project review and public acceptance have been often overlooked in favour of short-term economic and technical purposes (Winfield, 2016).

4.3.1. Salient considerations of futures studies for sustainability

According to Banister and Stead (2004), futures studies can be classified in three questions for thinking about the future: possible futures (what might happen?), probable futures (what is most likely to happen?), and preferable futures (what we would prefer to happen?). Similarly, as illustrated in Figure 4.3, Börjeson and colleagues (2006) identify three main categories of future scenarios studies: predictive (what will happen?), explorative (what can happen?) and normative (how can a specific desirable target be reached?). The categories are at the same time divided in six types:

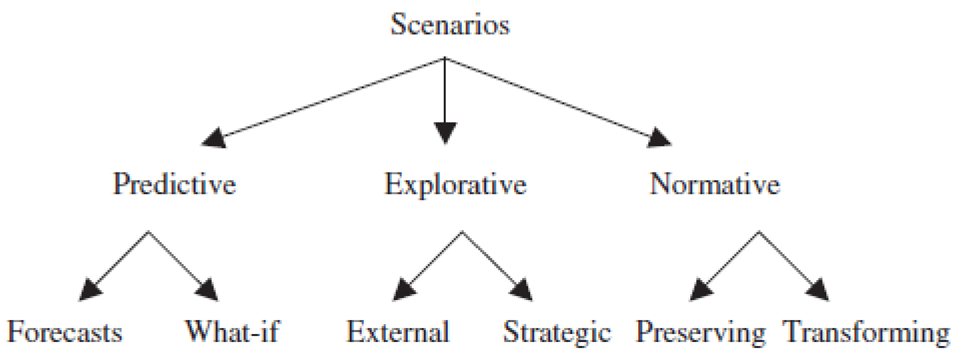


Figure 4.3. Börjeson and colleagues (2006) scenario typology with three categories and six types

Following Börjeson and colleagues' (2006) typology, the most predominant approaches to futures thinking since World War II have been predictive – through forecasting and modelling scenario study types (Kuosa, 2011; Masini, 2006). These consist in the prediction of "the most likely state in the system being studied", according to current technical and economic trends, and aligning decision-making with the predicted possible futures (Robinson, 1990, p. 821). Forecasting can be relevant for sustainability purposes as it can reveal the consequences of continuing along current trajectories and provide a basis for determining, anticipating, and adapting to already unavoidable changes (Bell, 1997). However, as a primary tool for policy-design, it is ill-suited to deal with the complexity of social and ecological problems that policy-makers face (Bindé, 2000; Inayatullah, 2008; Innerarity, 2012). These problems are considered to be particularly pluralistic, nebulous, multi-dimensional, non-linear, dynamic, socially constructed, and have no definitive solutions – in other words, they are "wicked problems" (Head, 2008; Rittel & Webber, 1973; Weber & Khademian, 2008). Hence, different authors have agreed that traditional forecasting is not sufficient. Godet (2010, p. 1462), for example, has stressed that forecasting tools and methods are useful but "cannot be taken as an ultimate solution for anticipating futures". Instead, futures approaches should help to foster collaboration and multi-scale alignment (Godet, 2010; Nikolakis, 2020; Swart et al., 2004). They must also be reflexive in order to address the agency and power dynamics involved in designing futures (Cornish, 2004; Inayatullah, 2018). Furthermore, advancing towards sustainability entails a shift away from harmful social and ecological trajectories, whereas traditional forecasting methods are not designed for breaking trends (Phdungsilp, 2011).

4.3.2. Futures studies in support of transforming towards sustainability – scenario planning and backcasting

Futures studies, as Inayatullah (2008, p. 4) remarks, can "help people to recover their agency, and help them to create the world in which they wish to live". The Sustainable Development Goals (SDGs) (UN General Assembly, 2015), for instance, propose targets concerning seventeen main interconnected problem areas (presented as goals) that are now contributing to and affected by severely adverse social and ecological effects. Pursuing the SDGs provides two basic scenarios: 1) predictive evidence shows that the adverse consequences of continuing in current trajectories are expected to intensify and create more negative social and ecological effects; and 2) attaining the targets is expected to decrease negative effects and increase the contributions towards social and ecological sustainability. The first scenario bears pessimistic visions of the future with low prospects for social and ecological well-being, while the second one entails changes towards more positive directions that increase the prospects for more hopeful and desirable futures of human and environmental prosperity. Therefore, authors have stressed that proposed tools for futures studies in favour of sustainability contributions should be inherently normative (Dreborg, 1996). That is, they must "reflect the need to incorporate long-lived natural and human processes and impacts", while addressing "the need for developing appropriate responses to unsustainable practices" (Robinson, 1990, p. 821). By doing so, futures studies for sustainability can help to envision the long-term characteristics of desirable futures, and to design policy pathways to move closer towards them (Alqvist & Rishiart, 2015; Bibri, 2018). More specifically, the field of futures studies has provided significant contributions in experimentation and innovation for better dealing with complexity (Derbyshire, 2016; Mulvihil & Kramkowski, 2010). For instance, some methods can aid in scanning the future "in a creative, rigorous and policy-relevant manner that reflect the normative character of sustainability and incorporates different perspectives" (Swart et al., 2004, p. 138).

Accordingly, tools and methods that explicitly deal with sustainability objectives, transformation needs, and complexity considerations have been proposed as design options for policy making. Two of the most salient are scenario planning and backcasting. According to Amer and colleagues (2013, p. 23), scenarios are the "description of a future situation and the course of events which allows one to move forward from the actual to the future situation". In practice, scenario planning can identify the "elements that are needed over a range of future conditions" for systems' design, including the social and biophysical contexts (Woods et al., 2012, p. 2838). Therefore, scenario planning has been proposed as a method to create policy objectives accompanied by pathways that lead to desirable sustainability futures (Chen & Huang, 2019; Thomson et al., 2020; Veenman, 2013). Backcasting, a normative type of scenario studies, focuses on identifying the characteristics of desirable futures and exploring the pathways and conditions necessary to reach the desired target (Börjeson et al., 2006; Vegragt & Quist, 2011). To that end, backcasting involves "working backwards from a particular desirable future end-point to the present in order to determine the physical feasibility of that future and what policy measures would be required to reach that point" (Robinson, 1990, p. 822). Figure 4.4 illustrates how instead of predicting futures that are likely to happen (e.g., through forecasting), backcasting aims to indicate how desirable futures can be attained (Mizuno et al., 2012). This approach has now been long deemed an effective tool for clarifying the strategic options and policy implications of initiatives to move towards sustainability-related targets, addressing complex issues and facilitating participatory knowledge co-production (Bibri, 2018; Mizuno et al., 2012; Nikolakis, 2020; Phdungsilp, 2011).

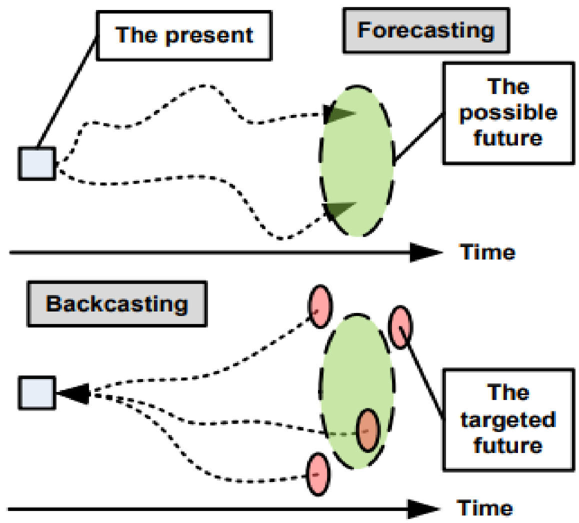


Figure 4.4. Mizuno et al.'s (2012) illustration of forecasting and backcasting

4.4. Directing transformations towards sustainability as a generic sustainability criteria category specified to electrical energy systems

Following a similar process as in Chapter 3 for the creation of generic sustainability criteria categories specified to electrical energy systems, this chapter proposes a sixth main criteria category (C6) for incorporation to the sustainability-based assessment framework developed in Chapter 3. The sixth main category, named "Transformation, integration of multiple positive effects, and minimization of adverse effects", is based on the main contributions to sustainability transformations research discussed in this chapter.

C6. Transformation, integration of multiple positive effects, and minimization of adverse effects
This criteria category incorporates and is applicable to the eight sustainability requirements for progress towards sustainability discussed in Chapter 2. C6 provides a transformative lens for the previous five developed criteria categories, seeking to shed light on opportunities for desirable change. By doing so, the comprehensive sustainability agenda is considered as interdependent with the sustainability and transformation goals more specific to electrical energy systems in response to climate change and broader sustainability-associated challenges. This involves recognizing that transforming requires practising precaution to deal with unpredictable long-term effects and supporting flexible criteria that facilitate modifications over time.

C6 plays an integrative role that encompasses the rest of the five criteria categories as mutually linked and supportive initiatives to support transformation. Particularly, C6 acknowledges that transformations are likely to happen as an accumulation of effects, resulting from multiple transitions occurring at different scales, that push systems into shifting to new structures and functions. Hence, C6 promotes the full suite of sustainability-based assessment criteria as multiple mutually reinforcing sustainability-contributing packages that feed systems with positive effects, while avoiding adverse effects, in order to transition and transform into more desirable systems. C6's integrative role must therefore recognize that transition and transformation effects can create interlinked dynamics leading to trade-offs that need to be minimized and managed when unavoidable. In this sense, this criteria category emphasizes the provision of lasting gains, and minimized risks, to the least advantaged and most vulnerable, and maintenance of valuable social-ecological systems. While the rules apply to all the criteria, C6 reiterates that adopting core trade-off rules (section 3.4.3) is key in directing and monitoring transitioning and transforming effects.

C6 embraces a diversity of approaches to explore a diversity of changes with context-specific considerations. To this effect, this main criteria category supports complementarity of existing and emerging approaches in efforts to transform towards sustainability. This entails special attention to taking diverse knowledges seriously, accepting a plurality of pathways, and embracing the political nature of transformations. Incorporating diverse knowledges is crucial to ensure that the interests of diverse participants and social groups in the electrical energy system, particularly the most disadvantaged, are well represented in decisions that seek for system transformations. Additionally, integrating knowledges from different system management components and adjacent sectors can facilitate the alignment and co-production of transformation goals that avoid increasing risks for the most vulnerable. C6 also recognizes that a plurality of possible pathways can lead to electrical energy system transformations. In this context, scenario planning and backcasting are identified as useful tools for drawing different possible combinations of policy and technical paths among multiple possible viable choices. In electrical energy system transformations, these decisions can entail, for instance, building different pathways for different regions and jurisdictional scales, choosing among soft and hard path options, or determining whether to advance promising technologies and programs in pilot projects or to favour proven low-risk options. In terms of embracing the political nature of transformations, C6 pays particular attention to the power dynamics and agency involved in efforts to move towards sustainability. To that end, this criteria category considers governance design options that provide opportunities for implementing desirable change (see Table 4.3).

C6 recognizes that electrical energy systems have overall characteristics and trajectories, desirable and undesirable, that can guide the changes needed for transforming for sustainability purposes. This criteria category highlights the need to protect and rehabilitate desirable characteristics and to redirect and transform the undesirable ones (see Chapter 3). For these purposes, C6 is informed by complex systems thinking, acknowledging that building resilience at multiple scales can provide larger-scale stability to transform smaller-scale system components that pose risks to the resilience of the larger system. In this sense, C6 incorporates just transitions as criteria that draw attention to protecting what is valuable and paying special attention to the interests of the most vulnerable in any efforts to maintaining desirable and changing undesirable key characteristics. For instance, C6 seeks to maintain key characteristics including the capacity to continue providing power for essential services for human well-being that are crucial to pursuing global sustainability goals (e.g., health, food, education, transportation), the capacity to distribute electricity to entire regions, contributing to energy security, as well as contributing positively to nations' economies (e.g., providing well-paid, lasting jobs). Conversely, C6 identifies and aims to transform undesirable characteristics such as continued contributions to greenhouse gas emissions and climate change, severe impacts to natural and socially valued systems, poor air quality and health risks, socioecological inequities and injustices, and failure to provide universal access to affordable, reliable, and modern energy services (IEA, 2022).

Table 4.4. The sixth main criteria category developed for the sustainability-based assessment framework specified to electrical energy systems

Transformation, integration of multiple positive effects, and minimization of adverse effects
Key considerations: ▪ Accumulating positive sustainability-oriented effects for desirable change, while avoiding trade-offs that pose risks to already disadvantaged groups, through the implementation of multiple and mutually reinforcing sustainability-contributing packages of initiatives. ▪ Enhancing capacity for addressing the governance challenges of transforming towards sustainability by incorporating governance design options that facilitate transformations (e.g., collaboration and multi-scale alignment, self-examination and clarification of political dynamics, adaptive capacity in policy- and decision-making for long-term considerations, specification to context). ▪ Supporting just transitions to ensure that transformation planning and practice build the resilience of what is valuable and pay special attention to the interests of the most vulnerable. ▪ Developing pathways to sustainability that address combinations of policy and technical options, deliberative processes, and strategic approaches that aim to identify how specific desirable targets can be reached, instead of aligning decision-making to predictions based on current technical and economic trends. ▪ Facilitating complementarity of different approaches to transformation by taking diverse knowledges seriously, accepting a plurality of pathways to sustainability and embracing the political nature of transformations

4.5. Transitioning and transforming towards sustainability in current adverse political energy contexts

Finally, it is important to highlight that there are considerable gaps to advance what it has been identified as required for transitioning and transforming systems from entrenched unsustainable trends and towards more desirable sustainability-associated effects. For instance, adverse political contexts can debilitate sustainability-oriented efforts for the sake of short-term economic gains and technocentric management approaches (see Chapter 2), undermining the considerations in the sustainability-based assessment framework for electrical energy systems.

Recently, different authors have identified that tendencies of right-wing populism and post-truth politics have posed notable challenges to transitioning and transforming energy systems (including electrical energy systems) towards sustainability. That is, efforts that have attempted to disregard reason and evidence, and to polarize energy and sustainability goals (e.g., climate goals) against mainstream political interests and overall socioeconomic well-being for particular political gains (Winfield et al., forthcoming). For example, some governments in Canada, the United States, and in some countries of the European Union have been able to stir opposition to and in some cases revert key energy transition efforts to tackling climate change (Fraune & Knodt, 2018). Trotter and Maconachie (2018) have identified that, while less successful, this has also been the case in some African countries. Additionally, the impacts of Russia's invasion on Ukraine pose relevant sustainability-associated challenges to the global energy context. Some authors have stressed that the conflict in Ukraine has resulted in increases of global energy prices and posed threats to energy security (e.g., reliability of supply and infrastructure, and market volatility), particularly for vulnerable countries, with the potential for severe long-term impacts (Benton et al., 2022; Zhou et al., 2023).

This thesis work's efforts to advance transformations towards sustainability in practice, particularly in the electrical energy systems of Ontario and Costa Rica, must face the rising challenges in the energy landscape. However, the political challenges can also provide opportunity for positive change. One example is that, despite right-wing populism and post-truth politics, global pressures and commitments to tackling climate change have strengthened the influence of smaller political groups and institutions that promote more meaningful sustainability and climate policy (Ćetković & Hagemann, 2020). Also, the risks of energy insecurity rising from the war in Ukraine can lead to a faster deployment of alternative energy sources (e.g., renewable energies) (Umar et al., 2022).

These aspects can reiterate the relevance of the sustainability-based assessment framework for electrical energy systems proposed in this thesis work. For instance, the sustainability-based assessment framework for electrical energy systems can be a tool to advance climate goals by transitioning and transforming through the accumulation of multiple positive and mutually reinforcing sustainability-associated effects that provide multiple and long-lasting benefits to social, ecological, and economic well-being. This includes the wider incorporation of renewable energies, and resource efficiency and conservation options. By considering and respecting complexity, the proposed framework also reiterates that transition and transformation need to address the political contexts that influence complex systems' change, or barriers to change. Therefore, as discussed in section 2.3.1, the framework acknowledges the need for human intervention to steer complex systems' change towards more sustainable trajectories. In this regard, relevant approaches to human-induced change towards sustainability mentioned earlier in this chapter can be key in tackling the political challenges and closing the gaps to what is needed for progress to accumulating positive sustainability effects. Some examples include approaches that recognize the influence of political contexts and emphasize the relevance of multi-scale initiatives, innovations and interventions, looking for leverage points, and niches for multiple transition steps for targeted change that could be scaled out and/or up, rather than relying exclusively (or even mainly) on large-scale top-down full system change (e.g., Angheloiu & Tennant, 2020; Fischer & Riechers, 2019; Westley & McGowan, 2017).

4.6. Summary of relevant insights

This chapter has proposed directing transformations towards sustainability as a key element to be included in the sustainability-based assessment framework specified to electrical energy systems. To that end, diverse relevant themes in the literature have been considered, and the following insights have been developed:

- Diverse approaches have acknowledged that transformations towards sustainability are likely to happen through an accumulation of effects that ultimately pushes the system into new structures and functions.
- Understanding the roles of transitions and transformations is likely to be useful in efforts to direct system changes towards greater sustainability. While "transitions" and "transformations" are used in various ways in the literature, they are best considered as different but potentially complementary phenomena in complex socio-ecological systems.
- Scoones and colleagues' action principles for attaining complementarity of diverse transformation approaches (e.g., structural, systemic and enabling) can be useful as a framework for identifying overall components of human-induced transformations.
- Recently, electrical energy systems have become relevant venues for the study of just transitions because of their relatively rapid changes, their contributions to climate change and their implications to job security, socially-valuable resources, and other socio-economic costs of transitioning.
- There are design options that can maximize transformative opportunities for governing transformations towards sustainability. This work has identified seven: 1) collaboration and multi-scale alignment, 2) sustainability-contributing packages, 3) complex systems lens, 4) reflexivity, 5) agency and power focus, 6) adaptability and (7) specification to context.

- Since they can aid in identifying how specific desirable targets can be reached, scenario planning and backcasting are deemed more appropriate than forecasting methods for developing policy pathways to sustainability.
- The themes explored in this chapter are considered relevant to the design of sustainability-based electrical energy systems. Therefore, directing transformations towards sustainability has been incorporated as a main criteria category for the sustainability assessment framework specified to electrical energy systems.
- It must be emphasized that current landscapes of conflict and political opposition to transitioning and transforming towards sustainability can greatly undermine relevant efforts towards long-lasting social, ecological, and economic well-being in different jurisdictions. Therefore, advancing works on transformation towards sustainability is key to clarify the positive pressures and opportunities to attain more desirable futures.

Chapter 5 (Research design and methods) focuses on the research methods, including case study selection considerations, and case study methods, adopted for this thesis work. The chapter presents Ontario and Costa Rica as the two case studies selected and delves into the processes and tools for data collection. Finally, Chapter 5 describes the specification process of the sustainability-based assessment framework to the two selected case studies.

CHAPTER 5. Research design and methods

Broadly, research relies on scientific methods for gathering relevant data in a systematized manner, so they can be applied in the study of phenomena and, by so doing, contribute to knowledge (Cortés & Iglesias, 2004; Kerlinger & Lee, 2002; Hernández et al., 2010; Tamayo y Tamayo, 2004). Nonetheless, while recognizing that rigorous research methodology is indispensable, inquiry design should allow for a degree of flexibility. In line with Ander-Egg's (2011) perspective, this work is approached with the belief that methods are by no means restrictive but essentially instrumental and organizational.

The first section of this chapter discusses the research methodology used for this thesis work. In general terms, the research is presented as qualitative, transdisciplinary, and exploratory. The second section focuses on the three case study methods adopted to conduct the research. The three case study methods used for this research are literature review, document research, and semi-structured interviews. The third section describes the specification process of the proposed sustainability-based assessment framework to the two selected case studies. Finally, the fourth section identifies four main limitations in conducting this thesis work.

5.1. Research methodology

Since philosophy provides "the general principles of theoretical thinking" (Moon & Blackman, 2010, p. 1168), it is sensible to delimit philosophical grounds when conducting qualitative inquiry (Creswell, 2009). The philosophical assumptions guiding this research are of an ontological nature. Ontological positions are well illustrated by considering positivism (there is one definitive truth) and constructivism (truth is individually constructed) as opposite ends of a spectrum of possibilities. This work embraces a philosophical posture that stands in between: scientific realism or critical realism. That is, the problem is approached by scientific, 'truth-seeking' tools that aim to explore human-constructed "layers to the reality" (Moses & Knutsen, 2010, p. 12). In this study, this scientific realism consists in recognizing and applying broad criteria and specifying them for particular contexts/applications.

Normally, research methods are classified as quantitative, qualitative, or mixed. The research reported here addresses electrical energy systems as socially-constructed and changeable phenomena. In this context, it aims to build and apply a sustainability-based assessment framework for overall electrical energy systems. At the same time, this work seeks to specify such framework to the context of two different jurisdictions and to provide an initial evaluation. Therefore, a qualitative study is conducted, since it is best suited to address the characteristics mentioned (Creswell, 2009; Kothari, 2004). Qualitative research in social sciences is to a good extent shaped by the values, experiences, and training of the researcher (Creswell, 2013). And it is thereby accepted that social scientists convey a profound interest on solving problems affecting the societal context that they are part of (Ander-Egg, 2011). In this light, my transdisciplinary profile will inform the encompassing aspects for the design of this study. Transdisciplinary research is necessary when problems of the world are highly complex to an extent that disciplinary boundaries must be crossed, interrelations respected and insights integrated (Buanes & Jentoft, 2009; Pohl, 2010; Wickson et al., 2006). As the pursuit of sustainability faces high complexity and extends beyond disciplinary borders, a transdisciplinary approach is well justified (Hadorn et al., 2006; Fam et al., 2017).

The research has been exploratory in a broad sense. Such a denomination is appropriate since this research engages with complex scenarios, of which understanding is yet incomplete, and proposes a largely novel evaluation tool for engaging with the problem issued (Hernández et al., 2010). Moreover, it extensively looks for key elements and their interactions that shape the problem (Berg & Lune, 2012). However, it is recognized that a descriptive element is necessary for context specification purposes. In addition, the research has a longitudinal approach, given that data have been collected from different points in time. Moreover, it sought evidence of how knowledge and decision-making approaches have evolved, and what openings and barriers have been involved. This is important in order to understand the historical context, the development of the problematique, and possibly causes, effects and response options (Hernández et al., 2010).

The design and planning of electrical energy systems depend in part on their particular contexts – e.g., social, geographical, political, technical, economic, etc. Hence, as presented below, a case study approach is considered appropriate for this research. Case studies aim to "locate the factors that account for the behaviour-patterns of the given unit as an integrated totality" (Kothari, 2004, p. 113). In this sense, adopting a case study approach for this research work was appropriate as a means of depicting problems that are unique but also present in different contexts (Creswell, 2013). Usually, case study approaches are divided in single case study and multiple case study. The first is used in research that aims to gain a deep understanding and provide a rich exploration of one single phenomenon, or group of phenomena (Yin, 2003). The latter is used to understand similarities and differences between multiple cases, and to explore phenomena present in each case and across the cases (Gustafsson, 2017). Since it studies the electrical energy systems of two different jurisdictions as main basis for inquiry, this work is considered a multiple case study.

5.1.1. Case study selection

Ontario and Costa Rica's electrical energy systems were selected as the two case studies for this thesis work. Since the possibility of replication is important for conducting a multiple case study (Yin, 2009), respecting the applied research methods (e.g., criteria for case study selection, case study methods, and data collection) was emphasized in each of the cases. The selection of the cases was influenced by the relevance of both electrical energy systems in global energy-related discussions, and by the already existing contributions to knowledge relevant to this thesis. For instance, one key consideration was that, while some progress has been made in recent decades, both jurisdictions have faced pressures to make more meaningful contributions to sustainability to avoid the severe risks posed by ongoing and emerging crises (e.g., climate change, extreme poverty, COVID-19 pandemic) (see Chapters 6 and 7). The case study selection was also made in consideration of four broad selection criteria (see below). Although this work does not primarily aim to be conducted as a comparative study, delimiting criteria were necessary for the case-study selection process. The four selection criteria developed to guide the case study selection are:

- concern about unsustainability risks – represented by documented commitments and/or actions;
- evident efforts to transform – transition plans or notable interest in alternative power systems design – towards greater contributions to sustainability;
- availability of data – e.g., academic articles, official government documents, reports, press coverage, etc.;
- scale – for representativity, the proposed study favours examples with different system characteristics (e.g., different national contexts, planning backgrounds, system sizes, levels of wealth and capacity).

The selection criteria were by no means rigid – some aspects appear stronger than others in each of the cases and between them. Nevertheless, bounding elements are necessary in order to test the replicability of the framework as well as to coherently draw overarching conclusions. Due to the uniqueness of each context, however, it is hard, and probably ineffective, to attempt direct comparisons between the cases. A focus on lessons that can be learned in detail from each system is preferred instead. The degree of comparability and its value can be determined in the concluding stages of the research by paying attention to overlaps between the two cases and identifying broad lessons.

Some additional considerations for the case study selection were related to the contextualities and background of the researcher. For instance, since I have resided in Ontario for most part of the thesis work, the electrical energy system of Ontario was a convenient venue of application. Another example is, since Spanish is my native language, and I have conducted research work for a master's degree in Spanish, studying Costa Rica was a good opportunity to do an examination of two electrical energy systems that are not only geographically but also culturally different. Overall, the two cases were considered as appropriate for conducting and applying the theoretical foundations of this research in a desired time.

5.1.2. Overview of the cases

Ontario as a case study is compatible with the considerations mentioned above. The continuing evolution and the pressures for desirable changes in this jurisdiction have been well documented. Also, while recent provincial decisions seem to be insufficient to break unsustainable trends, some relevant efforts have been made in the recent history, and there is potential for incremental transformative effects. The availability of data for this case was sufficient to shed light on the most relevant issues discussed in the electricity sector, as well as to inform an historical section that examines the evolution of the electrical energy system structure and the sustainability-related challenges. Costa Rica is also suitable as a case study for this research. The country has gained global attention for its efforts towards decarbonizing the electrical energy system.

However, there are also continuing concerns about the environmental and social effects of the electrical energy system operations. These aspects have been well documented in different data sources. The two jurisdictions are different in scale, geographical characteristics, and system structure. They therefore provide an opportunity to test the universality of the framework and to focus on the lessons learned in each case.

The electrical energy systems of both jurisdictions have been identified as relevant case studies for the purposes of this thesis. In the case of Ontario, the electrical energy system has experienced relevant transitions in the past three decades that are relevant for sustainability locally and globally. As a result, relevant work has been done regarding, for example, the incorporation of a new electricity market model (e.g., Carlson et al., 2013; Rivard & Yatchew, 2016), the closure of coal-fired power plants (e.g., Harris et al., 2015; Raymond, 2020; Winfield, 2005), and the advancement in the incorporation and deployment of demand response and resource conservation options (e.g., Lazowski et al., 2018; Love, 2017; Rowlands, 2008). More recently, the provincial electrical energy system has raised attention since government decisions of removing ambitious climate policy and official requirements for long-term electrical energy system planning that were crucial for pursuing sustainability objectives (Brisbois, 2020; Environmental Defence, 2020; Winfield, 2020b). In this sense, Ontario's electrical energy system has been studied extensively and remains relevant in sustainability-oriented efforts.

Although different from Ontario, the electrical energy system of Costa Rica has also experienced relevant transitions in the past three decades with implications for overall sustainability. In the Costa Rica case, some authors have pointed out that attaining an electrical energy system that is powered almost entirely by renewable energies has deflected attention from other key social and ecological issues stemming the operations of the electrical energy system (e.g., Arias, 2017; Comisión Defensora de los Ríos Convento y Sonador, 2016; Gutiérrez & Villalobos, 2020). These works highlight that past a pattern of large hydroelectricity development without consultation with communities and Indigenous groups needs improvement, while promoting salient options for governing the electrical energy system more democratically and participatorily. Equally important, another focal point has been the changing patterns in natural systems potentially affecting the reliability of the electrical energy system (e.g., Echevarría & Monge, 2017; MINAE et al., 2019), as well as the path dependency on large hydroelectricity projects and the need to diversify the electricity mix with alternative renewable energy options (e.g., Avendaño-Leadem & García-Sánchez, 2019; Van Riet, 2020). While needing more contributions to the scientific literature, Costa Rica as case study is relevant since the country has continued with decarbonization commitments and aims to be a global example to pursue more sustainable electrical energy systems (Government of Costa Rica, 2018).

5.2. Case study methods

Three case research methods were used for the purposes of this study. This section presents the methods (literature review, document research and semi-structured interviews) and describes the main considerations for their implementation.

5.2.1. Literature review

As mentioned, a comprehensive literature review is one of the adopted methods to gather theoretical and contextual data. A literature review can be considered a research project by itself, or it can also be embedded to inform a larger study, working as a research method (Onwegbuzie & Frels, 2016). In this case, the literature review is used as a method to build the intellectual foundations and the backgrounds for the understanding of the problem and means to address it. This work reflects Machi and McEvoy (2009) and Onwegbuzie and Frels's (2016) basic considerations for writing a literature review. These include selecting a topic based on the researcher's worldviews, conduct a literature search in different sources (e.g., books, journals, theses and dissertations, magazines, newspapers, web sites), storing and classifying relevant information, analysis and synthesis, and writing the review.

The fields of sustainability in complexity, electrical energy systems and sustainability, and directing transformations towards sustainability were selected as main bodies of knowledge. Hence, as suggested by Machi and McEvoy (2009), the related data were collected through a series of queries using search directories and entering the main key terms. The main search directories used include but are not limited to Scopus, University of Waterloo Library, and Google Scholar. Some examples of the keyword searches include 'sustainability + complexity', 'transformations + sustainability', 'energy + sustainability', among others. The queries were further defined as required by each segment of the thesis. For instance, broader searches were used for the theoretical foundations and more specific searches were used to explore the particular stories of Ontario and Costa Rica.

The synthesis of main concepts and insights drawn from the literature review provided a starting point for building the generic sustainability-based assessment framework specified to electrical energy systems. For instance, the review of literatures on sustainability in complexity (Chapter 2) aided identification of the main challenges for sustainability as a field of study and for the practice. Also, it provided a lens to consider more appropriately the complex interactions of our world, and their effects on sustainability-related issues and responses.

Review of the literature on electrical energy systems and sustainability (Chapter 3) provided the main considerations and broadly accepted sustainability-related goals for electrical energy systems. These insights, coupled with Chapter 2, were used to build the initial framework. Directing transformations towards sustainability (Chapter 4) explored recent approaches to transitions and transformations and shed light on relevant considerations for advancing overall contributions to sustainability. This body of knowledge was foundational for the incorporation of the novel sixth main criteria category in the generic framework. The literature review also helped to provide the background, historical context, and recent system characteristics for the two case studies. The generic electrical energy systems framework's design provided a base for the further specification to the particular characteristics of each of the case studies, and to incorporate the insights gathered in the field work.

5.2.2. Document research

Finding and analysing informative documents that reflect the processes and issues regarding power systems' design towards sustainability and the official responses to address related issues is crucial for this research. An exploration at a surface level was undertaken in initial stages of the thesis work to identify the attainability of relevant information about the potential cases. For this dissertation, a deeper immersion into document research was undertaken – one that looks for historical and political contexts, conventional planning perceptions, efforts to change, and related issues. By doing so, the backgrounds and developing issues for each context have been better understood and presented coherently throughout the thesis chapters. This process was fundamental for the specification of the evaluation framework.

The document research method adopted is similar to the one used for the literature review (Machi & McEvoy, 2009; Onwebugzie & Frels, 2016). The document search in this work includes the review of official government and non-government organizations' publications, private sector reports, legislative pieces, press coverage, and academic articles. This has been effective to obtain information about official decision-making, planning, policy-making, political contexts, and other salient events (e.g., government announcements, energy plans released, approval of bills, press coverage of electrical energy system-related events).

5.2.3. Semi-structured interviews

Interviewing is a widely used research method, effective for qualitative research (Creswell, 2009). The contributions of the participants can complement the data gathered in the document research and provide an empirical dimension on the understanding of issues (Newcomer et al., 2004). For this research work, the interviews were not considered as the main source of information for the case studies; they were instead considered as a support for the document research and framework specification. Therefore, since the nature of this study does not require a large number of interviews – around 15 interview requests were sent for each jurisdiction, with eight interviews per case study being done.

Recruitment and sampling

The inclusion criteria for the selection of the participants centred on needs for the interviewees to have deep knowledge, familiarity, and involvement in the electricity sector of regions studied. Moreover, representativity of different participants in the sector was necessary to attain a range of perspectives of the cases studied (Diefenback, 2009). For these purposes, five sectors of experience were considered for representativity in the selection of the participants: government, industry, utility companies, academia, and representation of the social community (see Table 5.1). In this sense, one key challenge was that conducting this research during the COVID-19 pandemic influenced the potential for more equal representation in data collection. For instance, the inability to visit communities and Indigenous groups from both jurisdictions in person limited the possibilities to recruit more community representatives to participate in this study. Also, the contextual characteristics of each case had influence in the recruitment processes and representation of opinions from relevant participants in the electrical energy system. One example, as shown in Table 5.1, is that because of the market structure of both electrical energy systems, Costa Rica does not have as many industrial actors as Ontario, and there was no participation from the industry sector for Costa Rica. Instead, participants from academia and the social community with previous experience in the industry sector were included.

Table 5.1. Number of participants by sector and jurisdiction

Sector	**Participants from Ontario**	**Participants from Costa Rica**
Government	1	1
Industry	1	-
Utility companies	3	2
Academia	1	3
Social community	2	2

The search for participants was done through online sources, informed in part by the literature review and document research. For instance, some academic works, government publications, and non-government organization reports relevant to the research included the contact information of the authors. Also, other participants were identified by visiting websites of organizations that have done relevant work and reviewing the directory section. Another approach used was the snowball sampling method. That is, the identification of a potential participant through recommendation by another interviewee (Lewis-Beck et al., 2004). After each interview, the participant was asked to recommend any other potential participants.

An introductory script and an information letter containing overall aspects of the study were elaborated and sent to invite the potential participants. If the potential participants agreed to being interviewed, a follow up message was sent back to confirm the time and date of their preference. When the details were determined, a confirmation email was sent back, along with the required consent forms. Also, a draft questionnaire was elaborated, aiming to capture perspectives from key experts, authorities, and key participants in the electricity sector. Accordingly, the interview questions were structured so that they evoke and collect insights that can be interpreted and analyzed under the framework criteria. The interviewing protocol and process was reviewed and received ethics approval by the University of Waterloo Research Ethics Committee (ORE#41403).

Interviewing process

The interviewing process took place from December 2020 to April 2021. The interviews consisted of five open-ended questions and some additional follow-up questions, according to the extent to which the interviewees covered the themes sought for the data collection. While the interviews were planned as sessions of 20 to 30 minutes, they were also, as noted above, designed to spark longer conversations and to draw key insights. Therefore, most of the interviews oscillated from 30 to 60 minutes, with some of them expanding to 75 to 90 minutes. The interviews were done via videocall or phone call, except for one interviewee who opted to provide written answers. Before starting the interview, the interviewees provided consent for the video and phone interviews to be recorded and gave permission to be quoted anonymously in the thesis document. The questions were asked one at a time and, based on Fylan's (2005) approach, the interviewees had the option to freely elaborate on the topics they considered relevant. On some occasions, by answering openly one of the questions, the interviewees covered themes that were expected to be attained from the following questions. In such cases, the answers were noted, and the related questions did not have to be asked again, unless there were some particular aspects in the following questions that still needed consideration.

For the purposes of this research, the questionnaire encompassed three overarching elements:

- Context – e.g., historical data, past and current issues, political structure, environment and resource features.
- Sustainability requirements (including climate safety and social-ecological integrity, affordability and equity, cost-effectiveness and efficiency, democratic and participatory governance, and precaution, modularity and resiliency) – e.g., what efforts have been made? What sustainability requirements have been strongly emphasized? Which ones are being ignored? What are the openings to attain the requirements? What are the barriers?
- Insights on transformation – e.g., What needs to be transformed? What are the main actors that can help to induce transformation? What transformative efforts have been implemented? What are the main barriers for positive change?

While the interview questions were elaborated to cover the overall considerations addressed in the generic sustainability-based assessment framework specified to electrical energy systems, the interviews were slightly customized to each of the participants' expertise (Fylan, 2005). This method is appropriate for engaging with complex issues of the world, as well as the perceptions and responses to them (van Teijlingen, 2014). Nonetheless, the questions aimed to be comprehensive of the considerations in the framework (see Appendix C and D). Table 5.2 shows an example of one question that was customized according to the different expertise of two interviewees.

Table 5.2. Question for interviewees in Ontario case study customized in consideration of expertise

<table>
<tr><td>
Question for participant in Ontario case study – NGO leader with experience in policy making and planning.
Evidence shows that Ontario's electricity-related activities face an absence of effective planning in project development, a lack of transparency, failure to respect legislated milestones, and questionable consultation processes with stakeholders, First Nations and the social community in general. This has been pointed out to be in part because a lack of commitment from national and provincial authorities to clarify what are the policy implications of attaining climate change and other social and environmental goals. Does your experience suggest the same?

How well aligned do you think are national, provincial, and municipal policy- and decision making for electrical energy system planning?
What are the key actors in the electricity sector that can influence positive change towards these goals?
Besides climate change, what do you consider to be the most relevant emerging issues for the electricity sector of the future?

</td></tr>
<tr><td>
Question for participant in Ontario case study – First Nations representative with experience in facilitating relationships with the energy sector.
My evidence suggests that the provincial government faces challenges of poor governance in energy-related activities. More specifically, it suggests that there is ineffective planning in project development, lack of transparency in implementation, failure to respect legislated milestones, and questionable consultation processes with stakeholders, First Nations and the social community in general. Does your experience in representing First Nations' and facilitating more positive relationships with the energy industry suggest the same?

According to your experience what are the main impacts that First Nations and communities will face in the future from energy undertakings?
Are there other important barriers to the reconciliation of conflicts between the interests of First Nations and the energy industry missing in the evidence I mentioned? And opportunities?
According to your experience, what is the perspective from the energy industry on how this should be solved and what needs to change to lessen tensions and for more appropriate conflict resolution?
Who do you think will be the main actors that might be involved, in favour and in opposition, for inducing positive changes?

</td></tr>
</table>

From the 16 interviewees, five preferred to be included anonymously in the study. Since this is a considerable share, considering the small sample, this study chose to provide all of the contributions anonymously. The contributions from the interviewees were incorporated to the analysis in a manner that emphasizes the comments more than the particular sources. However, the incorporation of the contributions to the analysis aims to provide a context according to the area of expertise, and the insights provided by each of the interviewees. Also, some contributions were presented to show general agreement, or disagreement, among the interviewees regarding the subjects discussed on the interviews.

Coding transcriptions

This research adopted a manual form of coding based on an inductive approach. That is, the analysis centred on the experiences shared by the participants rather than on existing categories in previous research (deductive approach) (Azungah, 2018). According to Basit (2003), both manual and electronic coding can be useful for qualitative research, depending on the size of the research sample, time availability and funds, and preference. Also, since this thesis addresses social phenomena, numerical interpretations are not necessary for coding. In this regard, Basit (2003, p. 151) posits that "it is the quality and richness of the response to a social situation which we should focus on".

Saldaña (2016) adds that coding methods for qualitative research are useful for presenting a consolidated meaning of the synthesis of the collected data. This can be organized in the form of major categories or themes that facilitate the management and presentation of the data (Williams & Moser, 2019). For the purposes of organizing the contributions of the participants retrieved inductively, the data were transcribed and classified using the main criteria categories and criteria in the specified framework to electrical energy systems. That is, while the categories were already established, the analysis centered on the participants' experiences was not strictly tied to rigid categorizations or expected outcomes. For instance, answers related to appropriate consultation processes were categorized in a section named "democratic and participatory governance", and answers related to challenges of implementing options to reduce costs in electricity-related operations were categorized as "cost-effectiveness, resource efficiency and conservation" (Table 5.3). It is noteworthy to mention that the transcriptions were not captured in a word-by-word manner and focused instead on capturing the more relevant insights for the criteria categories. In total, the average size of the databases in wordcounts was 932 words per interview (863 for Ontario and 1000 for Costa Rica), with a median of 882 words per interview (882 for Ontario and 891.5 for Costa Rica).

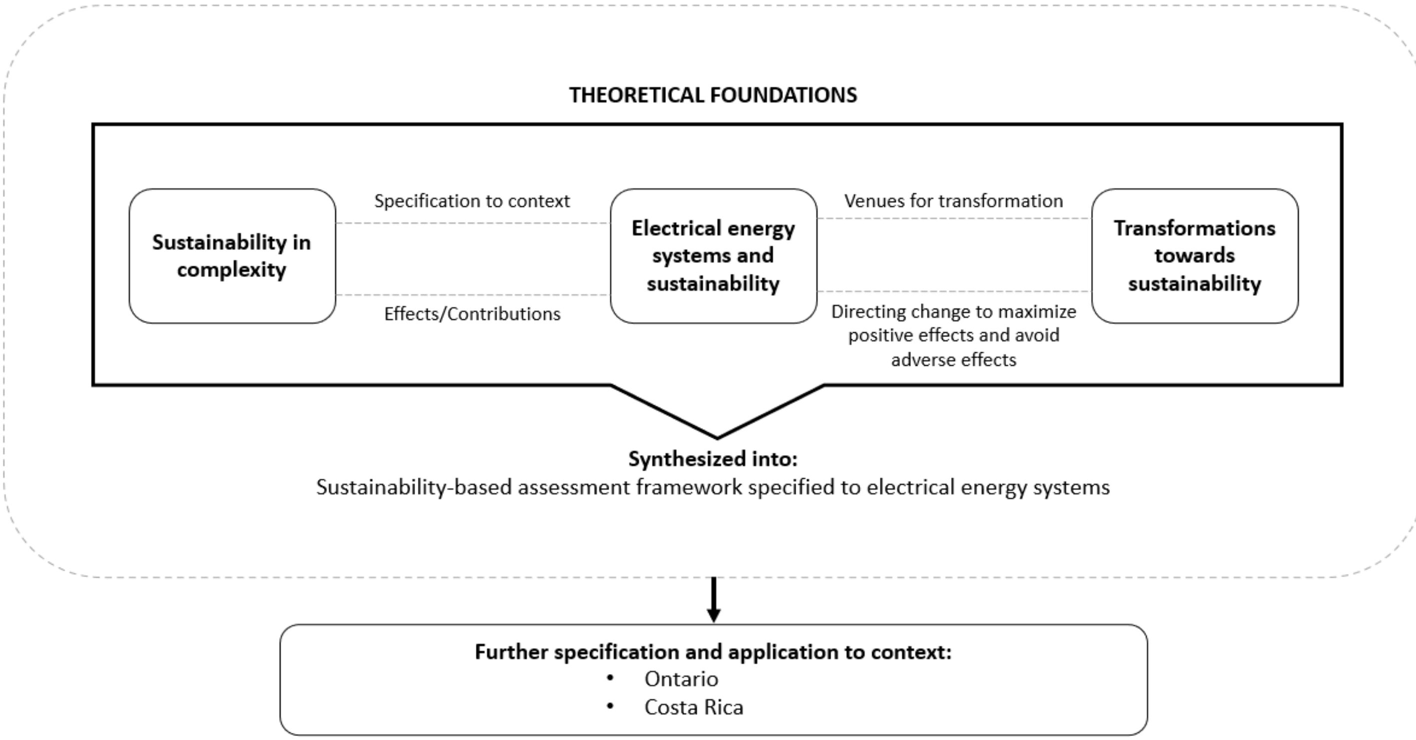
Table 5.3. Examples of the coding process

Main criteria category	**Criteria**	**Data**
Democratic and participatory governance	Ensuring democratic and participatory deliberation that promotes consultation with experts, stakeholders, First Nations, vulnerable groups and community leaders, and attains public acceptance through explicit and transparent processes	"I think where we need to improve is that when a company is next to a First Nations reserve, and has a major project, they simply have to consult, and they have to be required to do it from day one, and it has to be a real and meaningful consultation. And if they have impacts which cannot be mitigated, the government needs to have the law that says you have to compensate them"
Cost-effectiveness, resource efficiency and conservation	Building policy and technology pathways that enable the development and implementation of efficiency tools such as energy storage, smart grid technologies and demand response options	"The current structure is just financially unsustainable, and the province has turned its back on the options that could in fact deliver electricity at lower cost…"

5.3. Overview of theoretical foundations

Figure 5.1 shows the how the theoretical foundations were used in this thesis to build the sustainability-based assessment framework and develop the field research. First, the sustainability in complexity review (Chapter 2) delved into the conceptual and practical challenges of sustainability, and the implications of pursuing sustainability in a world of complexity. In relation to the other two bodies of literature (on electrical energy systems and sustainability transformations), Chapter 2 positions sustainability as the base for a practical assessment tool that can be specified and applied to diverse social and ecological contexts.

Figure 5.1. Theoretical foundations



Second, the electrical energy systems and sustainability review (Chapter 3) explored main sustainability-related issues, as well as relevant opportunities to make positive contributions towards sustainability, associated to electrical energy systems. This chapter positions electrical energy systems as relevant venues in need for transformation to decrease climate change-associated risks and contribute to attain global sustainability goals.

Finally, the transformations towards sustainability review (Chapter 4) delved into recent literature on diverse approaches to transformations towards sustainability. Chapter 4 also analyzed transitions and transformations as key components of complex systems' dynamics and human-induced change. This chapter complements those on the other fields of knowledge by providing key considerations in efforts to direct change towards sustainability in particular venues – in this case, electrical energy systems.

5.4. Specification of the framework

This thesis provides the elaboration of a sustainability-based assessment framework specified for electrical energy systems, as well as an initial evaluation. This framework is designed as a tool for evaluating electricity-related policy- and decision-making, long-term energy plans, and project proposals in any jurisdiction. Gibson et al.'s (2005) requirements for progress towards sustainability are used as the generic set of sustainability objectives that should be addressed in any major undertaking that aims to maximize contributions to sustainability. As elaborated in Chapter 2, the eight requirements are: 1) Socio-ecological system integrity; 2) livelihood sufficiency and opportunity; 3) intragenerational equity; 4) intergenerational equity; 5) resource maintenance and efficiency; 6) social-ecological civility and democratic governance; 7) precaution and adaptation; and 8) immediate and long-term integration. Additionally, Lovins (1977) soft paths approach, elaborated by more recent work, and coupled with overall accepted objectives of electrical energy systems discussed in the theory (Chapter 3), were considered as cornerstones for identifying the characteristics of electrical energy systems that contribute to sustainability. The insights from Chapter 2 and 3 provided the foundations to for the elaboration of five sustainability-based assessment criteria categories: 1) Climate safety and social-ecological integrity; 2) Intra- and inter-generational equity, accessibility, reliability, and affordability; 3) Cost-effectiveness, resource efficiency and conservation; 4) Democratic and participatory governance; and 5) Precaution, modularity and resiliency. The transformations literature is used to draw a rough map for concepts and approaches that represent the key considerations for designing and assessing transformational proposals and initiatives, as well as elaborating a sixth criteria category included in the framework (Chapter 4). The sixth criteria category – transformation, integration of multiple positive effects, and minimization of adverse effects – was incorporated to the generic criteria set for evaluation of all electrical energy systems.

After the initial sustainability-based assessment framework was specified for application broadly to overall electrical energy systems, this framework was then applied to evaluate electrical energy systems and associate decision making in recent years in both case studies. The findings from this exercise were used to identify elements to include in a framework more particularly specified for application in each case study. The relevant findings from the case study chapters include the insights from evaluation and the more particularly specified framework for future application in the two jurisdictions to guide and monitor further transformational changes.

The specification process was undertaken for each case to recognize the contextual realities of that case. The process followed Gibson's steps of criteria specification (see below) but was iterative and adjusted as needed to provide criteria categories with the same level of importance. This approach was adopted because, as highlighted by Gibson (2017), and as shown in Chapter 2, it has proved to be effective for application in many different undertakings and contexts throughout the years. For this task, however, the information gathered by the different methods has to be a primary resource to inform specification and application. Each context-specific framework presents a set of sustainability-based criteria as a supporting instrument to pursue multiple mutually reinforcing and long-lasting benefits. In addition, the approach applies a set of rules for trade-offs avoidance, presented in Chapter 3. An integrative assessment of this type can contribute to identifying both barriers and opportunities for taking steps to transformations towards sustainability. In general terms, the entire process was scanned through a lens that considers transformative system change implications. Gibson's (2017) steps of criteria specification are the following:

1. Take initial information about the purpose and alternatives for the potential undertaking in question.
2. Identify the key case/context considerations (issues, aspirations, vulnerabilities, openings, conflicts, potential for resolving or accommodating conflict, etc.) covering all purposes, alternatives and interests and anticipating possible trade-off concerns.
3. Ensure the considerations cover all of the generic sustainability assessment criteria.
4. Organize the considerations in a manageable number of understandable categories (with associated questions and indicators) that ensure attention to often neglected matters and recognize interactive effects, to form a criteria framework to guide all key judgements, including those about effects, comparison of options, and recommendations including enhancements and mitigation.
5. Review and reconsider the purposes and alternatives.
6. Adjust the criteria framework as new understandings, considerations and priorities emerge through the process.
7. Develop initial specification of trade-off rules.
8. Apply criteria in critical review of revised purpose definition and comparative evaluation of alternatives.
9. Identify mitigation needs and enhancement openings.
10. Identify trade-offs, and seek avoidance/mitigation.
11. Select preferred alternative.
12. Determine conditions of approval, rules for implementation.
13. Monitor, review and adjust implementation in light of the criteria, conditions of approval and actual effects.
14. Continue sustainability-based evaluations and responses until the undertaking disappears in the mists of time.

5.5. Positionality

I was born in Mazatlán, a city in the state of Sinaloa, located in the northwest region of Mexico, where I lived for 30 years. Sinaloa is nationally known for its agriculture, fishing, and tourism, but also for the entrenched social issues and violence related to organized crime and drug trafficking. My ethnicity is mostly a mix of Mexican Indigenous and Spanish heritage. However, I cannot and do not identify as Indigenous since I was not raised as such and did not have the cultural exposure, experiences, and hardships that Indigenous people in Mexico have. I come from a middle-class family and was raised, along with one sister, by a single mother. Throughout several years, my mother worked to build a successful career as a now retired full-time professor and researcher in the field of psychology. As such, she was able to provide financial support to complete my studies and to live a decent and comfortable life in Mazatlán. I moved to Canada in

2016 to pursue a PhD education in a sustainability program that was not offered in my country, and to pursue opportunities for a better quality of life.

As a researcher, I am trained as a social scientist, with more than 10 years of experience in Mexico and Canada, and am bilingual in Spanish and English. I started my training in Mexico, completing a four-year program to attain the degree of Bachelor of Science in Tourism Management, and a two-year Master's degree in Business Administration with a focus on Organizational Strategy and Communication. For my Master's degree, I researched the administrative implications of environmental considerations in the hotel industry by analyzing the experience of head managers in attaining and retaining environmental certifications in three different hotels. In Canada, I continued my training as a social scientist by pursuing a PhD degree in the program of Social and Ecological Sustainability, in the University of Waterloo, in which I have been a PhD candidate for six years.

My positionality has different implications for the research process. My position as an outsider in relation to the participants in both case studies entails that my capacity to understand cultural nuances in the selected jurisdictions is to some extent limited. For Ontario, while I am bilingual, English is not my native language and some nuances from specific points of view expressed by the participants may not be fully captured. Also, my socioeconomic experiences from being born and raised in a developing country will probably differ from the experiences of the participants living in a developed country. My experience growing up in a Spanish-speaking Latin American country may find some similarities with the Costa Rican context. However, there are still considerable differences in terms of the social, environmental, economic, and political contexts that I have not experienced.

In this sense, I cannot describe from my own experience the cultural implications that emerge from the relationship between the jurisdictional electrical energy systems and their socioecological environment. Furthermore, I have not experienced the struggles that Indigenous communities face day to day, especially when electrical energy system operations avoid consulting and including Indigenous rights and threaten natural systems that provide opportunity for livelihood.

At the same time, my position as an outsider can help to provide more objective and general findings relevant to the study of transforming electrical energy systems towards sustainability.

5.6. Limitations

There are four main limitations that need to be clarified for this thesis work:

First, this thesis is focused on the elaboration and specification, as well as on the viability of the proposed sustainability-based assessment frameworks, to electrical energy systems. This means that the purposes of this work are more oriented to develop the frameworks. While specified frameworks are used for an initial examination of the electrical energy systems in each case, the primary objective is to use the initial findings to identify what to include in a framework more particularly specified for application in both cases. In this regard, time considerations did not allow for a more extensive project (e.g., applying the final framework for a new evaluation in electrical energy system efforts for the two cases). Therefore, future works will need to focus on the application of the final framework to electrical energy system efforts in both jurisdictions (e.g., official electrical energy system plans and project proposals) as well as to other contexts.

Second, the incorporation of directing transformations towards sustainability as a main criteria category is a novel addition. This means that, while the initial framework for broad application to electrical energy systems was effective for the purposes of this study, this particular category may need particular attention in research focused on transformative change for sustainability purposes, and on further application of the overall and specified frameworks to other contexts.

Third, there are some language considerations for the Costa Rica case study. For instance, the incorporation of the data collected needs translation from Spanish to English. While Spanish is my native language, and I am fluent and have qualifications for doing scientific work in the English language, some additional challenges need to be considered. Particularly, some terminology in English cannot be translated literally into Spanish and vice versa. In this sense, both word-for-word translation, when possible, as well as adaptation when terms do not exist or do not have the same significance in English, were used. However, there may be risks of overlooking better options for appropriate terminology.

Fourth, as stated in section 5.5, my condition as a foreigner in both of the jurisdictions selected may limit my capacity to fully understand or interpret cultural nuances relevant to the study findings.

5.7. Summary of key considerations

This chapter has provided the main design characteristics and methodological considerations for this thesis work. The first section identifies this research as mainly qualitative, transdisciplinary, and exploratory. These approaches have been recognized as appropriate to examine problems that are socially-constructed and changeable, and that reflect the complex nature of our world.

Also, this chapter introduced a case study approach as a selected research approach for conducting this research. The following sections described the processes for case study selection and the case study methods. Ontario and Costa Rica were presented as the selected cases, and literature review, document research, and semi-structured interviews were presented as the case study methods. Furthermore, the processes for the application of such methods were described. These methods were adopted to find and understand the specificities of the cases relevant to the study, as well as to delve into the perceptions and responses to contextual issues.

The processes and steps for the specification of the proposed framework were also discussed in this chapter. This was an iterative process that followed basic rules for specification and that it was initially informed by the theoretical foundations' chapters. The further specification to context for each case was based on the findings from the literature review, document research, and interviews.

Finally, the limitations for conducting this study are clarified. This section recognizes that there are five limiting aspects for this study that need to be addressed in future research works. These are related to 1) the need to focus more specifically on evaluation, 2) particular attention to directing transformations towards sustainability as a main criterion category, 3) language considerations, and 4) my status as a foreigner in both cases.

CHAPTER 6. Case study – Ontario

This chapter examines Ontario as the first case study for this thesis document. In line with the research question, it aims to provide a sustainability-based assessment framework specified to this jurisdiction to evaluate how well the provincial electrical energy system is designed to support pathways towards sustainability in a complex world. For this purpose, the chapter intends to: 1) apply the sustainability-based assessment criteria for electrical energy systems elaborated in Chapters 3 and 4 for the development and application of criteria that is further specified to the Ontario context; 2) elaborate an initial evaluation of Ontario's electrical energy system and associated decision making in recent years by applying the overall framework specified to electrical energy systems; 3) use the findings from the initial evaluation to identify more particular elements specified for application in Ontario; and 4) develop a framework specified for the Ontario electrical energy system and its context for future applications to electrical energy system efforts.

The first part of the chapter presents the background and context for Ontario's electrical energy system. This section discusses Ontario's general characteristics as well as the electrical energy system characteristics, and the current system structure. Also, the section provides a recent history of electrical energy system planning in Ontario, including relevant events that inform the current key system and system change characteristics. The second part of the chapter focuses on the specification of the sustainability-based assessment framework for electrical energy systems for application to Ontario, recognizing its particular context. The starting point is the application of the six generic criteria categories for sustainability-based assessment of electrical energy systems set out in Chapter 4. These criteria are applied for an initial evaluation that provided key findings about what should be improved in Ontario. The second part also includes a section on trade-off considerations that discusses possible interacting effects among the criteria. In the third part of the chapter, the proposed sustainability-based assessment framework specified for application to Ontario's electrical energy system is presented. The framework was developed in light of the findings drawn from the initial evaluation of the provincial context. The final section includes conclusions relevant for the theory, the framework, and implications for Ontario.

6.1. Background and context: Ontario's electrical energy system

In its recent history, Ontario's electricity sector has faced persistent and evolving sustainability challenges. Notably, Mang-Benza and Hunsberger (2020, p. 520) point out that Ontario has "experienced drastic changes in energy policy over less than two decades". As further discussed below, some of these changes include the shift from Ontario Hydro – a unified provincial utility – to successive experiments in wholesale and retail market pricing and dividing the utility into different units, and to adopting a hybrid model of competitive market and provincial planning. All of this was carried out while also having to address problems related to aging infrastructure and pressures for renewables (SolarShare, 2015). Some authors have emphasized in this regard the influence of poor decision-making by provincial authorities in exacerbating social and ecological risks (Rosenbloom & Meadowcroft, 2014). Hence, while unexpected events have been problematic – e.g., particular aspects of market activity, technology development, decreasing demand, and weather conditions – ineffective long-term planning appears consistently as a main cause of problems. Consequently, important and novel steps taken towards a low-carbon electrical energy system have been overshadowed by the lasting effects of short-sighted decisions (Winfield, 2016a). In short, as discussed below, efforts to mitigate these effects and to respond to emerging pressures have shaped the present of Ontario's electrical energy system.

6.1.1. Ontario's general characteristics

Ontario is one of the thirteen provinces and territories that compose the Canadian territory (see Fig 6.1). The province is in the Great Lakes basin of North America and is the second largest province in the country, covering more than 1 million square kilometers (Government of Ontario, 2019). Particularly, there are more than 250,000 lakes in Ontario, which account for one fifth of the world's fresh water (Government of Ontario, 2019). According to the Ministry of Finance (2021), the province has a population of approximately 14,733,119 representing about 38.8% of Canada's population. In 2018, it recorded a gross domestic product of roughly CAD$857 billion, accounting for almost 39% of the national gross domestic product (Ontario Ministry Finance, 2020). Ontario's main economic activities "range from cultivating crops, to mining minerals, to manufacturing automobiles, to designing software and leading-edge technology" (Government of Ontario, 2019).

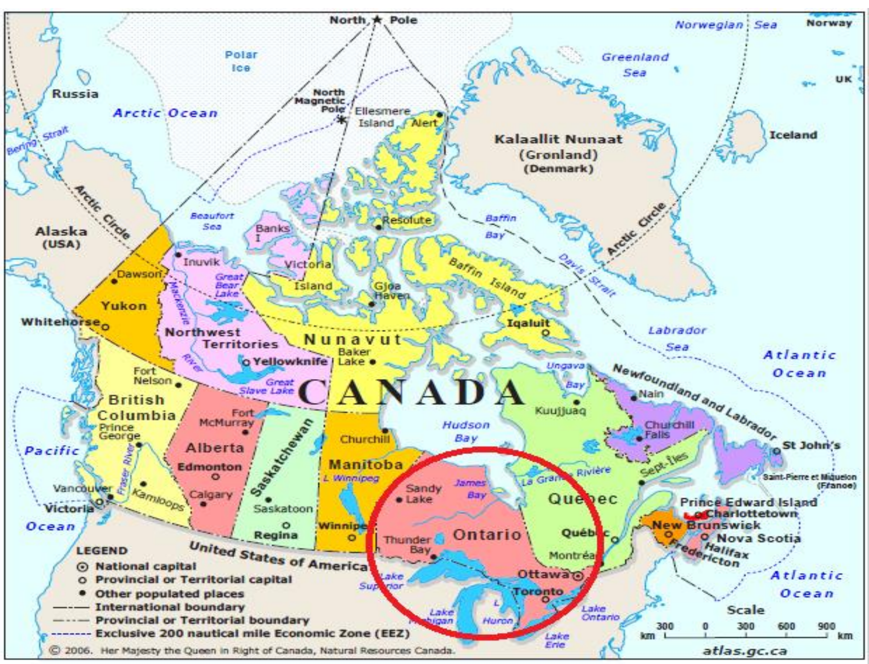
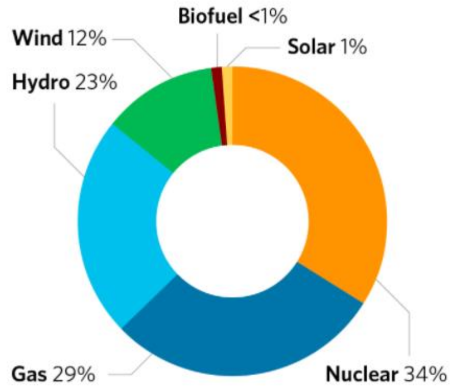


Figure 6.1. Ontario in the national map (NRCAN, 2006)

6.1.2. Characteristics of Ontario’s electrical energy system

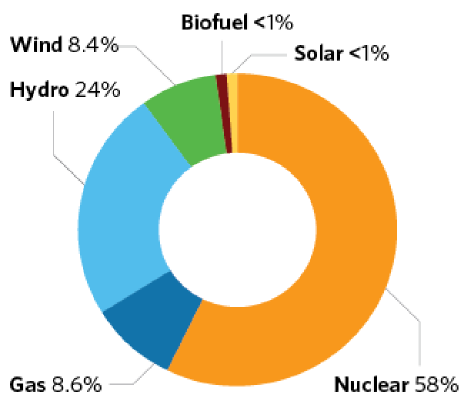
Canada’s Constitution allows for every province a high degree of autonomy for decision-making in their electrical energy systems. Each province, for example, has the responsibility to plan their own “development, conservation and management of sites and facilities in the province for the generation and production of electrical energy” (Government of Canada, 2021). Currently, Ontario has roughly 120 generating stations (Government of Ontario, 2019), with an installed transmission-connected generation capacity of roughly 38,645 megawatts distributed across the province (IESO, 2020a). Figure 6.2 depicts the distribution of the transmission lines across the province. The provincial electricity is generated from six different fuel sources – nuclear, natural gas, hydro, wind, biofuel and solar (IESO, 2020a). Nuclear power has the highest share in this mix with 34%, followed by gas with 29% and hydro with 23%. Figure 6.3 shows Ontario’s installed capacity mix by fuel type and Figure 6.4 shows the electricity generation output. Notably, Ontario is also leader in wind power in the country (Government of Ontario, 2019).

Figure 6.2. Transmission lines across the province of Ontario (EnPowered, 2021)



Nuclear	13,009 MW or 34%
Gas/Oil	11,317 MW or 29%
Hydro	9,060 MW or 23%
Wind	4,486 MW or 12%
Biofuel	295 MW or <1%
Solar	478 MW or 1%

Figure 6.3. Ontario's installed energy capacity by fuel type on Ontario's transmission system, as reported in the most recent Reliability Outlook, released September 2020 (IESO, 2020a)



Nuclear	83 TWh or 58%
Hydro	34.2 TWh or 24%
Gas/Oil	12.2 TWh or 8.6%
Wind	12 TWh or 8.4%
Solar	0.75 TWh or <1%
Biofuel	0.4 TWh or <1%

Figure 6.4. Ontario's total electricity generation output in 2021 (IESO, 2022b)

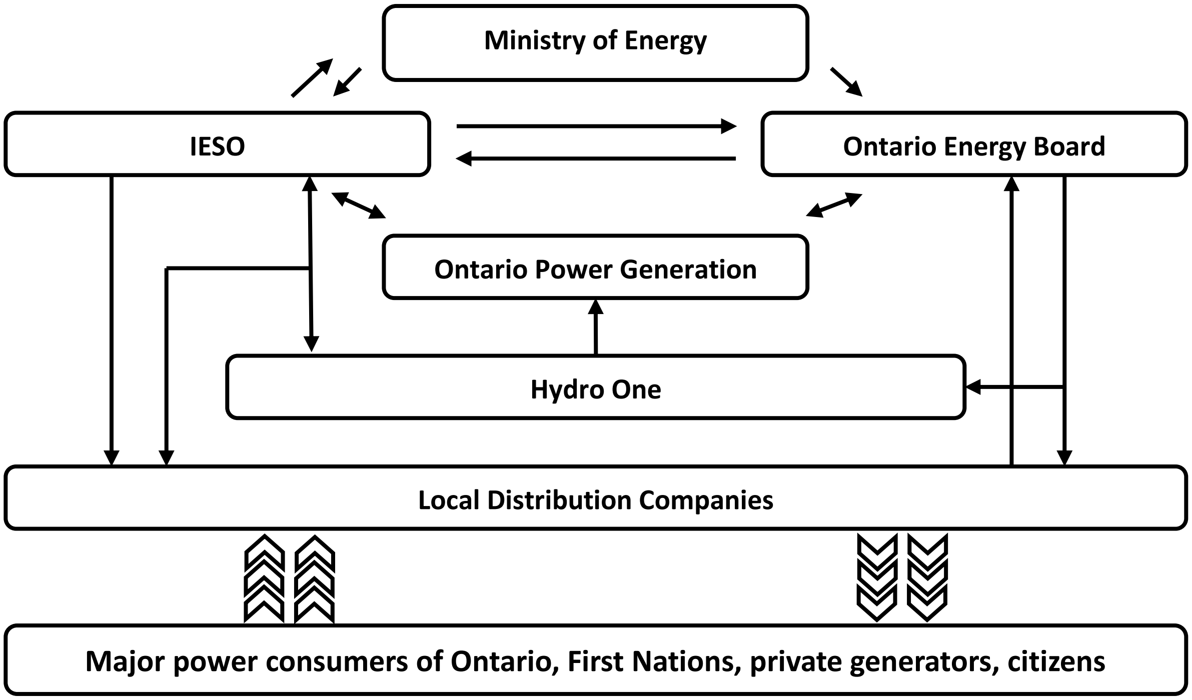
Finally, Ontario's electrical energy system is managed as a hybrid operational model. That is, the government defines overall system planning and the components of long-term projects and contracting, but the market is free for private actors to compete for contracts (Rivard & Yatchew, 2016; Winfield & Weiler, 2018). This process is carried out by a cluster of provincially created entities assigned to oversee different aspects of the sector's operations. Since the different regions in Ontario have their own contextual electricity needs, the provincial government coordinates electricity planning at local, regional, and provincial scales (IESO, 2021). For instance, Figure 6.5 illustrates Ontario's 21 planning regions (IESO, 2021). These have as their main goals the coordination of multi-regional planning, the engagement of citizens, and the integration of design options (IESO, 2021).

Figure 6.5. Ontario's 21 planning regions (IESO, 2021)

6.1.3. Current structure

Most of Ontario's electricity is generated by Ontario Power Generation, a Crown corporation owned by the province (OEB, 2022) and provincial scale transmission activities are mostly run by Hydro One, which is majorly government owned (Hydro One Limited, 2021). Meanwhile, local distribution companies manage the local electricity supply (OEB, 2022). The Independent Electricity System Operator (IESO), another Crown corporation, is a key actor in managing the provincial electrical energy system. The operations of the IESO, which are subject to the requirements of the Ministry of Energy, Northern Development and Mines and the Ontario Energy Board, include overseeing electricity grid operations in real-time, directing overall electrical energy system planning, and managing the involvement of participants in the electricity market (IESO, 2022a). The Ministry of Energy, Northern Development and Mines develops the policy and legislative frameworks that guide the provincial system operations (Government of Ontario, 2021). The same Ministry is responsible for advancing the economic development of the northern portion of the province and for regulating the mining sector (Government of Ontario, 2021). The Ontario Energy Board is a government agency that is in charge of regulating the provincial electricity sector and enforcing the laws set in the legislation (OEB, 2023). The Ontario Energy Board's key responsibilities include setting electricity rates, and reviewing proposals for electricity-related projects, initiatives, and long-term planning (OEB, 2023). Other key actors outside the governmental sphere have major influence on electricity policy and decision-making. For instance, major power consumers, First Nations, communities, and private generators can influence the success or failure of proposed plans (OPA/IESO, 2013; Thomson et al., 2021). Figure 6.6 illustrates the flow of interactions among the different institutions.

Figure 6.6. Ontario's electrical energy system planning structure based on Ministry of Energy (2015) and Ontario Energy Board (2022)



6.1.4. Recent history of electrical energy system planning in Ontario

The planning structure of the Ontario electrical energy system has been modified many times through the years, until becoming the current one. Among other factors, these changes reflect evolving policy- and decision-making forced by looming sustainability-related and economic issues. In addition, key actors have seized emerging perceptions of problems, policy development and political interests as windows of opportunity to introduce novel policy in planning processes (Rowlands, 2007). As a result, Ontario's electricity structure has evolved through a continuing reconfiguration of pieces from different political cycles.

The Electricity Act

In 1998, the Progressive Conservative Party, then holding a majority in Ontario's legislature, passed and implemented the Electricity Act with the goal to establish the electricity sector as an open market. This legislation was based on the recommendations of an Advisory Committee that was appointed to propose alternatives for a future electrical energy system design. The committee, through a document known as the MacDonald Report, suggested a "more market-based" approach (Trebilcock & Hrab, 2005, p. 124). The Electricity Act set "the rules for the deregulation of the Ontario power sector" (Carlson et al., 2013, p. 8) under which sector authorities were prepared to open the market for private participation and competition. Without much attention to significant environmental considerations, the authorities argued that self-regulated market forces would introduce to the market more sustainable options for electricity generation and conservation (Rowlands, 2007). Before the Electricity Act was implemented, the public utility Ontario Hydro had a monopolistic control over generation and transmission, but was under public scrutiny due to its contribution to a massive provincial debt (Trebilcock & Hrab, 2005). After implementation of the new legislation, Ontario Hydro was divided into four components: Ontario Power Generation Inc, Ontario Electricity Services Company Inc, Ontario Electricity Financial Corporation, and Independent Electricity Market Operator (Nuclear Engineering International, 1999).

The market finally opened in April 2002, allowing consumers to buy their electricity provisions from private generators. However, after a few months, users saw their electricity bills rise to levels significantly higher than what they used to pay before deregulation. In this regard, the Independent Market Operator (IMO, 2003, p. 1) reported that unusual high temperatures caused an unforeseen elevation in consumption that overlapped with the depletion of hydroelectric resources and scheduled outages. To this, Rivard and Yatchew (2016) add that uncertainty about the future of the market and lack of transparency undermined the prospects for private investors' participation. Consequently, with soaring consumption and less than expected private generators, demand surpassing supply became a real concern. Hence, the Independent Market Operator announced near the end of 2002 that a shortage in generation capacity threatened the system's ability to provide reliable and affordable electricity (IMO, 2003). Finally, the provincial government intervened by freezing retail prices in November 2002 (Trebilcock & Hrab, 2005) and afterwards recognized that these circumstances "impeded the evolution of a competitive retail market" (Rivard and Yatchew, 2016, p. 223).

The Electricity Restructuring Act

In 2003 the Liberal Party came into power in the province (Rowlands, 2007) and, notably, set as an ambitious goal to close Ontario's coal-fired power plants by 2007 (Winfield, 2005). As a result, in 2004, the Electricity Restructuring Act was passed, with its main feature being to shift the existing system to a hybrid system (Rivard and Yatchew, 2016). This consisted in favouring an open, competitive market that was supported by provincial long-term planning (Government of Ontario, 2004). Hence, the Electricity Restructuring Act's enactment bore some structural changes oriented to pay better attention to long-term electricity planning (Carlson et al., 2013). For instance, the OPA was created as a planning authority expected to develop an Integrated Power System Plan. Moreover, what used to be the Independent Market Operator – which was essentially an independent market surveillance entity, and one of the four components resulting from the division of Ontario Hydro – became the IESO(Carlson et al., 2013). At the same time, the OEB was assigned to "ensure that the [Integrated Power System Plan]… was cost-effective and met the requirements of the government's directives" (Carlson et al., 2013, p. 9). Overall, the OEB and the IESO's joint task was to ensure transmission capacity, reliability and foster competition (Doern & Gattinger, 2003). This restructuring set the stage for the hybrid system that prevails today (Rivard & Yatchew, 2016). However, as discussed below, some modifications and a series of mandates mainly redirected some provincial objectives for the electricity sector.

Green Energy, Green Economy Act

In 2006, following a supply-mix directive by the Minister of Energy, the OPA developed its first Integrated Power System Plan – submitted for the OEB to assess in 2007 (Carlson et al., 2013). Also, in 2006, the government implemented a Global Adjustment charge in the electricity bills to cover the difference between electricity market rates and the cost of contractual obligations with private generation and infrastructure. Afterwards, in 2008, the scheduled OEB hearing to consider the plan was suspended upon further instructions of a new Minister of Energy, who issued a new mandate that required increased emphasis on renewables and conservation initiatives, while keeping a significant share of nuclear capacity (Winfield et al., 2010). However, the government chose not to require public review of a new version of the Integrated Power System Plan. Instead, the government introduced the Green Energy, Green Economy Act, which was passed by the Ontario Legislature in 2009. As a main feature, the act enabled introduction of a Feed-in-Tariff program to promote renewables' adoption, but it also gave the Minister of Energy more control over the OPA (Government of Ontario, 2009).

In 2010, the Ministry of Energy developed its own Long-Term Energy Plan. The new plan again emphasized continuing heavy reliance on nuclear energy, plus ensuring renewable energy capacity, and recognizing the need for conservation and demand management programs (Government of Ontario, 2010). In 2011, the Minister of Energy mandated the OPA to create a new Integrated Power System Plan, but this did not occur (Carlson et al., 2013). Instead, with a new Liberal Party administration, an updated Long Term Energy Plan was published in 2013. This plan focused on principles of "cost-effectiveness, reliability, clean energy, community engagement and an emphasis on conservation and demand management before building new generation" (Government of Ontario, 2013, p. 4). Then, in 2015, the government merged the OPA, which for many years had been responsible for developing long-term electricity projects and contracting, with the IESO (IESO, 2015). The resulting entity retained the IESO's name and combined the functions of both organizations. In the same year, the closing process of coal-fired power plants, proposed in 2003, was completed. This decision was greatly motivated by concerns of severe risks related to poor air quality and health issues. For instance, 660 premature deaths and 1100 emergency room visits per year linked to toxic emissions from coal plants were recorded by 2007 (Jones, 2007) At that time, the provincial government also began to address climate change mitigation obligations. In 2016, for instance, it approved a cap-and-trade policy in part to advance transition to a low-carbon provincial electrical energy system (Raymond, 2020).

In 2017, with a new Minister of Energy in charge, the provincial government released a new Long-Term Energy Plan with the banner of "Delivering Fairness and Choice" to Ontario citizens (Government of Ontario, 2017). The plan proposed eight key principles to deliver fairness and choice: affordable and accessible energy, a flexible energy system, technological innovation, improving the performance of utilities and regulators, strengthening conservation and demand management, low-carbon systems, First Nation and Métis communities' participation, and regional system planning (Government of Ontario, 2017). However, as discussed below, a new provincial government introduced new changes with less ambitious climate and socio-environmental goals.

The Green Energy Repeal Act

In 2018, a new Progressive Conservative government came into provincial power, revoking some growing efforts in the past decades to achieve climate commitments and related sustainability goals. This government repealed the Green Energy Act passed in 2009 (Government of Ontario, 2018) and, despite controversy, cancelled 800 contracts for renewable energy projects (Brisbois, 2020). In the same year, Bill 4, the Cap-and-Trade Cancellation Act was passed (Ministry of the Environment, Conservation and Parks, 2018a), repealing the cap-and-trade policy approved in 2016. According to Environmental Defence, the cancellation of the cap-and-trade policy also entailed that the province lost "$2 billion worth of carbon reduction programs it funded" (Environmental Defence, 2020, p. 5).

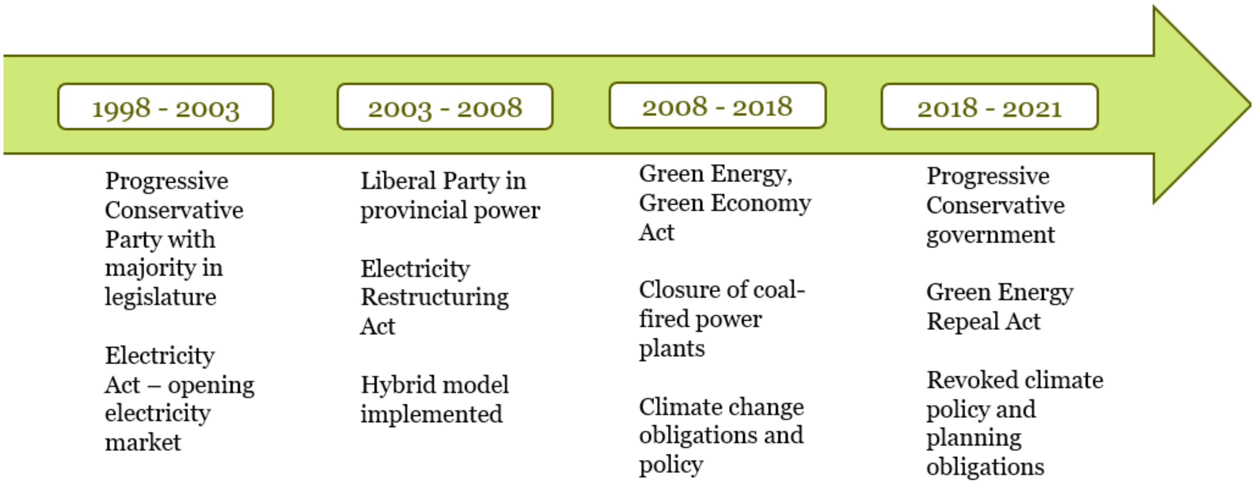
Later in 2018, the new authorities released their new environmental and climate provincial goals in the Made-in-Ontario Environment Plan (Ministry of the Environment, Conservation and Parks, 2018b). The plan stated as main goals protecting "air, land and water, preventing and reducing litter and waste, supporting Ontarians to continue to do their share to reduce greenhouse gas emissions, and helping communities and families prepare for climate change" (Ministry of the Environment, Conservation and Parks, 2018b, p. 2). Environmental Defence (2020) has reported that while progress has been made in areas with limited potential for climate-related improvements, the overall potential for meeting global climate change goals is very weak. They also report that these decisions, in addition to more recent efforts to eliminate carbon pricing, are likely to pose risks to human and environmental health. Added to this, the federal government's National Inventory Report 1990-2018 showed that, compared to 2017, Ontario's greenhouse gas emissions had already increased by 10 mega-tonnes by the end of 2018 (Environment and Climate Change Canada, 2020). In 2019, additionally, Global Adjustment charges, which have been controversial and have seen some increases since their incorporation in 2006, raised to the point of accounting for 45 to 60 percent of the electricity bill (Rivard, 2019), creating concerns about future economic challenges.

In 2020, the federal government made official the Canadian commitment to eliminate most harmful greenhouse gas emissions in the atmosphere by 2050, with the approval of the Canadian Net Zero Emissions Accountability Act (Minister of the Environment, 2020). This act "requires the Government of Canada to set national targets for reducing greenhouse gas… emissions and establishes a planning, reporting and assessment process with the aim of achieving net-zero emissions by 2050" (Linden-Fraser, 2020, p. 1). This entails establishing legal obligations to attain climate and sustainability-related goals and to clarify the actions required to meet such goals. One relevant aspect of the plan is the requirement to set five-year targets from 2030 to 2050 (Minister of the Environment, 2020). However, as noted above, recent decisions by Ontario's provincial government have diverged from national electrical energy system commitments (e.g., cancelling hundreds of renewable energy projects, and revoking climate change policy). Additionally, in 2020, the Progressive Conservative government removed the mandatory timeframes for governments to deliver the provincial energy plan (Environmental Registry of Ontario, 2020). This decision also meant leaving Ontario's electrical energy system without an official requirement for long-term energy planning and approved sustainability assessment criteria for plans, projects, and initiatives. According to Winfield (2022), the current governmental unwillingness to commit to key sustainability-oriented efforts poses key challenges for future aspirations to social and ecological well-being that need attention now. In this regard, Winfield and others (forthcoming) have identified that the current provincial government has adopted a political strategy of right-wing populism and "post-truth politics" that ignore science-based evidence and polarize climate change and other sustainability objectives against short-term socioeconomic benefits.

While Ontario's electrical energy system landscape continues to shift, recent official decisions with long-term implications have indicated more clearly the pathways that the province will be taking in the near future (M. Winfield, personal communication, December 4, 2022). These chosen pathways are expected to pose high costs, and high social and environmental risks, and have ignored national and global sustainability goals. Some relevant choices include boosting the nuclear energy industry – e.g., by refurbishing the Bruce, Darlington, and Pickering nuclear generating stations (Financial Accountability Office of Ontario, 2017), and investing in small nuclear reactors (Zimonjic, 2020). Another relevant decision is to increase use of existing natural gas power plants and to raise natural gas-based electricity generation capacity by 1500 megawatts, with expected increases in greenhouse gas emissions from the electrical energy system by 300% (Purcell, 2020). Additionally, the provincial government has decided to continue the highly expensive subsidy programs to reduce electricity bills to households and businesses, which is expected to cost the province a total CAD$118.1 billion by 2039 to 2040, and around CAD$6.9 billion yearly (Financial Accountability Office of Ontario, 2022).

Figure 6.7 presents a timeline that summarizes key events discussed above, relevant to the changing context of Ontario's electrical energy system during the past two decades.

Figure 6.7. Timeline for Ontario's recent electrical energy system history



Summary of key system and system change characteristics

- With a new hybrid operational model, the government has a role in overall system planning and in defining the components of long-term projects and contracting, but there is encouragement for private actors to compete for contracts.
- The elected governments have oscillated between the long-term planning efforts of some of the Liberal governments and the short-term, market-centered preferences of the Progressive Conservatives
- In the recent history, persisting cost-related issues, poor air quality, and a rise of health risks have motivated some of the most significant changes in generation and policy-design (e.g., closure of coal-fired power plants, pressure to favour renewables, low-emissions policy)
- There is an existing misalignment between some relevant federal government commitments and provincial government efforts – e.g., federal commitment to net-zero emissions, and provincial weakening of climate change mitigation and adaptation efforts

6.2. Specifying the framework

Issues surrounding Ontario's electrical energy system have been closely tied to sustainability-related considerations for at least 20 years. In this regard, the province has made evident efforts to address growing concerns, with a degree of success. For instance, decisions to phase out coal-fired plants helped to reduce electrical energy system greenhouse gas emissions – from 35 mega-tonnes in 2005 to less than 7 mega-tonnes in 2014, and to roughly 4 mega-tonnes in 2018 (IESO, 2020b). Nevertheless, past governmental decisions (Rosenbloom & Meadowcroft, 2014), and ineffective electricity planning (OPA/IESO, 2013) have limited other potential positive outcomes from provincial action. For example, ineffective consultation processes and investing in options with high capital risk have led to the cancellation of highly expensive projects and the creation of long-term affordability challenges (Morrow, 2015; SolarShare, 2015; Winfield, 2016). Also, recent projections indicate significant increases in greenhouse gas emissions in the next ten years (IESO, 2020b).

With this in consideration, the initial framework of sustainability assessment criteria specified for applications to electrical energy systems, proposed in Chapters 3 and 4, is used in this section as a lens to examine Ontario's most salient issues. The examination is based on the literature review and document research and is complemented with insights gathered in the interviewing process. For these purposes, this section focuses on 1) using the initial framework to describe and do an initial assessment of the Ontario electrical energy system and associated planning in recent years, and 2) identifying key contextual elements to further specify the framework for future applications that assess the Ontario electrical energy system and related efforts.

6.2.1. Climate safety and socio-ecological integrity

Ontario's electrical energy system requires a stronger focus on climate safety. The divergence between recent federal commitments to attain net-zero emissions and Ontario's government lack of interest in meaningfully pursuing climate goals poses difficult challenges for maximizing positive effects provided by the electrical energy system. The province has indeed had some successes – like completing the closure of coal-fired power plants (Harris et al., 2015) and significant reductions in harmful emissions (Environment and Climate Change Canada, 2020), largely sparked by pressing events related to poor air quality and health issues (Rowlands, 2007). However, salient official efforts that were established to develop alternatives for pursuing global climate-related obligations have been stifled. The IESO (2020b) has reported that greenhouse gas emissions from the Ontario electricity sector are projected to increase 7 mega-tonnes from 2018 to 2030. In this regard, one interviewee from academia agreed that the provincial government has demonstrated a denial on pursuing climate change goals, and that decision-making has undermined efforts to reduce harmful emissions.

This scenario has different implications for the provincial electrical energy system and the broader requirements for progress towards sustainability. One interviewee from industry, for example, pointed out that the electricity sector has the difficult challenge to meet net-zero commitments while meeting energy needs for everyone. Therefore, there is a need for an integrated strategic plan, provincially and nationally, that clarifies how the climate and other sustainability-related targets will be met (Winfield, 2020b). In this sense, climate related factors should have to play an important role in the evaluation of future options (Environmental Defence, 2020). According to one interviewee from utility companies, the narrative on climate change from different actors has been constantly evolving. The same expert stressed that there is growing attention in the industry towards adapting and reinforcing system infrastructure to enhance resilience capacity in the face of unavoidable climate change effects. Other relevant considerations are the technical implications and demand considerations of a projected increase on electric vehicles that need to be addressed for ensuring reliability of supply. However, such implications also exist for buildings, industry, the residential sector, heating, and others.

Furthermore, Ontario's electrical energy system needs to ensure that plans and projects, as well as design options, that stem from climate action provide fair and long-lasting benefits for the most vulnerable to the effects of climate change. The attainment of climate change goals is at the same time affected by broader considerations of cost-effectiveness and resource conservation (Love, 2017). Notably, electricity costs have risen in part because of an accumulation of negative effects from many short-sighted decisions (Winfield, 2020b). This, at the same time, has undermined the capacity for public approval and financial support to climate change related efforts.

6.2.2. Intra- and inter-generational equity, accessibility, reliability, and affordability

In terms of accessibility, reliability, and affordability, one relevant statistic is that Canada has provided access to reliable electricity to 100% of the population since at least 1990 (World Bank Group, 2022). Additionally, the IESO's (2022) *Reliability Outlook* has reported that the electrical energy system has resource and transmission capacity to continue providing reliable electricity to all until at least 2024. One concern in Ontario, however, has been the ongoing difficulties to maintain an affordable electrical energy system. The Association of Major Power Consumers of Ontario (AMPCO, 2019), for example, has emphasized that the provincial rates have reached some of the highest in North America. As stressed above, Ontario's electrical energy system has a long history of cost-related issues that have contributed to rising electricity prices (see section 6.1.4). Additionally, Ontario's efforts to maintain affordable electricity prices through subsidy programs poses notable risks, like continuing increases in electricity bills in the next two decades (Financial Accountability Office of Ontario, 2022). In this regard, a recent report has estimated that Ontario's nine energy and electricity subsidy programs will cost the province CAD118.1 billion (Financial Accountability Office of Ontario, 2022). According to interviewees from academia and utility companies, other key contributing factors have included the cancellation of high capital cost projects, expensive refurbishment of nuclear plants and construction of gas plants, short-sighted decision making. To this, Songsore and colleagues (2018) have added that the province and electrical energy system managers have struggled with building effective policy making to incorporate low-carbon options, like renewable energies, while maintaining affordable electricity prices. Interviewees from industry and utility companies have also identified this as one of the main challenges for the further adoption of cheaper low-carbon options.

However, maintaining reliability while safely incorporating promising alternatives requires the promotion of adequate policy options and technological development (e.g., energy storage, distributed generation, renewable energies) (Rosenbloom, 2018). For instance, one interviewee from utility companies mentioned that one of the main future challenges will be to ensure reliability in the system's growing unpredictability and complexity (e.g., more distributed systems, with the addition of many moving parts, and with electricity flowing multi-directionally, instead of the conventional linear supply flow). To this, the expert added that more technological development will be necessary to manage distribution and transmission needs safely.

Ontario's electrical energy system also needs to create more effective options for making broader contributions to equity in livelihood opportunity. The cancellation of the Green Energy Act, for instance, has disproportionate adverse impacts on First Nations and local communities, including a halt on some opportunities for Indigenous owners and communities to compete fairly in the market (Karanasios & Parker, 2016; MacLaren, 2021). The provincial electrical energy system should provide more meaningful benefits for the social community, and for those directly affected by the operations of the system (e.g., rural communities and First Nations). For instance, one future challenge is to enhance the capacity of the system to provide more long-term and decent employment for such groups. One interviewee from industry stressed that, usually, electrical energy system planners' priorities are mostly focused on system reliability, and that they do not pay the same attention to employment, harmful emissions, and costs. In this regard, interviewees from industry and social community drew attention to electricity initiatives that are more oriented to community needs and benefits, and that do not only offer financial compensation for land use (e.g., CalCCA, 2021; City of London, 2013; Our Energy Guelph, 2018).

This main criterion category has diverse overlaps with the other sustainability requirements. Interviewees utility companies consider that there are still important price-related challenges for options relevant to attaining climate goals. Pricing challenges are at the same time a key factor for the system's incapacity to attain broader public approval of low-carbon options (Rosenbloom, 2018). For instance, one interviewee from utility companies stressed that efforts proposed in the Green Energy Act (e.g., increasing behind-the-meter generators connected to the system) without provincial compensation for added infrastructure to the utilities and distribution companies, was financially unsustainable. However, some experts have also highlighted the billion-dollar losses in cancelling ongoing contracts for renewable energy and conservation projects (Environmental Defence, 2020). Maximizing the capacity for affordable electricity and more equal opportunities for livelihood also depends on the contributions made to other main categories. For example, broad contributions to cost-effectiveness, resource efficiency and conservation can help to reduce prices (e.g., Global Adjustment costs). Additionally, electrical energy system decision-making needs to ensure that the technical options proposed for attaining lower costs contribute to the system reliability and resiliency.

6.2.3. Cost-effectiveness, resource efficiency and conservation

Ontario has achieved some advancements but requires more improvements in this category. Coupled with the implications of climate change effects, cost-related issues are likely to be significant for Ontario's future electrical energy systems (Rivard, 2018). Efficiency and conservation have been identified as effective options for the provincial system to reduce costs and provide associated benefits (e.g., reduction in harmful emissions and electricity prices) (Love, 2017), and have been prioritized in provincial plans for many years (e.g., IESO, 2009; Government of Ontario, 2010, 2013, 2017). On this matter, however, some experts have documented Ontario's policy context as a constantly evolving matter (e.g., Love, 2017;

Rowlands, 2007; Winfield, 2016). While notable progress has been made in the past to adopt cost-effective options – including renewable energies (REN21, 2014) and efficiency and conservation programs (Environmental Commissioner of Ontario, 2018) – the provincial political context is challenging. Some authors have suggested, for instance, that the province is opting to take a path towards maintaining a nuclear-based electrical energy system, and away from a renewables-based one (e.g., Environmental Commissioner of Ontario, 2018; Winfield, 2020a). Two relevant examples include the recent provincial decisions to cancel 800 projects that were expected to generate over 1,000 megawatts from renewable sources (Brisbois, 2020), and to approve highly expensive refurbishments in Bruce, Darlington and Pickering nuclear generating stations (estimated in CAD$25 billion) (Financial Accountability Office of Ontario, 2017).

There are overlapping implications for Ontario's electrical energy system to make overall contributions to sustainability. Cost-related issues are key in the public approval and broader acceptance of new options, and provincial denial to pursue climate goals has undermined such prospects. Regarding renewable energy, one interviewee from industry mentioned that while options have become cheaper, installation costs remain expensive for residential standards, and that the period for investment recovery is long. In this sense, better alignment with federal and municipal efforts is crucial (Gaede and Rowlands, 2018). Some interviewees from academia and social community have recognized that policy alignment has been inconsistent. For instance, one interviewee from utility companies stressed that Ontario's changing policy environment, often politically driven, makes it challenging for local utilities and distribution companies to maintain competitive and affordable pricing.

In energy conservation, Ontario has been recognized as having an advanced focus on smart conservation and demand management tools, compared to other provinces (Winfield & Weiler, 2018). One interviewee from government mentions that, while they need more progress, provincial efficiency and conservation efforts have been broad. Nonetheless, some authors have recognized that additional research, policy and strategic development are needed to create more favourable conditions for social acceptance by considering community needs (Chaplin, 2016; Lazowski et al., 2018; Sommerville et al., 2018). One interviewee from government also stressed that provincial efforts need to better recognize, and to take more seriously, the opportunities for broad benefits that efficiency provides. Also, usual conservation policies need to better align supply and demand to reduce consumption by industrial consumers and facilitate associated benefits (Sen, 2017). Furthermore, the technical implications mentioned earlier are also relevant to ensure the system is capable to manage and match demand and supply power loads, while preserving the stability and reliability of the system. According to one interviewee from utility companies, there has been progress made in this regard, but more developments in that area are needed for the near future.

6.2.4. Democratic and participatory governance

The provincial government has received strong criticism related to poor governance of the electrical energy system. This includes the absence of effective planning, lack of transparency, ignoring legislated milestones, and questionable stakeholder consultation processes (Goulding, 2013; Ministry of Energy, 2015; Rivard, 2018; Vegh, 2016, 2017; Winfield, 2016). In this regard, authors have argued that despite institutional changes in generation, and transmission to a lesser extent, Ontario maintains a "centralized model of grid organization" (Rosenbloom and Meadowcroft, 2014, p. 679). This has been problematic from different angles. For example, Rivard and Yatchew (2016) have claimed that perceptions of governmental intervention for political interests rather than for sound electricity planning, have demotivated private participation. Also, one interviewee from utility companies has suggested that policy making focused predominantly on immediate responses to political controversies has undermined the capacity of local companies to manage the system. Evidently, the province needs to better align planning processes to the multiple jurisdictional scales and the dynamics between and among them (Rosenbloom, 2019). Gaede and Rowlands (2018, p. 275), in the same vein, have remarked that "the electricity system itself is poorly aligned in Ontario, in that possible developmental pathways for different sub-sectors are diverging with potentially detrimental consequences for the grid as a whole".

Another persisting problem for provincial authorities is a lack of effective and meaningful efforts to establish community participation, and to attain public support through effective governance processes on proposed projects (Carlson et al., 2013; Winfield, 2016). According to one interviewee from academia, failure to take planning and public engagement processes seriously has already had significant consequences. One relevant example is the cancellation of two natural gas power plants due to an absence of channels for public input and decisions made mostly in consideration of technical aspects (Winfield, 2016). In this regard, the OPA and the IESO have acknowledged that a "better balance [of] local needs and concerns with provincial requirements" (OPA/IESO, 2013, p. 19) is key for electricity planning and societal well-being.

Ontario needs to improve the governance capacity for electricity initiatives to engage more effectively with the relevant actors in the electrical energy system at multiple scales (Gaede & Rowlands 2018; Rosenbloom, 2019). One crucial implication for the system management is consideration of, and consultation with, First Nations and local communities. Interviewees from social community have emphasized that, while there has been some progress in terms of policy and law making, authorities and managers of energy-related projects often prioritize economic stimulus over First Nations and environmental interests. Hence, the electricity sector needs to guarantee respecting consultation processes, as well as appropriate compensation in consideration of the local needs.

The province also needs to improve in including local utilities and distribution companies in official decision-making processes. One interviewee from government emphasized that better commercial relationships with other provincial systems (e.g., Quebec and regional systems in the United States) would be beneficial for the reliability and affordability of the system. Also, the electrical energy system requires further community engagement for widespread, cultural adoption of conservation and demand management tools, as well as renewable energy projects, at multiple levels (Adachi & Rowlands, 2010; Lazowski et al, 2018). One recent provincial effort, however, to foster community engagement in electrical energy system-related decisions is the IESO's (2022) *Long-Term Request for Proposals Engagement Plan*. The plan promotes engagement with multiple actors, especially with municipalities and Indigenous communities, to attain broad public input regarding the IESO's proposal for 1000 MW of new and expanded electrical energy system infrastructure by 2026 (IESO, 2022).

6.2.5. Precaution, modularity and resiliency

Promoting precaution, modularity, and resiliency has important implications for the design of electrical energy systems in Ontario that contribute broadly to sustainability (Winfield et al., 2010). First, Ontario needs to enhance the system capacity to develop technological advancements and scientific innovations to support broad adoption of promising alternatives for attaining climate goals. A bigger role for energy storage, for instance, is likely needed for decentralized generation, diversification of sources, and further deployment of electric vehicles, as well as for conservation and efficiency purposes (Gaede & Rowlands, 2018). One relevant opportunity is that Ontario's electricity sector has shown an inclination towards efficiency and conservation, and therefore has an advanced potential for the further implementation of emerging options (Love, 2017). Nonetheless, as previously mentioned, electrical energy system managers need to ensure to enhance democratic and participatory governance capacity for the social acceptance of energy storage, renewables, and other conservation and efficiency options (Winfield, 2016).

Ontario's decision to refurbish and maintain the current nuclear generation capacity, considering it as key to meet reliability and reducing emissions to the atmosphere, also creates effects that challenge social-ecological integrity and intergenerational equity. While small modular reactors have been proposed as an alternative for modularity (Ontario Power Generation, 2021), there are more interacting effects to consider. For instance, intergenerational effects of not having effective long-term solutions for the disposal of radioactive by-products, permanent decommission after use, toxic waste in life-cycle processes, as well as high cost-related risks for future generations (Environmental Commissioner of Ontario, 2018; Winfield, 2020a). Also, nuclear power systems are not flexible enough to facilitate the incorporation of new, safer and cheaper options and can reinforce a technological lock-in scenario in the provincial electrical energy system (Winfield, 2020a). One interviewee from utility companies, for example, stressed that base-load generators have a limited capacity for demand response since they cannot be turned down. Consequently, the incorporation of distributed generation while base-load generators are operating can create risks of over supply.

6.2.6. Transformation, integration of multiple positive effects, and minimization of adverse effects

Ontario's electrical energy system needs an increased capacity to provide positive, multiple, and mutually reinforcing sustainability effects and interactions. Since provincial authorities have removed the requirement for a long-term energy plan, Ontario currently does not have planning processes or frameworks with officially approved and published criteria, requirements, or objectives (Winfield, 2020b). Similarly, one interviewee from social community suggested that Ontario requires more effective, clear, participatory, and integrative plans than the ones that have been implemented in the recent history. In addition, recent decisions by the provincial government have significantly weakened contributions towards attaining climate goals (e.g., Environmental Defence, 2020). Another system design implication for Ontario is to enhance capacities for the meaningful adoption of governance options that have been identified to increase sustainability-related benefits (e.g., Vegh, 2018).

A key issue noted by interviewees in academia, government, social community, and utility companies is that efforts and goals among multiple jurisdictional scales are often misaligned. Accordingly, effective and enforceable mechanisms for collaboration are necessary. For instance, increased efforts to include First Nations and community needs in decision-making (Rakshit et al., 2019), as well as to meaningfully engage with other crucial actors in the system such as local distribution companies, utilities, industry, and power consumers (Songsore et al., 2018). In addition, improvements to electrical energy system management will have to address continuing problems involving decision making based on vested interests and short-term economic responses (Brisbois, 2020). In this regard, electrical energy system decision-making has been identified by some of the interviewees as highly politicized, and that responses to politically driven pressures have undermined responses to long-term issues (Brisbois, 2020). Forward-looking electricity-related decision making in Ontario also needs to ensure just transitions as part electrical energy system changes. This entails respecting the obligations to First Nations and communities' interests, and protecting and increasing resilience capacity of valuable social-ecological system components (Rakshit et al., 2019). As mentioned previously, interviewees in social community have remarked that electricity-related project decisions have often disregarded protecting Indigenous land and cultural identity, and that Indigenous peoples are usually not consulted and compensated appropriately. Other interviewees in utility companies have emphasized that provincial authorities need to provide more alternatives to alleviate problems faced by those who are more adversely affected by ongoing and unavoidable changes (e.g., climate change and COVID-19 pandemic effects).

These aspects have implications for other key considerations in this category. For example, the lack of a provincial long-term plan diminishes the provincial capacity to build policy pathways towards sustainability-related goals (Winfield, 2020b). The provincial electrical energy system, hence, requires an established set of desirable goals and clarifying the actions needed to attain them (e.g., backcasting and scenario-based planning), instead of prioritizing immediate political considerations, and current technical and economic trends (Brisbois, 2020; Vegh, 2018). Also, an absence of effective consultation and engagement with key actors entails weakened possibilities for complementarity of diverse approaches, innovation, and knowledge co-production (Winfield, 2016).

The consideration of inducing transitions and transformations towards a provincial electrical energy system that provides multiple and long-lasting positive effects also overlaps with the other sustainability criteria. Insufficient efforts to enable transitions and transformations in initiatives to pursue climate goals, for example, have resulted in only marginal adjustments without transformational outcomes (Environmental Defence, 2020). Furthermore, Ontario's electrical energy system needs an enhanced capacity to provide more positive social and environmental effects especially in response to the needs of vulnerable social groups. In this sense, as proposed in the framework, Ontario's future system design can benefit from adopting an approach of implementing multiple and mutually reinforcing sustainability-contributing packages of initiatives. Also, an approach to maximizing contributions to directing transformations towards sustainability can support more precautionary decision-making that avoids highly costly financial as well as social and ecological risks. In terms of reliability, furthermore, an enhanced capacity for collaboration and knowledge co-production can accelerate the innovation and technical advancements necessary to safely incorporate and operate promising alternatives (e.g., decentralization and diversification, demand response, smart grid tools, energy storage, efficiency, etc.).

6.3. Sustainability-based assessment framework specified to Ontario's electrical energy system

Table 6.1 presents the sustainability-based assessment framework specified to the Ontario context. This framework has been elaborated in consideration of the overall accepted goals for electrical energy systems and honed with the incorporation of the findings presented above, obtained from the application of the initial generic framework to evaluate Ontario's electrical energy system and associated planning in recent years. The framework is developed as a tool for application in future evaluations of electrical energy system-related efforts, such as provincial plans, projects, and initiatives. Also, the elaboration of the framework is relevant to this dissertation since it highlights key elements that contribute to answer the main research question. At the same time, it has proven to be an effective exercise in the pursuit to better design electrical energy systems to support pathways towards sustainability.

Table 6.1. Proposed sustainability-based assessment framework specified for application to Ontario's electrical energy system

Climate safety and social-ecological integrity

- Reducing and reversing greenhouse gas emissions to the atmosphere, and other substances that aggravate climate change, as well as adapting to and mitigating associated adverse effects.
    - Minimizing greenhouse gas emissions in all life-cycle processes of the electrical energy system's operations – e.g., generation, distribution, transmission.

- Maximizing the share of renewable energy sources by facilitating promising options in the overall electricity mix.
    - Enhancing the development and implementation of smart grid tools that are promising to efficiency and greenhouse gas emission reductions – e.g., smart meters, energy storage.
- Preserving citizen's health and community well-being.
    - Maintaining safe air, water and soil quality levels through the minimization of toxic waste emissions and promotion of safe management in all life-cycle processes.
    - Avoiding design options that pose risks of significant adverse effects to human well-being and the environment if the system fails unexpectedly – e.g., system malfunction, extreme weather conditions, accidents, releasing harmful substances to the environment.
- Maintaining life-support systems that contribute to socio-economic benefits such as long-lasting jobs and livelihood sufficiency.
    - Minimizing electricity project-related impacts to soil quality and agricultural land, as well as fisheries and forest areas.
- Preserving biodiversity populations and natural habitats to enhance the potential for positive social-ecological dynamics and effects.
    - Supporting technology and policy options that avoid threats to animal species and negative impacts to habitats
    - Favouring electricity generation and delivery projects that minimize risks of harmful impacts to biodiversity in all life-cycle processes – e.g., material procurement, construction, operation, waste disposal.

Intra- and inter-generational equity, accessibility, reliability, and affordability

- Providing equity in opportunity for present and future generations, including decent and long-lasting jobs, livelihood sufficiency and improvement to Indigenous peoples and disadvantaged groups
    - Ensuring that consultation obligations, and appropriate compensation when necessary, to First Nations and rural communities are respected
    - Supporting policy making and electrical energy system projects that enable community-oriented benefits, and that avoid risks to present and future generations
    - Favouring project proposals that can create direct and indirect employment opportunities that are well paid, long lasting, conveniently located and otherwise accessible, fulfilling/challenging, etc.

- Favouring system design options that are easy to understand, operate and adjust, over others that require higher levels of specialization and technical expertise
- Ensuring affordable electricity for all citizens, including First Nations and rural communities, as well as major power consumers that provide essential services for socio-economic well-being.
    - Promoting of cost-effective and efficient options in electricity projects and programs to reduce Global Adjustment and other operation costs
    - Supporting pricing tools and smart technologies that help to better align electricity supply and demand and promote off-peak consumption – e.g., advanced metering infrastructure, smart meters, self-healing grids.
    - Avoiding long- and short-term economic risks in project approval – e.g., long-term commitments to high capital and operation cost projects
- Ensuring technical reliability and viability for all citizens, including First Nations and rural communities in the face of unexpected events (e.g., extreme weather, blackouts, and system malfunction).
    - Supporting development and implementation of technology options that can increase the modularity, reliability, resiliency and safety of the electrical energy system – e.g., smart grid and self-healing grid tools

Cost-effectiveness, resource efficiency and conservation

- Minimizing provision costs and social-ecological costs
    - Enhancing the capacity for public approval of proposals that are cost-effective in terms of provision costs (e.g., costs related to construction, operation and distribution) and social-ecological costs (e.g., costs related to poor air and water quality and the impacts on human health).
    - Minimizing electricity losses in all life-cycle processes of generation and delivery activities
- Minimizing the consumption of natural and community-valued resources
    - Enhancing electrical energy systems' efficiency and matching electricity quality and quantity to end-user needs
    - Maximizing the approval of options for new energy infrastructure and retrofitting that minimize electricity losses in all life cycles of existing and proposed projects.
- Building policy and technology pathways that enable the development and implementation of efficiency tools such as energy storage, smart grid technologies and demand response options
    - Increasing the capacity of industries and major power consumers for off-peak consumption – e.g., smart grid tools

- Enhancing aligned multi-jurisdictional efforts for the widespread adoption of and community engagement to energy efficiency and conservation programs.
- Enabling the further development of current technologies and implementation stages for conservation and demand management tools.

- Building capacity to avoid reliance on the extraction and consumption of fossil fuels
  - Enhancing technical capacity for increasing the share of renewable energy in the electricity mix, reliably and at affordable costs
  - Maximizing public acceptance, technological development, and policy pathways creation for the widespread adoption of affordable and reliable renewable energies

Democratic and participatory governance

- Ensuring democratic and participatory deliberation that promotes consultation with experts, stakeholders, First Nations, vulnerable groups and community leaders, and attains public acceptance through explicit and transparent processes
  - Avoiding streamlining of official processes for faster approval of electrical energy system projects, as well as decision-making that is based only on technical and economic considerations
  - Ensuring that decision-making considers community needs – e.g., addressing citizens' health and safety (and other) concerns, finding effective means for equitable distribution of financial benefits, promoting community participation and respecting cultural heritage landscapes
- Enhancing capacity for innovation and knowledge integration from the citizens, First Nations, key actors and communities in the province
  - Enhancing reflexivity to recognize political pressures in governance processes (e.g., agency, vested interests, power dynamics)
  - Increasing citizen engagement for the adoption of renewable energy and demand response technologies
  - Maximizing the alignment of policy development efforts between multiple jurisdictions (e.g., federal, provincial, municipal)
- Favouring policy-making design and planning that clarifies the implications of attaining climate and associated social-ecological objectives
  - Promoting the incorporation of tools for policy pathways development that are better suited for breaking negative trends – e.g., backcasting and scenario planning

Precaution, modularity and resiliency

- Supporting prudent and precautionary policy- and decision-making in consideration of unpredictability and incomplete understanding of complex social-ecological dynamics
    - Favouring design options that avoid risks of severe socio-economic crises and irreversible damage to vital life-support systems
    - Increasing the system's adaptive capacity for modifications over time as well as greater system compatibility for the integration of diverse sources to the grid
    - Avoiding project proposals that increase path dependency and pose socio-economic-environmental risks (e.g., capital intensive, massive and wasteful long-term projects with low capacity for modifications over time)
- Supporting design options that minimize vulnerability to system failure and maximize recovery capacity to potential threats (e.g., extreme weather events, blackouts, system malfunctions, release of toxic waste, etc.)
    - Building policy pathways for the development and deployment of technologies that increase the modularity, flexibility and resilience of the electrical energy system – e.g., energy storage, demand/supply monitoring, smart grids, microgrids, self-healing grids, etc.
    - Increasing the widespread adoption and public approval of smart grid tools and initiatives for community engagement

Transformation, integration of multiple positive effects, and minimization of adverse effects

- Accumulating positive sustainability-oriented effects for desirable change, while avoiding trade-off scenarios that pose risks to already disadvantaged groups, through the implementation of multiple and mutually reinforcing sustainability-contributing packages of initiatives.
    - Implementing official energy plans with sets of goals and criteria oriented to accumulate benefits that are compatible and mutually supportive among sectors (e.g., electricity, transportation, buildings, residential, etc.)
- Enhancing capacity for addressing governance challenges that hinder the accumulation of positive effects by incorporating effective governance design options.
    - Advancing knowledge and practical capacity for more effective collaboration and multi-scale alignment, self-examination and clarification of political dynamics, adaptive capacity in policy- and decision-making for long-term considerations, specification to context
- Supporting just transitions to ensure that electrical energy system planning and operations build the resilience of what is valuable and pay special attention to the interests of the most vulnerable
    - Respecting consultation obligations with those most affected by the system operations

- Avoiding decision-making and trade-offs that prioritize economic and political interests by creating intra- and inter-generational burdens to vulnerable groups, citizens, and the environment
  - Providing more effective targeted relief to those that are more affected by ongoing and unavoidable changes (e.g., climate change, price increases, and COVID-19 pandemic effects)
- Developing pathways to sustainability that address combinations of policy and technical options, deliberative processes, and strategic approaches aim to identify how specific desirable targets can be reached, instead of aligning decision-making to predictions based on current technical and economic trends.
  - Promoting backcasting, scenario planning and other visioning and negative trend-breaking approaches identified for policy-design and planning
- Facilitating complementarity of different approaches to transformation by taking diverse knowledges seriously, accepting a plurality of pathways to sustainability and embracing the political nature of transformations
  - Promoting effective and meaningful engagement with key actors in the electrical energy system to strengthen complementarity of diverse approaches for knowledge co-production and innovation.

6.4. Trade-off considerations

Designing electrical energy systems in Ontario to support pathways that deliver mutually supporting positive sustainability effects involves avoiding unnecessary trade-offs, and effectively managing those that are recognized and well-justified as unavoidable, by following appropriate trade-off rules (see Chapter 3). Following Gibson and colleagues' (2005) trade-off rules (see Chapter 3), this section identifies four relevant aspects to consider for possible trade-off scenarios in designing a sustainability-based version of the Ontarian electrical energy system. Particularly, the first two considerations can be considered as spatial trade-offs, and the last two can be considered temporal trade-offs. While Gibson and colleagues' (2005) trade-off rules informed the development process, the trade-off considerations shown below were developed inductively from key insights gathered from the document research and field work, and the application process. The four identified aspects are the following:

- Addressing the interacting effects between electrical energy system project proposals and their social and ecological context. For instance, construction and resource extraction operations considered in generation, transmission and distribution proposals can conflict with First Nations and community interests. The province needs to ensure more effective consultation and binding obligations to better avoid, monitor, mitigate, and compensate when necessary, adverse effects to the rivers, air, soil, forests, as well as protected and socially valued areas.

- Minimizing cost-related effects in electrical energy system decision-making that can result in expensive bills for key participants, including industry, consumers, and local providers. In this sense, options to increase cost-effectiveness such as efficiency, conservation and demand response options, and avoiding unnecessarily high financial risks, must be prioritized in project planning and development stages. However, policy mechanisms in support of attaining climate goals might result in initial Global Adjustment costs that need to be alleviated, particularly for the most vulnerable groups.
- Avoiding mid- and long-term trade-offs related to affordability, reliability, and the social-ecological integrity that can emerge from system design-options. The widespread adoption of, for instance, electric vehicles must be implemented while ensuring that deployment advancements do not surpass the technical capacity of the system to manage supply and demand. This, along with related alternatives like energy storage and renewable energies, must also avoid the accumulation of negative intergenerational effects – e.g., accumulation of toxic substances in the environment.
- Avoiding sacrifices in open, transparent, and participatory consultation processes for social acceptance for the sake of quick responses to short-term economic and political pressures.

6.5. Conclusions

This section provides concluding insights for three different aspects of this study. These are conclusions relevant to the theory adopted as foundational for this thesis work, conclusions relevant for the specification and application of the framework, and finally conclusions that provide implications for designing Ontario's electrical energy system to contribute to transitions towards sustainability.

6.5.1. Theory

Ontario's electrical energy system continues to be constantly evolving in terms of politics, technology, economy, policy making, and social and environmental pressures. In this context, the absence of official energy plans, in a context of climate-related and social pressures, makes sustainability-based literature focused on Ontario's electrical energy system more relevant. The provincial policy misalignment to smaller and larger scales (e.g., local and national) indicates the need for more effective multi-scale approaches to facilitate desirable transitions and transformations in the electrical energy system (Keating & Katina, 2019). This entails recognizing that decisions at particular jurisdictional levels can generate and accumulate interacting effects, positive and negative, at different scales.

Also, the consideration of trade-off scenarios is key to avoid unnecessary adverse effects resulting from interactions and vested interests among the different components and provincial actors in the electrical energy system (Geels et al., 2017). Sustainability-based approaches can play a relevant role in advancing new modalities of electricity planning, policy making, and project assessment that consider the interlinked effects, and that provide more effective solutions to address them integrally. However, as transformations' literature suggests (e.g, Folke et al., 2020), more research into the possible cumulative effects of past and ongoing initiatives is essential to better understand the upcoming challenges, and to design electrical energy systems that can anticipate the evolving necessities of the next decades – including recognizing the consequences of short-sighted decisions, climate change impacts, and effects from the COVID-19 pandemic.

The incorporation of knowledge on transitions and transformations in complex systems informed the examination of Ontario's recent contextual capacity to induce electrical energy system transformations. The theory suggests, in this regard, that emerging efforts to study, evaluate and plan changes to electrical energy systems should be developed as packages of initiatives that contribute to the accumulation of positive and mutually supportive effects (Gibson, 2017). This accumulation can also stimulate the electrical energy system to increase its positive contributions towards net-zero greenhouse gas emissions and to provide broader social benefits. However, one relevant challenge is the alignment of cumulative effects in different initiatives at different scales. In this regard, theoretical contributions that apply a sustainability-based approach to more specific electricity-related initiatives, and that pay attention to aligning with other similar efforts are relevant.

6.5.2. Framework

The proposed generic criteria specified for electrical energy systems is overarching and well-suited to be further specified to the main electricity-related contextualities in Ontario. In the criteria for electrical energy systems generally, the incorporation of a criteria category centred on transformation, integration of multiple positive effects, and minimization of adverse effects is a novel addition to the application of sustainability-based assessments. The category was suitable for application in the Ontario context and helped to shed light on elements that can increase opportunities for positive change. However, more contributions to knowledge about directing system change are needed to test and hone the criteria in that category.

While the document research provided sufficient knowledge to understand the main contextual considerations, the interviews provided more nuanced insights. For instance, while cost-effectiveness and affordability issues are agreed upon as key challenges for the Ontario context, the interviewees have different perceptions about the electrical energy system-related implications of overcoming such challenges. In this sense, complexity thinking provides a lens to consider a broad suite of possible interacting effects among the criteria, and to consider diverging and conflicting views. The framework, however, needs to facilitate attention to more specific initiatives and promising alternatives that are relevant to making progress in each of the criteria categories. As suggested above, the framework needs to be enriched by more applications in different provincial jurisdictions (plans, projects and initiatives). At the same time, further application of the proposed framework will depend on the compatibility of the framework to other context-specification and application efforts.

6.5.3. Implications for Ontario

Ontario's electricity sector has made some progress towards attaining sustainability-related goals in the past decades (e.g., closure of coal-fired power plants, advancements in conservation and demand response programs and technology). However, the documents and field research suggest that the province has significant challenges to overcome. Ontario's electrical energy system has not yet been designed to be compatible with emerging options in the global context (e.g., storage options and further adoption of renewables). Also, as suggested by official projections, climate change and social-ecological integrity will be key considerations for future electrical energy systems. At present, there is limited provincial government interest in climate change effects and in establishing clear targets and actions needed to attain them. This has been partly attributed to the prioritization of short-term political and economic interests over coherent long-term objectives. Better alignment of provincial initiatives with federal and global commitments, and with municipal and community efforts would help. Also useful would be the application of more effective planning tools – for instance, backcasting and scenario planning approaches have been deemed more adequate for long-term planning than conventional approaches of accommodating to predictions of future demand based on current trends. Another consideration is that Ontario's electricity sector needs a strengthened capacity to deliver equity in livelihood opportunity for the vulnerable and the most affected by the effects of electrical energy system operations and ongoing environmental changes. For example, electricity projects need to be designed to deliver broader positive effects to First Nations and communities – e.g., ensuring that consultation obligations are respected, creating long-lasting jobs, and protecting land and socially valuable sites. An encompassing challenge is that recent provincial decisions have favoured the continuation of conventional models of electricity generation and management. In this regard, some interviewees stressed that Ontario is not currently managed to be on a transitioning energy path, and that the province is not likely to see major advancements in the near future if continuing with current trends.

The process of application of the generic framework, evaluation and development of a context-specific sustainability-based assessment framework carried out in this chapter will serve as a guide for Chapter 7. The next chapter focuses on Costa Rica's electrical energy system as a case study, and it also aims to provide contributions relevant to answering the research question on this dissertation.

CHAPTER 7. Case study – Costa Rica

In this chapter, Costa Rica's electrical energy system is examined as the second case study of this thesis. As in the first case study, the chapter aims to inform possible answers for the research question – how well are electrical energy systems designed to support pathways towards sustainability in a complex world? Following the same structure as in the Ontario case, this chapter aims to: 1) apply the generic criteria specified for overall electrical energy systems (developed in Chapters 3 and 4) to the Costa Rica case; 2) elaborate an initial evaluation of Costa Rica's electrical energy system and associated decision making in recent years by applying the overall framework specified to electrical energy systems; 3) use the findings from the initial evaluation to identify more particular elements specified for application in Costa Rica; and 4) develop a framework specified for the Costa Rica electrical energy system and its context for future applications to electrical energy system efforts.

The first section of this chapter provides the background and context of Costa Rica's electrical energy system, including Costa Rica's general and electrical energy system characteristics, the current institutional structure, and recent history of electrical energy system planning. The second section focuses on specifying the sustainability-based assessment framework for electrical energy systems for application to Costa Rica. The third section of the chapter introduces the proposed sustainability-based assessment framework specified for application to Costa Rica's electrical energy system. The section also provides three trade-off considerations for possible interacting effects among the criteria that need particular attention. The final section presents the conclusions for the case study relevant for the theory, the framework, and implications for Costa Rica.

7.1. Background and context: Costa Rica's electrical energy system

There are relevant background and contextual characteristics that influence, and are influenced by, the Costa Rican electrical energy system. First, this section provides general information about biophysical and economic characteristics. Costa Rica's geographical context is rich in biodiversity and natural resources that support different economic sectors. Second, this section introduces key electrical energy system characteristics relevant to consider for context specification. Notably, the Costa Rican electrical energy system is almost entirely powered by renewable energies and provides broad electricity access. Particularly, the geographical context is favourable for hydroelectricity generation, which is predominant in the national electricity mix. Third, eight key institutions and other characteristics in the Costa Rican electrical energy system institutional structure are presented. Finally, this section includes the recent history of electrical energy system planning in Costa Rica, exploring relevant events since the 1990s that have shaped current system characteristics.

7.1.1. Costa Rica's general characteristics

Costa Rica is a country located in the region of Central America, bordering Nicaragua, Panama, the Caribbean Sea, and the Pacific Ocean (Figure 7.1). The country covers a surface of more than

51,000 square kilometers (MINAE, 2020a), which is divided into seven provinces inhabited by more than 5 million people (INEC, 2021). Natural ecosystem areas cover more than 50% of the national territory, and more than 27% of such areas is protected (MINAE et al., 2018). In addition, there are approximately 120 thousand species of flora and fauna, accounting for 6.5% of the planetary biodiversity (MINAE et al., 2018). Costa Rica also has vast water resources – there are 34 river basins that provide water for the most relevant sectors in the country (e.g., agriculture, electricity, industry, tourism) (Reyes & Tabora, 2016). In 2020, Costa Rica recorded a GDP of more than US$61 billion (Grupo Banco Mundial, 2021), with manufacturing, tourism industry and services, agriculture, forestry, and fishing as main economic activities (INEC, 2021).

Figure 7.1. National map of Costa Rica with provincial divisions (Geology.com, 2021).

7.1.2. Electrical energy system characteristics

Costa Rica has relevant potential for renewable energy such as hydro, wind, geothermal, solar and biomass (Government of Costa Rica, 2018). Accordingly, the Costa Rican electrical energy system stands out for being renewable-based – renewable-based generation has surpassed 98% in the electricity mix since 2015 (ICE, 2020). Particularly, the country's high precipitation levels and abundant river systems are favourable for hydroelectricity generation (Gutiérrez & Villalobos, 2020; Rojas, 2016). In terms of installed capacity, hydro power accounts for 65.9% of the national share, followed by coal and/or natural gas with 13.4%, wind with 11.1%, and geothermal with 7.4% (Figure 7.2).

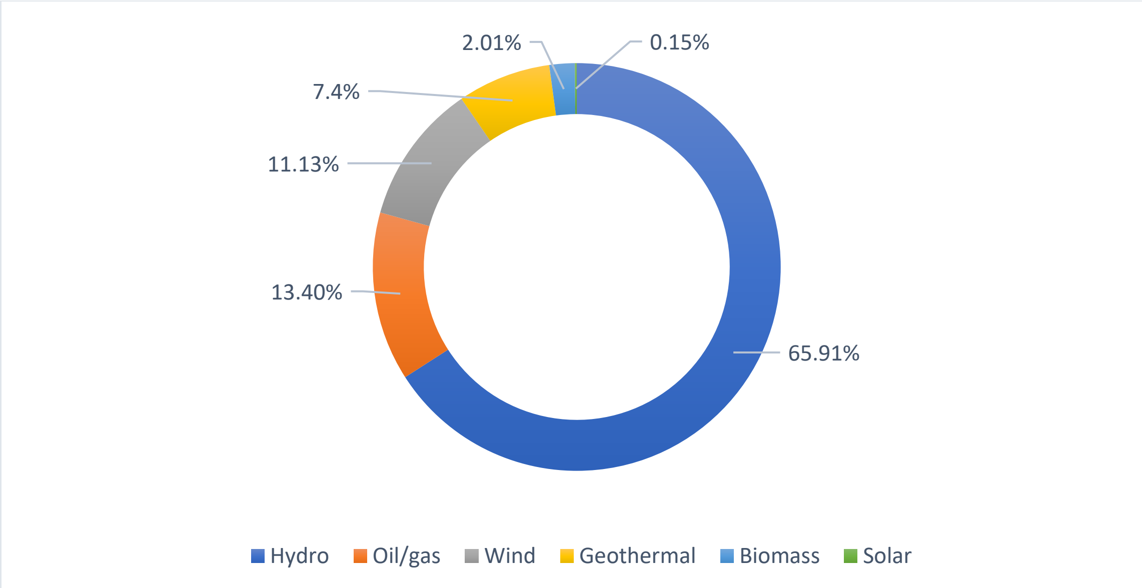


Figure 7.2. Percentage of installed capacity of the national electrical energy system, based on CENCE (2021)

In 2020, hydroelectricity accounted for 71.9% of Costa Rica's total electricity generation, followed by geothermal with 15.8% and wind with 12.6%, and only 0.8% by fossil fuels (see Figure 7.3). Another notable characteristic is that Costa Rica's electrical energy system provides electricity access to more than 99% of the population (CENCE, 2021). In sum, there are 444 generation units in the country, 40 of them owned by the Costa Rican Institute of Electricity (ICE), which is the main electricity producer (Grupo ICE, 2020). In 2020, Costa Rica's electrical energy system covered a demand of roughly 11,500 GWh of electricity. Notably, this represented a decrease of 2.77% in relation to the electricity demand in 2019 of 11,000 GWh, being the first year with decreasing electricity demand since 2009 (CENCE, 2021). According to some reports, the decrease was a result of tourism, transportation, industry, and some other socioeconomic sectors reducing their activities as well as changes in social habits due to the COVID-19 pandemic (Sánchez Úbeda et al., 2021; Sandí Meza & Recinos Carvajal, 2022). In terms of market participation, the Costa Rican electricity market can be described as a monopsony. That is, while the electricity market is open for some private participation (CRIE, 2020), the ICE is the only buyer of the electricity generated nationwide.

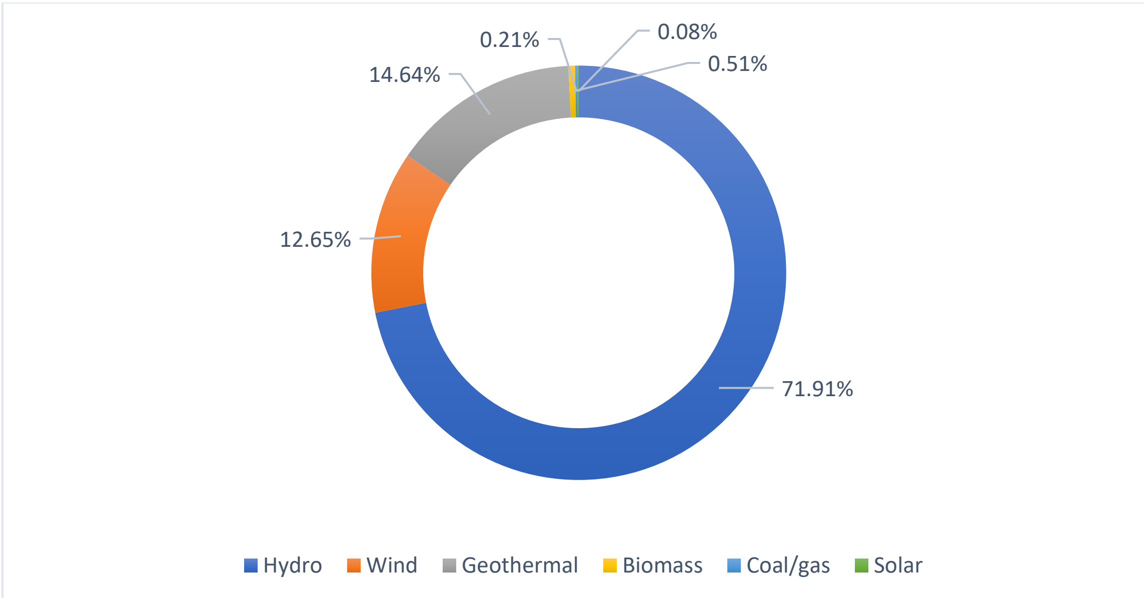


Figure 7.3. Net electricity generation by source in 2020, based on CENCE (2021)

7.1.3. Current structure

Costa Rica's electrical energy system is mainly integrated by eight key distribution companies. Each company has an assigned concession area, with the ICE covering the majority of the national territory's electricity demand (ARESEP, 2019). Figure 7.4 illustrates the concession areas assigned to each distribution company and the electricity access percentage in the assigned areas.

Figure 7.4. Electricity access percentage by distribution company, July 2017 (based on ARESEP, 2018)

Distribution company	Area (square kilometers)	Coverage percentage (%)
ICE	38,715	98.09
CNFL	885	100
ESPH	104	100
JASEC	1103	100
COOPEGUANACASTE	3915	99.63
COOPELESCA	4851	99.63
COOPESANTOS	1275	99.70
COOPEALFARO	252	100
COSTA RICA	51100	99.39

Table 7.1 shows the eight key distribution companies, including the regions they cover and their role. The ICE is considered the main actor, overseeing most of the national generation, transmission and distribution, system operations, and project planning. The CNFL (a subcomponent of the ICE) manages national operations, being the largest distribution company in the country (Ballestero & López, 2017). In addition, there are two main municipal distribution companies. First, the ESPH is a public utility company that oversees the provision of electricity, water, sewage and telecommunications in the region of Heredia (ESPH, 2020). And second, the JASEC, also a public utility, is oriented to provide electricity services in the province of Cartago (Espinoza, 2017). The last four key participants are co-operatives for rural electrification in the areas of Guanacaste, San Carlos and the Northern region, San José and Cartago, and the Zarcero canton (CONELECTRICAS, 2021). These are non-profit entities that provide electricity services to its associates, who are also owners. The co-operatives were established in 1964 as a response to lack of electricity access in rural areas and are now recognized as relevant participants in the system (CONELECTRICAS, 2021). Finally, private actors are restricted by law to small- and medium-scale generation and can only sell the electricity to the ICE (Asamblea Legislativa, 1995).

Table 7.1. Eight key distribution companies in Costa Rica

Institution	Region	Role
Instituto Costarricense de Electricidad (ICE)	National	Oversees national generation, transmisión, and distribution
Compañía Nacional de Fuerza y Luz (CNFL)	National	Distribution
Empresa de Servicios Públicos de Heredia (ESPH)	Heredia	Distribution
Junta Administrativa del Servicio Eléctrico de Cartago (JASEC)	Cartago	Distribution
Cooperativa de Electrificación Rural de San Carlos, R.L. (COOPELESCA)	San Carlos, Sarapiqui, Grecia, Alajuela, Los Chiles, and San Ramón cantons	Rural electrification cooperative
Cooperativa de Electrificación Rural Los Santos, R.L. (COOPESANTOS)	Acosta, Aserrí, Cartago, Desamparados, Dota, El Guarco, León Cortés, Mora, and Tarrazú cantons	Rural electrification cooperative
Cooperativa de Electrificación Rural de Guanacaste, R.L. (COOPEGUANACASTE)	Nicoya Peninsula	Rural electrification cooperative
Cooperativa de Electricación Rural de Alfaro Ruiz, R.L. (COOPEALFARO)	Zarcero canton	Rural electrification cooperative

The key institutions are interconnected through the operations and infrastructure of the National Energy Control Centre (CENCE) (Rojas, 2016). This institution (also a subcomponent of the ICE) oversees management and planning operations, as well as electricity transactions (Rojas, 2016). The Regulatory Authority of Public Services is responsible of addressing consumer and producer needs, including electricity prices, in accordance with national electrical energy system goals (ARESEP, 2021). The Ministry of Environment and Energy oversees policy design for the electrical energy system and the development of the National Energy Plan (Ministerio de Hacienda, 2018)

The Costa Rican electrical energy system is part of a multi-national transmission grid known as the Central American Electrical Interconnection System (SIEPAC). The SIEPAC connects the electricity grids of six countries – Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, and Panama (CRIE, 2019). This project consists of two main components: 1) the creation of a Regional Electricity Market (MER), and 2) the construction of the first interconnected Central American transmission system (Echevarría & Monge, 2017). The MER is a regional electricity market where the countries connected to the SIEPAC can make international electricity transactions (CRIE, 2019). The SIEPAC's transmission system connects the electricity grid of the six Central American countries through a 230 kV transmission line of 1793 km of length (Echevarría & Monge, 2017). The SIEPAC's installed capacity has been upgraded over the years – from approximately 11756 MW in 2011 to 18373 MW in 2019, with an average annual increase of 5.6% – and it is expected to continue increasing (CEPAL, 2020).

7.1.4. Recent history of electrical energy system planning

Costa Rica's electrical energy system has a rich history that can be traced back to 1884 (Obregón, 2014). The key institutions of today's electrical energy system mentioned above were all created between 1941 and 1969 (Obregón, 2014). However, this thesis focuses on a more recent history that includes a very active period of electricity-related legislation, reform proposals, and social mobilizations that gained traction during the 1990s. These elements have had a direct influence on the Costa Rican electrical energy system of today.

The ICE combo

Before 1990, Costa Rica's electrical energy system had no restrictions for the participation of private actors in the electricity market, and the ICE generated 90% of the national electricity mix (Chávez & Cortéz, 2013). However, this changed in September of 1990, during the first presidential term of Oscar Arias, from the National Liberation Party. The Arias presidency attained the approval of Law 7200 – Law for the Authorization of Autonomous or Parallel Electricity Generation (SCIJ, 1990). This law allowed the participation of private hydroelectricity projects with a generation capacity of up to 20 megawatts (SCIJ, 1990). Also, private generation contracts were limited to 15 years, and the share of private generation in the national electricity mix could not exceed 15% (SCIJ, 1990). However, political disputes and social mobilizations against the liberalization of the electricity market halted many of the Law 7200's proposed initiatives, including those above (Rovira Mas, 2001). Community leaders and environmentalists were concerned about the effects of deregulating natural areas and rivers for unrestricted exploitation (Gutierréz & Villalobos, 2020). Also, ICE workers showed concerns about the implications of private participation on the distribution of local benefits (Hoffman, 2008).

In 1994, with José María Figueres Olsen (also from the National Liberation Party) as president elect, the Costa Rican government continued to pursue the electricity market privatization. For example, the Law 7508 was submitted to the legislative assembly in 1995 as a reform to increase private participation in relation to Law 7200 – to a maximum of 30% private generation, 50 megawatts of installed capacity and 20-year contracts (Asamblea Legislativa, 1995). In 1996, the Figueres government elaborated the initiative popularly known as the *combo*, consisting of three main proposals: 1) a new law for dividing the electricity and telecommunications sectors, with the ICE now focusing exclusively on electricity-related operations; 2) a new general electricity law; and 3) a new law for telecommunications (Cartagena, 2010).

In 1998, president Miguel Ángel Rodríguez Echeverría, from the Christian Social Unity Party, was elected, and the following year representatives in congress agreed to accelerate the approval of the *combo* (Cartagena, 2010). The *combo* had approval in an initial debate by the national legislative assembly in March of 2000, spurring mobilizations from different social groups in opposition (Gangas & Retana, 2006; Menjívar, 2004). The opposition was based mostly on distributional arguments, claiming that the benefits were mostly for powerful actors, and that serious risks were posed to ecosystems and communities that relied on them for livelihood (Bull, 2005). Ultimately, the Costa Rican government decided to withdraw the project, since the protests and other mobilizations persisted (Carazo, 2001).

Social mobilizations for justice, the protection of rivers and Indigenous territories

The experience with the *combo* law helped to solidify cooperation among diverse social groups against procedural, distributional and recognition injustices from electrical energy system operations. In 2001, the Costa Rican Federation for the Conservation of the Environment (FECON) organized the first National Forum on Hydroelectric Dams and Communities, gathering community representatives from different parts of the country to share knowledge on experiences with injustice issues (Gutiérrez & Villalobos, 2020). This, coupled with a second forum carried out in 2003, led to a larger network in defence of rivers threatened by hydroelectric projects (Gutiérrez & Villalobos, 2020).

In 2006, Oscar Arias was elected for a second non-consecutive term in the presidency, and efforts to reform the electrical energy system resurfaced with the approval of the Central American Free Trade Agreement (CAFTA) in 2007 (García-Sánchez, 2012). In the same period, the government released the Peace with Nature initiative, presenting as overall aims attaining carbon neutrality by 2021, replenishing natural areas and diversifying the electricity mix (Ministerio de Relaciones Exteriores y Culto, 2008).

In 2010, Laura Chinchilla, from the National Liberation Party, was elected president of Costa Rica and proposed the new bill Expediente No. 17812 to support efforts for an open electricity market (Asamblea Legislativa de la República de Costa Rica, 2010). Later, in 2012, the Pérez Zeledón and Buenos Aires cantons became the zones of highest tension between proponents of hydropower projects and communities seeking to protect the rivers (Arias, 2017). Some experts reported that the tensions arose when a “swarm of fourteen hydroelectric projects” collided with the “solid opposition of the local forces” (Gutiérrez & Villalobos, 2020, p. 145). Ultimately, the fourteen projects were stopped due to the effective collaboration between diverse community groups with the support of civil society organizations (Gutiérrez & Villalobos, 2020). According to Gutiérrez and Villalobos (2020), 35 projects around the country have been stopped by public opposition.

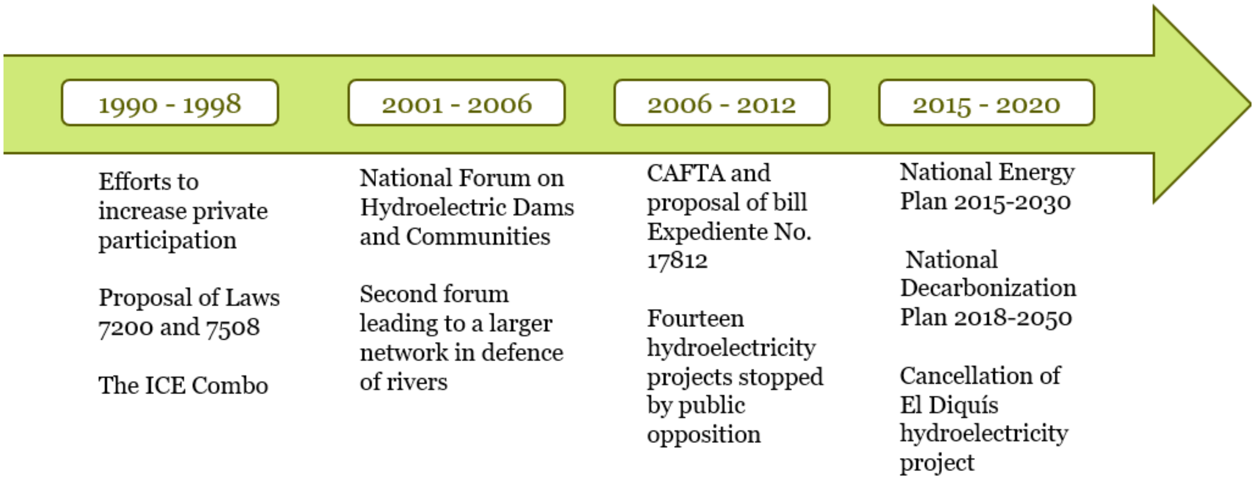
The National Energy Plan 2015-2030 and the National Decarbonization Plan 2018-2050
In 2015, with Luis Guillermo Solís (from the Citizen Action Party) as president, Costa Rica's government released the National Energy Plan 2015-2030. This plan placed less emphasis on increasing the number of hydropower projects and focused more strongly on enhancing the electrical energy system and transportation sector's efficiency (e.g., Zárate & Ramírez, 2016). The plan recognized failures by the national government to respect Indigenous territories, environmental considerations and to pursue community engagement during the projects' development stages (MINAE, 2015). However, the plan did not offer concrete solutions for the acknowledged decades of rising conflict. While community leaders were invited to dialogue sessions, some pointed out that their opinions were not considered, and that hydropower development was still prioritized (Comisión en Defensa de los Ríos Convento y Sonador, 2016). In the same year, Costa Rica generated 100% of its electricity from renewable sources for most of the year (Rojas, 2016), but local communities continued to deal with the largely negative local impacts of electrical energy system operations (Gutiérrez, 2020).

During Carlos Alvarado Quesada's (from the Citizen Action Party) presidency, in 2018, the president of the ICE announced the cancellation of the hydroelectricity project El Diquís, after a long period of conflict and deliberations (Chacón, 2018). The project, expected to be the largest in Latin America, had been officially declared by the federal government as a matter of national interest (SCIJ, 2008). However, the project was not yet approved since Costa Rican authorities were required by a UN representative in 2011 to implement adequate consultation, and address broader tensions, with Indigenous communities (Anaya, 2011). Ultimately, on November of 2018, the president of the ICE announced the cancellation of the project and the loss of USD$174 millions in investment (Chacón, 2018).

In 2019, the Government of Costa Rica released the National Decarbonization Plan (NDP) 2018-2050 (Gobierno de Costa Rica, 2019). The plan adopted the concepts of transformational change, as opposed to incremental change, and a backcasting approach to define short-, mid-, and long-term goals (Gobierno de Costa Rica, 2019). However, while the plan attracted some positive comments (2050 Pathways Platform, 2019), it also received criticism. Gutiérrez (2020) described the plan as an "imaginarium" where Costa Rica is a leader in environmental preservation and sustainability, while oil is predominant in the overall energy system. The plan also received some critiques for being unclear, unrealistic, incomplete, inconsistent, technocratic, unfair, and marginalising (e.g., Álvarez et al., 2019; Marín, 2019; Mora, 2019).

Figure 7.5 shows a timeline for the recent history of Costa Rica's electrical energy systems, including key events discussed above.

Figure 7.5. Timeline for Costa Rica's recent electrical energy system history



Summary of key system and system change characteristics

- Costa Rica has focused on using the vast hydrological resources provided by the geographical context to attain a renewable-based electrical energy system that also delivers broad access to the population.
- The national electrical energy system is connected to the Central American Electrical Interconnection System, a larger-scale transmission grid that connects the electricity grids of six countries in Central America. The related electricity transactions are done through the Regional Electricity Market.
- Community mobilization has played a key role in raising public awareness of the human and environmental consequences of large hydroelectricity projects, and in spurring cancellation of proposed projects that have posed threats to protected areas and culturally valued components.
- The Costa Rican electricity market has been described as a monopsony – there is limited private participation and the ICE is the only buyer of electricity from private generation. However, elected governments have made consistent efforts to open the market for more private actors' participation in the electricity market.

7.2. Specifying the framework

This section follows the same method used in Chapter 6 for specifying the sustainability-based assessment framework to Costa Rica's context. That is: the initial set of sustainability assessment criteria specified for applications to electrical energy systems, proposed in Chapters 3 and 4, is used in this section as a lens to examine Costa Rica's most salient issues. The specification of the sustainability-based assessment framework for Costa Rica's context is based on the literature review and document research and is complemented with insights gathered in the interviewing process. For these purposes, this section focuses on 1) using the initial framework to do an initial assessment of the Costa Rican electrical energy system and associated planning in recent years, and 2) identifying key contextual elements to further specify the framework for future evaluations of the Costa Rican electrical energy system and related efforts.

7.2.1. Climate safety and social-ecological integrity

Costa Rica has been recognized by global energy authorities for having a renewable-based electrical energy system (MINAE et al., 2019). However, oil-based products account for 62% of the overall energy mix, with transportation contributing more than 50% of the country's GHG emissions. Interviewees from academia and social community stressed that such reliance on oil has caused issues of volatile currency flow and oil prices, negative impacts to human health, and the disruption of ecosystems. Rapid Transition Alliance (2019) has reported that more than 60% of Costa Rica's population commutes by using oil-fueled vehicles. According to interviewees in government and academia, most responses have focused on electrifying transportation, but the implications of an increased electricity demand require more attention in future deliberations.

Adapting to and mitigating the adverse effects of climate change is a relevant consideration in national deliberations. Studies have shown that ongoing climate change effects on water and other natural systems already pose risks for essential sectors in the country (Echevarría & Monge, 2017; MINAE et al., 2019). For instance, hurricane, storm, flood, and drought periods are expected to intensify and cause disruptions in social and ecological systems (Guerrero, 2015). As a result, the reliability of water resources for hydroelectricity generation can be affected (García-Sánchez & Avendaño-Leadem, 2018; MINAE et al., 2018). While one interviewee in government considered that the electrical energy system is able to adapt to current climate change projections, other interviewees in academia and social community stressed that some effects can be unpredictable. For example, one interviewee in social community reported that in the Reventazón River different parts of the same river basin could be affected by different climate change effects, and predictive tools are not precise enough to determine the effects of each individual area.

According to interviewees in academia and social community national authorities must also favour decisions that protect natural and other essential life-support systems. For instance, studies have shown that hydropower plant operations can disrupt the flow patterns and chemical composition of rivers and living organisms that depend on the river systems (Farah-Pérez et al., 2020; Navarro-Picado et al., 2017). Interviewees in academia, government, utility companies, and social community underscored this aspect since water is a vital resource for Costa Rica's well-being – including but not limited to its role as a main resource for electricity generation. Another salient aspect reported by the MINAE (2020b) is that a significant number of monkeys, birds and other species are electrocuted or injured yearly. One interviewee in utility companies pointed out that a relevant challenge is minimizing social and environmental risks while maintaining electrical energy system infrastructure. For instance, according to the same interviewee, during heavy storms, some trees are vulnerable to fall on distribution lines and cause blackouts but removing the trees can spark public disapproval.

Different experts have reported that electrical energy system management and planning in Costa Rica has struggled to respect protected areas, environmental regulations, and human rights (Arias, 2017; Carls & Haffar, 2010; Gutiérrez & Villalobos, 2020). One interviewee in social community stressed that some hydropower projects have prioritized economic gains over maintaining valued land and community access to rivers, creating unrest in rural and Indigenous communities. For example, El Diquís hydropower project, according to Carbone (2018), threatened thousands of hectares of the Terrabá-Sierpe national wetlands. Also, the project threatened 285 archeological sites, as well as more than six hundred hectares of the Terrabá Indigenous land (Carbone, 2018). Similarly, there are different documented cases about social mobilizations against imperiling social and ecological risks raised by hydroelectricity development (Arias, 2017; Ballestero & López, 2017; Gutiérrez & Villalobos, 2020).

7.2.2. Intra- and inter-generational equity, accessibility, reliability, and affordability

The national electrical energy system notably provides electricity access to more than 99% of the population (ICE, 2019). On this subject, interviewees in academia and government considered Costa Rica's pricing model as a key factor. That is, according to one interviewee in academia, the national government provides subsidies to maintain equal electricity prices for everyone, including in remote areas where provision is usually more expensive. This is known in the country as a solidarity pricing model. However, one main challenge for promoting inter- and intra-generational equity is the management of electrical energy system risks and benefits. Community leaders have reported that hydroelectricity projects usually offer short-term benefits to the communities, but the risks often pose long-lasting adverse effects to the local and national socioecological context (Comisión Defensora de los Ríos Convento y Sonador, 2016). Another interviewee in social community reported that financial compensations offered to the communities are usually very low compared to the overall revenue for some actors. Also, interviewees in academia and social community pointed out that authorities often focus on offering financial compensation and less attention is paid to fulfilling other community interests.

In terms of affordability, the Government of Costa Rica (2018, p. 13) has identified that "one of the challenges would be in guaranteeing the electricity supply keeps competitive prices, while maintaining a renewable, efficient and reliable matrix". In 2015, for example, the MINAE (2015) reported that electricity rates had consistently showed rising trends since the early 1990s (MINAE, 2015). More recently, industry representatives have submitted to the ARESEP their official opposition to requests from the CNFL to increase the price of electricity that they generate by 19.2% in 2022 (Cámara de Industrias de Costa Rica, 2021). Additionally, the high costs and financial losses of large hydroelectricity projects in Costa Rica have been a challenge for ensuring affordability. For instance, interviewees in academia suggested that the repair costs of some hydroelectricity projects, like El Pirrís and Reventazón, have resulted in higher electricity bills. Another important consideration, according to one interviewee in utility companies is that some existing regulations can create unequal financial risks for some actors with limited resources in the electrical energy system. One example is that rural electrification cooperatives are obligated to pay additional fees if they surpass the generation costs limit established by the ICE (SCIJ, 2019).

Interviewees in government and utility companies pointed out an existing concern about the short-term costs of having a renewable electrical energy system that also ensures broad accessibility. Van Riet and colleagues (2020), however, have identified scenarios where attaining fully renewable-based electrical energy systems can reduce electricity generation costs. Another interviewee in social community suggested that investing in renewable energy can help to avoid some long-term social, environmental, and economic risks and costs. For instance, the interviewee added that while investing in oil may be cheaper initially for Costa Rica, it can also create long-term risks with more severe effects – e.g., losing energy sovereignty, and vulnerability to oil price fluctuations. At the same time, switching to oil would conflict with Costa Rica's climate change mitigation, adaptation, and capacity-building commitments including to become carbon neutral (Dobles, n.d.).

7.2.3. Cost-effectiveness, resource efficiency and conservation

In 2015, the Plan Nacional de Energía recognized resource efficiency and conservation as the main objectives to ensure accessibility, reliability, affordability, and competitiveness (MINAE, 2015). However, Costa Rica has experienced difficulties to minimize electrical energy system costs. One well-documented example is the high projected costs and financial losses in the El Diquís hydropower plant project. In 2011, the initially estimated cost was more than USD$ 2.1 billion (Arroyo et al., 2012). By the end of 2015, the ICE (2017) reported more than USD$ 3.6 billion in projected investment costs. Moreover, when El Diquís project was closed in 2018, the president of the ICE announced that USD$174 million in investments were lost (Chacón, 2018). Furthermore, the ICE declared by the end of the same year the loss of ₡252,000,000,000 (approximately USD$411 million), largely attributed to the failure of the El Diquís project (Valverde, 2019). Interviewees in government and utility companies agreed that financial losses, coupled with the ongoing impacts of the COVID-19 pandemic, may position cost-effectiveness as one of the most relevant themes for the future electrical energy system.

The National Energy Plan 2015-2030 acknowledged that there have been difficulties to effectively implement official efficiency strategies and to include key actors in policy development (MINAE, 2015). Some relevant initial efforts were in 1994, with the creation of the National Commission on Energy Efficiency (CONACE) (MINAE, 2015) and the National Plan of Energy Conservation, and the approval of the Law 7447 on the Regulation of the Rational Use of Energy (Asamblea Legislativa, 1994). However, according to Chanto (2011), the application strategies for the actions established in the plan were mostly unsuccessful.

According to interviewees in academia and utility companies, technologies that promote energy efficiency and cost reductions can play a greater role in covering the national electricity needs. For instance, some authors have pointed out that Costa Rica has great potential for solar energy that has not been fully developed (Avendaño-Leadem & García-Sánchez, 2019; Guzmán-

Hernández et al., 2016). In this regard, one interviewee in academia remarked that Costa Rica has the infrastructure and management experience to integrate new system components. However, another interviewee in academia stressed that a key challenge will be to facilitate "the incorporation of the new global trends in technology and innovation that could help the electrical energy system to increase efficiency and reduce costs". Interviewees in academia, utility companies, social community, and government recognized that this requires shifting to new market models and investment opportunities that better accommodate distributed generation, energy storage, and demand response options. Alternatively, one interviewee in utility companies identified a lack of interest in some demonstrably successful efficiency and conservation strategies (e.g., fostering a culture of conservation and promoting more studies on viability and compatibility of new technologies), and options that focus on generation have been prioritized.

7.2.4. Democratic and participatory governance

Planning and decision-making in large hydroelectricity projects has been a significant challenge for democratic and participatory governance. For instance, Rojas (2016) has remarked that Costa Rica needs electricity planning approaches that are more suitable to attain long-term objectives and participation. Some authors have documented governance issues in different cases like the Boruca (Carls & Haffar, 2010), El Diquís (Pérez, 2011) and San Rafael (Arias, 2017) hydroelectricity projects. Generally, hydroelectricity governance problems have included lack of transparency, streamlining, violations to Indigenous and human rights, disruption of protected areas, insufficient consultation, and failure to foster participation (e.g., Cambronero & Fernández, 2017; Gutiérrez & Villalobos, 2020). Interviewees in academia and government suggested that such problems should decrease with recent national decisions to halt large hydroelectricity development. However, other interviewees in social community and academia pointed out that the past paradigm of avoiding consultation obligations also creates concerns about the governance of new electrical energy system components.

Improving consultation processes in electrical energy system projects is a consideration that requires particular attention. The Costa Rican government has recognized the importance of consultation with key actors, including communities, for preserving social and environmental well-being (Banco Interamericano de Desarrollo, 2020). One interviewee in social community stressed in this regard that consultation processes in Costa Rica are challenging because there are many different people, with many different worldviews, values, and interests, that need to be represented. The same participant suggested that Costa Rica should develop consultation processes that focus on demonstrating to the communities the advantages and impacts of electrical energy system projects and fostering collective solutions.

Another challenge is facilitating collaboration and participation from different key actors for the improvement of official processes for social acceptance and project approval. Gutiérrez and Villalobos (2020), for instance, have identified that community mobilization, rather than governmental action, has incentivized public and private actors to include local interests. In the same vein, one interviewee in social community emphasized that communities have promoted the advancement of "real processes for dialogue and representation", instead of processes that do not include community interests and suggestions in final decisions. Interviewees in academia and social community also suggested that the lack of effective reconciliation of misaligned goals between different relevant actors has contributed to delays in project development timelines, inappropriate consultation to prioritize short-term interests, and in some cases increases in initial anticipated costs of proposed projects. Broadly, interviewees in academia, social community, utility companies, and government identified the need to shift from current models of centralized electrical energy system management, with great power and influence granted to a few actors, towards new models of more participatory decision-making.

Development and integration of knowledge also play an important role in better governing future electrical energy systems. For instance, the advancement and transparency of water systems information is essential since, as pointed out by one interviewee in academia, there are rising social concerns about the uncertain climate change-related effects on resource access and distribution. One important step, according to one interviewee in social community, is the decentralization of electricity information and technical knowledge to facilitate community-based electricity projects and citizen participation in the grid. For instance, one interviewee in academia pointed out that more attention is now being paid to the emergence of prosumers with the advancement of smart grid technologies.

7.2.5. Precaution, modularity, and resiliency

Precaution in decision-making is necessary to deal with the uncertain long-term effects of current global crises. Namely, the socioeconomic effects of the COVID-19 pandemic can undermine the capacity of national sectors to meet climate goals and to support social and ecological well-being (DCC, 2020). For example, one interviewee in government noted that efforts to decarbonize the transportation sector have been delayed because of the ongoing effects of COVID-19 on the economy. In this regard, another interviewee in academia remarked that advancing electric vehicles will require a stronger capacity to respond to demand needs, exploring more favourable market models, and investing in technology and infrastructure.

Increasing resiliency and minimizing vulnerability are essential considering the limited capacity to predict adverse climate change effects and changes in electricity demand trends. For instance, the Costa Rican and the Central American electrical energy systems have been vulnerable to severe meteorological events, resulting in damaged infrastructure, system failure, and blackouts (e.g., SICA, 2017; Teletica, 2020). In addition, interviewees in academia, social community, and government stressed that more alternatives for electricity generation and back up options are being explored since the reliability of some renewable energy options (e.g., solar, wind and hydro) is being affected by climate change effects. Notably, interviewees in academia and social community emphasized that there has been a growing interest in geothermal energy because it can be a more stable option. Other alternative sources that are gaining more attention include biomass (e.g., Ulloa et al., 2018) and offshore wind (ICE, 2021). Another key consideration pointed out by interviewees in academia, utility companies, and government is that recent electricity demand has not been as high as predicted, resulting in unanticipated social and economic impacts (e.g., Chacón, 2018). On this subject, interviewees in academia, government, and social community emphasized that crucial responses include incorporating demand response options (e.g., smart grid tools) more broadly to improve the monitoring of seasonal and daily demand fluctuations.

The National Decarbonization Plan 2018-2050 established as a main goal the "consolidation of the national electrical energy system with capacity, flexibility, intelligence and resilience, necessary to supply and manage renewable energy at a competitive cost" (Gobierno de Costa Rica, 2018, p. 60). To this end, smart grid tools, energy storage, and demand response have been identified as viable options (Echeverría & Monge, 2017; Espinosa, 2020; Valverde et al., 2017). Some recent progress includes efforts by the ICE and CNFL to universalize the installation of smart meters in their concession areas (Grupo ICE, 2021). These efforts aim to increase the system capacity to collect electricity flow data for strengthening capacity for demand response and modularity – e.g., implementing prepaid electricity services, enhancing the ability to locate faults, and monitoring voltage quality to match end-user needs (ICE, 2021). According to one interviewee in government, other recent efforts include the in-progress CENCE's Demand Management and Virtual Plants project, which aims to help in developing the regulations and policy necessary to effectively incorporate prosumers, demand management, distributed generation, and smart grid technologies by 2023.

Energy storage has also been recognized as a viable technological option that can provide multiple benefits for the future of the electrical energy system (Murillo, 2020; Umaña, 2017). According to interviewees in academia, utility companies, government, and social community, energy storage can facilitate the integration of electricity generated by different sources and help to decrease path dependency on hydroelectricity. One interviewee in utility companies pointed out that electrical energy system authorities have paid attention to Australia, Germany, California, and other areas in the United States, as relevant examples for promoting storage and smart technology deployment. One challenge acknowledged by some relevant actors is that electrical energy system infrastructure and regulations need to be modified to be compatible with new system design options – including energy storage, a more open market, distributed generation, etc. (Canales, 2021).

7.2.6. Transformation, integration of multiple positive effects, and minimization of adverse effects

As discussed in the theoretical foundations chapters, electrical energy system managers need to increase the capacity to promote multiple and mutually reinforcing sustainability-oriented initiatives. Interviewees in academia and government highlighted that Costa Rica is experiencing the pressures from global energy transitions towards more decentralized and participatory management, as well as more distributed generation, electrification of vehicles, prosumers, and higher capacity for smart grids and energy storage. According to interviewees in academia and social community, electricity companies and authorities therefore need to adapt to and find opportunities from such transitions while contributing positive effects to social and ecological sustainability. Another key consideration is the probable increased participation of private actors in the electricity market. In this regard, interviewees in social community emphasized that private electricity projects need to be aligned with Costa Rica's sustainability-related goals. One key issue to address, according to one interviewee in government, is the lack of a general law or independent planning entity in Costa Rica that provides guidelines for aligning electrical energy system operations towards common goals.

As discussed in Chapter 4, implementing governance for sustainability-based design options can induce the accumulation of positive effects in electrical energy system transitions. One essential aspect, according to interviewees in social community, is improving the capacity for collaboration and knowledge co-production with communities and key actors. One interviewee in social community added that promoting the participation of local communities must be supported by "the public policy required to facilitate and stimulate such participation". Also, one interviewee in utility companies added that private actors' increased role in the system must be directed by market policies to ensure that private projects contribute positively with resources that are usually unattainable by State-owned companies. Specifying possible policy pathways that can lead to attaining desirable electrical energy system futures is another key consideration. For instance, one interviewee in academia suggested that planning can be improved by implementing tools to break path dependency and negative trends – e.g., prospective visioning, backcasting, and scenario planning.

Electrical energy system transitions must be directed to maintain valuable characteristics and avoid the creation of unfair burdens to the most vulnerable. One interviewee in social community suggested that authorities and key actors must focus on alleviating the overall context of tension that exists between national authorities and communities. Moreover, any adoption of more open market models must avoid increasing negative social and environmental effects. Some interviewees in social community reported that there are community concerns about authorities allowing private projects to prioritize economic interests over local needs. New market policies must also include the needs of rural cooperatives and other key actors that provide essential services with limited resources. One interviewee in utility companies, for example, emphasized that rural cooperatives are often overlooked in decision making and are affected by financial burdens imposed under some current regulations. Additionally, there are potential adverse effects from an increased electricity demand to electrify transportation. Some interviewees in social community emphasized that some effects could include increasing fossil fuels use and restarting large hydroelectricity development and consequent social and environmental issues.

Deliberations for transitioning electrical energy systems must be informed by the integration of diverse knowledge and a diversity of approaches to system change. In this sense, interviewees in social community pointed out that Indigenous groups' contributions are seldom included in national electrical energy system planning. Also, contributions from different streams of knowledge and interdisciplinary work are crucial to tackle the already unavoidable adverse effects of climate change. One interviewee in social community identified a recent lack of governmental interest in monitoring the rivers and understanding social and environmental patterns (e.g., hydrological, geological, biological, and social considerations of river areas). In this regard, knowledge and broad access to official data is key for governing water systems and addressing vulnerabilities of the electrical energy system to climate change effects (Rodriguez & Sáez, 2020). Moreover, it is necessary to advance knowledge on the social, ecologic, and economic impacts of, as well as public acceptance strategies for, smart grid, energy storage, and demand response alternatives. On this matter, one interviewee in academia remarked that multi-disciplinary studies, simulation analyses, and isolated projects are essential to test the impacts and promote the broad acceptance of micro grids and smart grids.

7.3. Sustainability-based assessment framework specified to Costa Rica's electrical energy system

Table 7.2 presents the sustainability-based assessment framework specified to the Costa Rica context. The framework specified for application in Costa Rica has been developed as a tool for application in future evaluations of national electrical energy system decision making and planning. At the same time, applying the framework is expected to contribute key insights to answer the main research question for this thesis work.

For the elaboration of this framework, the main criteria proposed in the initial framework for sustainability-based assessment specified to electrical energy systems (elaborated in chapters 3 and 4) guided the data collection process to reveal the issues specific to Costa Rica. That is, the understanding of main global issues, debates, goals, and design options relevant to transitioning and transforming electrical energy systems towards sustainability (see chapters 3 and 4) provided a lens to identify and understand the main sustainability-related aspects specific to Costa Rica. These main aspects were then classified into six main criteria categories, with sets of sub-criteria, that incorporate the identified globally relevant and case-specific sustainability considerations for electrical energy systems.

Table 7.2. Proposed sustainability-based assessment framework specified for application to Costa Rica's electrical energy system

Climate safety and social-ecological integrity

- Minimizing the overall energy mix contributions to GHG emissions to the atmosphere, and other substances that aggravate climate change and associated social, ecological, and economic adverse effects.
    - Avoiding reliance on fossil fuels to cover the potentially increased electricity demand from electrifying transportation and to decarbonize other sectors.
    - Maximizing the share of viable renewable energy alternatives in the overall electricity mix – e.g., wind, offshore wind, solar, geothermal, etc.

- Advancing the adoption of smart meters, energy storage, and other demand reduction options that are promising to reduce harmful emissions.

- Adapting to and mitigating climate change associated effects to the electrical energy system and broader socioecological systems – e.g., intensified periods of hurricanes, storms, floods, and droughts.
    - Promoting distributed generation, efficiency and demand reduction options that can reduce the heavy reliance on water resources.
    - Supporting studies and monitoring to collect key knowledge on rivers, water systems and other life-support systems, and possible climate change effects (e.g., hydrological, geological, biological, and social considerations).
- Minimizing negative impacts from the operations and life cycle processes of the electrical energy system on the broader socioecological context.
- Protecting natural systems and valued system components for social and ecological well-being, and that contribute to lasting socio-economic benefits.
    - Respecting protected areas, environmental regulations, and human rights, and avoiding decision-making and planning that prioritize economic gains over valued land and community access to water, fisheries, and other essential resources for community livelihood and sufficiency.
    - Maintaining safe quality of river and other life-support systems' composition and functions that are essential to living organisms and key components in the biophysical context.
    - Favouring policy, design options, and technologies that reduce electricity infrastructure threats to flora and fauna species (e.g., electrocution by power lines).

Intra- and inter-generational equity, accessibility, reliability, and affordability

- Ensuring a fair distribution of inter- and intra-generational risks and benefits stemming from electrical energy system-related projects
    - Promoting a fair distribution of financial benefits from and fulfilling intergenerational livelihood and cultural interests of communities directly affected by the operations of the electrical energy system.
    - Favouring project proposals that increase direct and indirect employment opportunities that are well paid, long lasting, conveniently located and otherwise accessible, fulfilling/challenging, etc.
    - Favouring system design options that are easy to understand and operate, over others that require higher levels of specialization and technical expertise.

- Ensuring affordable prices and broad access to all citizens, communities, and major power consumers that provide essential services, while maintaining a renewable electricity mix.
    - Avoiding long- and short-term economic risks in project approval – e.g., long-term commitments to high capital and operation cost hydropower and other electricity projects.
    - Preserving a favourable policy context to maintain the national solidarity pricing model and avoiding policies that create unequal financial risks for relevant actors with less resources (e.g., rural cooperatives).
    - Supporting smart grid tools to enhance the system capacity for demand reduction strategies that can minimize costs (e.g., off-peak consumption).
    - Avoiding energy resource options that pose severe long-term risks – e.g., losing energy sovereignty, oil price fluctuations, conflict with decarbonization commitments.
    - Enhancing technical capacity for attaining alternative options reliably and at affordable costs (e.g., solar, geothermal, off-shore wind generation, energy storage).

Cost-effectiveness, resource efficiency and conservation

- Promoting cost-effective options that help minimize all costs (e.g., provision and social-ecological) and financial losses in electricity generation projects and other system operations.
    - Ensuring due process for public acceptance and project approval to reduce provision costs (e.g., construction, operation, repair, and distribution) and social-ecological costs (e.g., public disapproval and disruption of rivers and valued land).
    - Promoting new energy infrastructure and retrofitting, as well as conservation culture, to minimize electricity losses in all life cycles of existing and proposed projects.
- Building policy, market models, and technology pathways that enable the development and implementation of efficiency tools such as energy storage, smart grid technologies and demand response options.
    - Developing policies and market strategies to better align efficiency goals at multiple jurisdictional levels and different sectors.
    - Enhancing efforts for widespread community engagement in energy efficiency and conservation programs in multiple sectors.
    - Promoting studies on viability and compatibility to enable the further development of current technologies and implementation stages for energy storage and demand response tools.

- Promoting efficiency and conservation technologies, strategies, and programs.
    - Maximizing public engagement to improve programs, learning and acceptance, fostering technological development, and creation of policy pathways for the widespread adoption of affordable and reliable renewable energies.
    - Supporting policy-design that aims to minimize energy consumption and avoids focusing narrowly on electricity generation options.

Democratic and participatory governance

- Ensuring democratic and participatory deliberation including experts and relevant actors including rural cooperatives, industry, vulnerable groups, and community leaders for electrical energy system projects.
    - Attaining public acceptance through explicit and transparent project approval processes that demonstrate the advantages and impacts of electricity projects and foster collective solutions.
    - Avoiding streamlining of official processes merely for faster approval of electrical energy system projects, as well as avoiding decision-making that is predominantly based on short-term technical and economic considerations.
    - Developing policies that facilitate and stimulate citizen participation and collaboration to better address community concerns – e.g., preserving access to rivers and other valued resources, finding effective means for equitable distribution of financial benefits, respecting human rights as well as protected areas and Indigenous territories, avoiding negative impacts imposed on local community lifestyle.
- Enhancing system capacity to create opportunities for innovation and knowledge integration involving diverse citizens, independent experts, key actors, and communities.
    - Favouring citizen engagement in the emergence of prosumers, as well as in the adoption of renewable energy and demand management programs and technologies.
    - Improving the alignment of policy development efforts and goals among multiple electrical energy system actors (e.g., governments, institutions, communities, private companies, rural cooperatives and other relevant actors).
- Favouring policy-making design that clarifies the implications of attaining climate and associated social-ecological objectives.
    - Promoting the incorporation of tools for policy pathways development and long-term planning that are better suited for breaking negative trends – e.g., scenario planning, backcasting, and related prospective studies.

Precaution, modularity, and resiliency

- Supporting design options that minimize system vulnerability to failure and maximize recovery capacity to severe meteorological events (e.g., intensified hurricanes, storms, floods and droughts) and other potential threats (e.g., electric overloads, blackouts, system malfunction in the Central American grid, etc.).
    - Advancing knowledge for the development and broad acceptance of promising technological alternatives to increase efficiency and conservation, improve demand response, lower harmful emissions, reduce costs, enhance distributed generation and safely deploy electric vehicles.
    - Developing policy pathways for the adoption of technologies and programs that increase the modularity, flexibility and resilience of the electrical energy system – e.g., energy storage, demand/supply monitoring, smart grids, microgrids, self-healing grids, etc.
- Supporting prudent and precautionary policy- and decision-making to address the unpredictability and incomplete understanding of the long-lasting effects of current events (e.g., transition to electric vehicles, lower-than-expected electricity demand, climate change and COVID-19 pandemic).
    - Favouring design options that avoid risks of severe financial losses and socio-economic crises, and irreversible damage to vital life-support systems.
    - Increasing the system's adaptive capacity for modifications over time as well as greater system compatibility for the integration of diverse sources and backup options to the grid.
    - Avoiding the approval of proposals that increase path dependency on electricity projects that pose social, ecological, and economic risks (e.g., capital intensive, massive, socially and environmentally disruptive long-term projects, with low capacity for modifications over time).
    - Promoting tools and strategies to increase the understanding of changes in electricity demand – e.g., monitoring of seasonal and daily demand fluctuations.

Transformation, integration of multiple positive effects, and minimization of adverse effects

- Implementing multiple and mutually reinforcing packages of sustainability-based initiatives to maximize positive contributions to climate and other social and environmental goals.

- Implementing official planning that develops sets of overarching goals and criteria for institutions and projects, including the transition towards electric transportation (e.g., policy, infrastructure, electricity demand).
- Developing policy and guidelines to strengthen official sustainability-based assessment processes and to ensure a better alignment of objectives for social and environmental well-being at different levels – e.g., local, national, regional.

- Incorporating governance design options to facilitate the accumulation of positive effects in electrical energy system transitions.
    - Favouring policy-making that recognizes constant change in the global and local electricity context and is adaptive to new system components like the widespread deployment of electric vehicles and advancement of distributed generation, prosumers, demand response, energy storage, and decentralized and participatory models of management.
    - Ensuring effective and inclusive collaboration of the multiple key actors in the transition towards increasing the role of private actors in the electricity market.
    - Enhancing the capacity for reflexivity to identify political dynamics and pressures in governance processes (e.g., acknowledging the alignment of economic interests between government and private actors, and the misalignment with community interests).
- Supporting just transitions to ensure that electrical energy system planning and operations build the resilience of what is valuable and pay special attention to the interests of the most vulnerable
    - Avoiding decision-making and trade-offs that create inequitable intra- and inter-generational burdens, especially to Indigenous groups, local communities, vulnerable groups, as well as rivers, forests, and other life-support systems.
    - Avoiding the re-emergence of large hydroelectricity and other projects that may pose social and ecological risks in the transition towards adopting new system design options (e.g., electric vehicles, distributed generation, energy storage, demand response, smart grids).
    - Ensuring that new market strategies (e.g., more actors to competing for electricity projects, tariffs for prosumers using grid services) respect the already established national principles of solidarity and universal access.
- Developing policy pathways that clarify how specific desirable targets can be reached, instead of aligning decision-making to predictions based on current technical and economic trends
    - Promoting policy-design and planning that avoid prioritizing short-term gains and specify decisions that should be made today to attain desirable characteristics in the long-term (e.g., prospective visioning and modelling, backcasting, scenario planning and other negative trend-breaking approaches).

- Integrating diverse knowledge, accepting a plurality of pathways to, and embracing the political nature of the electrical energy system transition.
    - Improving engagement and knowledge co-production strategies to include Indigenous groups' contributions into the different stages and final decision-making of electrical energy system planning.
    - Promoting strategies to develop and better include different streams of knowledge and interdisciplinary work, as well as new global advancements in science, innovation, and technology, in decision- and policy-making.
    - Establishing public scrutiny and independent evaluation processes for deliberation to address the political nature of different project assessment teams – e.g., diverse approaches, backgrounds, political views, evaluation processes and approval outcomes.

7.3.1. Trade-off considerations

This section identifies three evident trade-off considerations in the study and evaluation of the Costa Rican electrical energy system. The application of the sustainability-based assessment framework specified to electrical energy systems in Costa Rica reveals that efforts to meet each of the criteria categories will possibly lead to undesirable interacting effects and trade-off scenarios that need to be managed. The three main considerations found are the following:

First, promoting the widespread adoption of electric vehicles to minimize the emission of harmful substances to the atmosphere from the overall energy mix is likely to spur increases in electricity demand. Decision-making and planning must ensure that options to meet the increased demand do not lead to the re-emergence of poorly governed large hydropower projects that have historically created social conflict and negative ecological effects. One important aspect is to pay attention to how the increased electricity demand is going to be met and minimizing the adverse effects of additional generation projects possibly required.

Second, the implementation of new market models to favour the adoption of emerging technology and innovation for distributed generation, demand response options and energy storage might benefit from the inclusion of private and other key actors to the national and regional electricity market. However, national authorities must guarantee that the economic gains of potential electricity projects emerging from the participation of private actors are not prioritized over environmental regulations and the inter- and intra-generational sufficiency for livelihood and cultural identity of Indigenous and local communities. For instance, official consultation processes must avoid streamlining for rapid approval to meet short-term economic interests and political pressures.

Third, technical capacity and financial stability must be ensured while advancing new system infrastructure and retrofitting for ensuring ecosystems integrity, promoting efficiency, and minimizing vulnerability. For instance, the implementation of some system design options may lead to initial costs that increase prices and electricity bills. Also, some design options may not be reasonably affordable by some actors in the electrical energy system with limited resources. Electrical energy system planning must therefore avoid unnecessary financial risks in project approval and foster cost-effectiveness, and pay particular attention to promoting private and public, as well as citizen engagement, for efficiency and conservation culture. Overall, official electrical energy system authorities must maintain the already established principles of solidarity and universal access.

7.4. Conclusions

This section provides three concluding sections relevant to the Costa Rica case study and to the overall thesis work. The three concluding sections are divided into relevant insights for the theory, the application and specification of the framework, and implications for pursuing electrical energy systems that contribute to sustainability benefits in Costa Rica.

7.4.1. Theory

This case study provides relevant insights related to sustainability-in-complexity literature. One relevant consideration is that while Costa Rica has attained an electrical energy system almost entirely powered by renewable energy, there are broader negative effects to sustainability that need to be addressed. In Costa Rica, as sustainability-in-complexity theory suggests (see section 2.3.1), failure to consider multi-scale effects from some decisions has created negative effects in interlinked areas. For instance, pursuing a renewable electrical energy system without effective governance considerations has created social conflict and negative environmental effects. Therefore, adopting a lens that posits that sustainability-oriented efforts should be pursued as the integrated maximization of positive cumulative effects in multiple sectors and levels has been suitable for this case study (e.g., Atlin & Gibson, 2017; Diefenderfer et al., 2016).

The incorporation of attention to transitions and transformations towards sustainability in the theoretical foundations is also relevant in the study of specific cases. Costa Rica is experiencing ongoing transitions in the electrical energy system that have proven to be difficult to manage due to the multiple interacting components and interests involved (e.g., Olsson et al., 2017). Moreover, the background study shows that such system components have been transitioning constantly according to global electrical energy system trends and political pressures. This should be considered in any attempt to contribute to the sustainability-based assessment theory – sustainability does not have a particular ultimate form since social and ecological systems are ever-evolving (Kates et al., 2005; Robinson, 2004).

This case study is also relevant to approaching electrical energy systems as important venues to maximize contributions to sustainability. The Costa Rica case reveals that the incorporation of new system components to tackle climate change (e.g., renewable energy development) must be governed effectively to avoid the accumulation of other long-term social and ecological adverse effects (Doelle, 2017). Likewise, future studies need to pay attention to the governance-related aspects of adopting promising alternatives for technology and innovation emerging in the global electricity landscape. For example, advocates of the implementation of energy storage, demand response, smart grids, and renewable energy alternatives, must find effective ways to attain social acceptance and citizen participation for a more rapid transition.

7.4.2. Framework

The initial sustainability based-assessment framework specified for electrical energy systems was a useful tool for developing a framework specified to the Costa Rican context. The proposed criteria informed the data collection process, and the main categories aligned generally well with what key informants considered as relevant issues to address. However, more contributions by more key actors will be necessary in the future. A more advanced version of framework criteria for application to specific plans and projects would itself need further revision and contributions from more planning authorities, independent experts, community leaders, and other key electrical energy system actors.

Particularly, it is crucial to ensure that the contributions of groups with less influence and resources (such as local communities, Indigenous groups and rural cooperatives) are well represented in the final criteria. In this case, the development of the framework relied more heavily on the expertise from the interviewees in comparison to the Ontario case since the availability of documents was not as vast. Nonetheless, the examination of the Costa Rican context has provided relevant insights for future works that aim to specify sustainability-based assessment criteria to electrical energy system-related plans, projects and initiatives, in Costa Rica and other jurisdictions.

Directing electrical energy system transformations to maximize positive effects as a main criteria category also needs particular attention. As a novel addition to sustainability-based assessment frameworks, this criterion will need to be honed with further applications in practice and theory. However, an initial specification and application process demonstrated that the framework's key considerations are relevant to this case. Namely, the key considerations facilitated the recognition of context-specific transitioning challenges in the national electrical energy system landscape. Future sustainability-based assessment frameworks will need to be informed by applications to emerging plans and projects for electric vehicle development and related electricity demand, energy storage, distributed generation and demand reduction.

7.4.3. Implications for Costa Rica

There are relevant opportunities for transformational change in Costa Rica's electrical energy system stimulated by global energy transitions – e.g., from oil-fueled to electric vehicles; from relying strongly on large hydroelectricity development to more distributed generation motivated by reliability risks associated to changing patterns in natural resource systems, social conflict and unexpected demand trend changes; and from the ICE being the one central actor to potentially increasing the participation of other key actors. However, these aspects also pose relevant challenges for designing the electrical energy system to generate broad and long-lasting sustainability benefits.

Given Costa Rica's historical context, one overarching aspect to consider is the need for conflict resolution, or at least conflict management, between local communities and the government and private actors. Electrical energy system authorities need to demonstrate that they can improve efforts to respect human rights, Indigenous groups' needs, and environmental regulations, as well as to foster citizen participation and improved processes for the public approval of projects. In this sense, this case study has suggested relevant governance design options that can help to attain such goals.

Transitioning to electrifying transportation requires finding ways to meet the subsequent electricity demand without debilitating Costa Rica's sustainability efforts. For instance, electrical energy system managers must avoid strengthening path dependency on large hydropower projects and instead focus on system design options that favour efficiency, cost-effectiveness, and more distributed generation. Technology options like smart grid and demand response tools, energy storage, as well as alternative renewable energy like smaller hydroelectricity, on- and off-shore wind, solar, and geothermal projects are proving to be viable alternatives. However, authorities must focus on building policy pathways to facilitate the transitions while maintaining the principles of solidarity in affordability, universal access, and financial stability.

The Costa Rican electrical energy system also needs improved efforts for integration and co-production of knowledge to better understand and tackle pressing challenges like the short- and long-term effects of climate change and the COVID-19 pandemic. For instance, the misalignment of goals between different key actors has hindered the capacity of implementing initiatives that are mutually reinforcing for the accumulation of positive sustainability-associated effects. In this sense, one important step may be the incorporation of an electrical energy system planning entity that is independent to the ICE and other key actors.

Chapter 8 presents the analysis of the process of developing and applying a sustainability-based assessment framework for electrical energy systems specified to the contexts of Ontario and Costa Rica. The chapter includes the main insights retrieved from the adopted theoretical foundations, as well as from the case study work. Chapter 8 also shows the key findings from the case studies and provides a comparison of notable similarities and differences in the key findings. Overall, the chapter highlights the main lessons and concluding arguments from the elaboration of a sustainability-based assessment framework specified to electrical energy system and for further specification to particular contexts.

CHAPTER 8. Framework analysis – comparing the case studies

This chapter provides an analysis of the sustainability-based assessment framework specified to electrical energy systems built in this thesis work for the study of two cases: Ontario and Costa Rica. The framework has been illustrated and examined during this work by specifying and applying it to the contexts of the two cases in chapters 6 and 7. The analysis in this chapter includes relevant insights resulting from the framework development, and from the specification and application processes for both case studies. While this was not intended to be a comparative study, there were notable similarities and differences in the findings from specification to context and application in the two cases that provided key lessons for this study.

The chapter is divided into four main sections. The first section presents the summary of findings from the case study works that were drawn in chapters 6 and 7. This includes the Ontario case findings and the Costa Rica case findings. The second section provides a comparison of findings from the specification to context and application of the sustainability-based assessment frameworks for the two electrical energy systems. This comparison was done by developing a table setting out the most notable similarities and differences in the findings from the specification to context and application of the specified frameworks in the two cases. The third section introduces an analysis of the similarities and differences, exploring the comparability in more detail and providing salient examples from the cases. Finally, the fourth section presents the key lessons learned from the analysis carried out in the previous sections. The key lessons are relevant not only to the two cases and jurisdictions but also to the overall study as an effort to advance general knowledge on specification and application of sustainability-based assessment in particular contexts.

8.1. Summary of findings from the case studies

8.1.1. Ontario case findings

Ontario's electrical energy system needs to overcome significant challenges in order to make more positive sustainability-related contributions to the provincial, national, and global social and ecological context. In general, some key participants in the electrical energy system recognized that Ontario is not currently managed to be on a transitioning energy path, and that the province is not likely to see major advancements in the near future if it continues with current approaches.

One key finding is that applications of sustainability-based assessments to Ontario's electrical energy system need to pay particular attention to the political context in the province. Provincial electricity-related objectives have oscillated considerably depending on the political party that is in government, and the changing political context has undermined long-term planning. Currently, provincial authorities have removed official requirements for long-term energy planning towards attaining climate change-related goals. This is clearly unfortunate, since studying the cumulative effects of past and recent events and anticipating future needs, problems, and opportunities are crucial for designing electrical energy systems that maximize positive contributions to sustainability.

Another key consideration is that the province faces cost-related issues that have contributed to consistent increases in electricity prices and have hindered the capacity for attaining public approval of new design options. In this regard, there is only partial agreement between different key actors on the main causes of current pressing cost-related issues and the actions needed for overcoming such challenges. However, paying attention to the possible interacting effects among the sustainability-based assessment criteria helped to integrate divergent views in the context-specific framework and to identify the most salient issues.

In the past, some events related to severe health risks, poor air and water quality, and social pressures pushed Ontario to make some progress towards sustainability-based goals. These included the closure of coal-fired power plants, incorporating some renewable energy options, and advancements in conservation and demand response technologies and programs. However, the electrical energy system has not yet been designed to be compatible with emerging technical options in the global context and has very limited capacity for changes over time. Furthermore, the province has decided not to follow national net-zero goals and there is limited interest in pursuing climate change goals.

Ontario also needs to improve efforts to address key sustainability requirements such as democratic and participatory governance as well as inter- and intra-generational equity. Particularly, provincial electrical energy system management has overlooked First Nations and local communities' rights to be consulted, creation of long-lasting jobs, and protecting land and other socially valuable sites.

8.1.2. Costa Rica case findings

Costa Rica has been considered as an example to follow globally for tackling climate change since the country has achieved and maintained an electrical energy system that is almost entirely powered by renewable energy. However, the processes of specification to context and application of the sustainability-based assessment framework shed light on broader interlinked areas that need to be improved urgently. For instance, despite the accomplishments in the electricity sector, the transportation sector is still dependent on fossil fuels and contributes greatly to harmful emissions to the atmosphere.

One salient finding is that specification and application of sustainability-based assessments for Costa Rica need to pay special attention to improving governance efforts. This includes ensuring better representation of groups with limited influence and resources in decision-making (e.g., local communities, Indigenous groups, rural electrification cooperatives). In fact, pursuing a renewable electrical energy system without an adequate consideration of key requirements for governing towards sustainability has led to the accumulation of long-term social and ecological adverse effects. A background of large hydroelectricity development without consultation has created a sustained context of tension between governments, Indigenous groups and local communities, and private actors. Additionally, ignoring environmental regulations has at times threatened the preservation of protected natural areas and sites of cultural value.

This case has also illustrated that a Costa Rican electrical energy system that makes overall contributions to sustainability cannot have a particular ultimate form, underscoring the relevance of fostering capacity for changes over time. The background study showed that system components have been transitioning, and continue to evolve, in response to global trends and political pressures. For instance, some opportunities for transformational change include the following shifts: from gasoline vehicles to electric vehicles; from relying strongly on large hydroelectricity development to more distributed generation motivated by better managing reliability risks associated with changing patterns in natural resource systems, social conflict and unexpected demand trend changes; and from the Costa Rican Institute of Electricity (ICE) being the one central actor to potentially increasing the participation of other key actors. Therefore, it is crucial to ensure that the transitions are carried out in a just manner and without compromising Costa Rica's climate change goals and other sustainability objectives.

8.2. Comparison of the similarities and differences of the findings from building, specifying to context, and applying the specified frameworks

In general, the criteria determined for the specified frameworks developed in Chapters 6 and 7 were similar. However, the contextual characteristics of Ontario and Costa Rica's electrical energy systems determined most of the differences in the building of each specified framework and in the findings when the specified frameworks were applied. This section focuses on providing insights about how the two specified frameworks compare considering the notable similarities and differences found for each of the criteria categories. It is noteworthy to mention that the similarities and differences associated with each of the criteria categories also entail interacting effects involving the rest of the criteria.

8.2.1. Climate safety and social-ecological integrity

There were three notable similarities and two differences associated with climate safety and social-ecological integrity. First, both jurisdictions have demonstrated an inclination towards making efforts to increase the adoption of electric vehicles. This has sparked questions about how the electricity demand to power the potentially increased deployment of electric vehicles will be met. In Costa Rica, for example, there are concerns about some key actors in the electrical energy system considering the incorporation of fossil fuels to the electricity mix as a response. Therefore, avoiding reliance on fossil fuels to meet electric vehicles' demand had to be emphasized in the framework specified to Costa Rica.

Second, climate change needs particular attention in both cases. On the one hand, recent decisions by Ontario's provincial government have demonstrated a lack of interest in following national and global climate change commitments. On the other hand, Costa Rica's specified framework drew particular attention to expected climate change effects such as intensified periods of hurricanes, storms, floods, and droughts.

Third, while it has been recognized as a relevant criterion, some electrical energy system projects in both jurisdictions have failed to respect human rights, protected areas, and some environmental regulations. In Costa Rica, for example, some electricity projects have threatened national wetlands, archeological sites, and Indigenous land (e.g., Carbone, 2018).

One of the most notable differences is that Ontario's provincial government has recently decided to not follow national commitments to attain net-zero emissions. For instance, the cancellation of the Green Energy and Green Economy Act also entailed the cancellation of 800 contracts for renewable energy projects (Brisbois, 2020). In this regard, Ontario projects considerable increases in greenhouse gas emissions by the year 2030 from the electrical energy sector, making climate safety and social-ecological integrity a key consideration for future electrical energy system operations. Costa Rica, in comparison, has succeeded on maintaining a renewable-based electrical energy system, particularly based on hydroelectricity. Since 2015, renewable-based generation has surpassed 98% of the share in the electricity mix (ICE, 2020).

8.2.2. Intra- and inter-generational equity, accessibility, reliability, and affordability

For this criteria category, three notable similarities and two differences have been uncovered. The first similarity is that decision-making in both jurisdictions has been strongly based on system reliability considerations and less attention has been paid to considerations that have impact on intra- and inter-generational equity and livelihood opportunity. In Ontario, for instance, employment and costs considerations need to be considered more equally in decision-making, instead of only focusing on reliability (see Chapter 6). In Costa Rica, authorities have prioritized the provision of economic compensation to groups negatively affected by the operations of the electrical energy system but have failed to consider other long-lasting benefits for the communities (Comisión Defensora de los Ríos Convento y Sonador, 2016).

Second, both cases have shown consistent annual increases in electricity prices, posing risks to maintaining affordable electricity for all. Ontario, for example, has reached some of the highest electricity rates in North America (AMPCO, 2019), while Costa Rica has seen increases in electricity prices since the early 1990s, to a point of causing industry representatives to protest against the increases (Cámara de Industrias de Costa Rica, 2021).

Third, concerns from key participants in the electrical energy system in the two jurisdictions about immediate costs have delayed efforts to achieve and maintain a renewable-based electricity mix. For example, challenges to maintain affordable prices in Ontario have undermined the public approval of low-carbon electricity programs and system options.

Regarding the differences, some characteristics of the pricing models in the two jurisdictions were relevant to the specification and application. In Ontario, particularly, Global Adjustment has been a key consideration in electricity pricing. That is, the costs of providing and maintaining electrical energy system-related infrastructure and programs are added to the electricity bill. Costa Rica has implemented a solidarity pricing model where equal electricity rates to all are maintained with the support of governmental subsidies. While this has helped to preserve broad accessibility, some interviewees identified that price increases tied to cost-related issues have created concerns about the system's capacity to provide full coverage while ensuring an affordable and renewable-based electrical energy system.

8.2.3. Cost-effectiveness, resource efficiency and conservation

Two similarities and two differences associated with cost-effectiveness, resource efficiency and conservation were identified as the most notable. First, electrical energy system management in both jurisdictions has had difficulties minimizing costs in generation, transmission, and distribution operations. Ontario, for example, approved highly expensive refurbishments of the Bruce, Darlington, and Pickering nuclear generation stations that were estimated in CAD$25 billion (Financial Accountability Office of Ontario, 2017). Additionally, the province has lost billions of dollars from the cancellation of electricity generation projects and programs for conservation and carbon dioxide emission reductions. Similarly, in Costa Rica, the cancellation of El Diquís hydroelectricity project in 2018 resulted in financial loss that accounted for US$174 million in investment costs (Chacón, 2018). Moreover, the expensive repair costs of some large hydroelectricity projects (e.g., El Pirrís and Reventazón) have created affordability challenges and other cost-related issues in Costa Rica.

Second, while some relevant efforts have been made, the two jurisdictions have failed to fully embrace strategies for energy efficiency and conservation, and instead have prioritized options to increase electricity generation. In Ontario, efficiency and conservation have been identified as viable options to lowering costs, minimizing harmful emissions, and reducing electricity prices, but have been hindered by a constantly changing policy context (Love, 2017). In Costa Rica, efficiency and conservation have been highlighted for decades as key components to pursue but policy-making and strategies for implementation have been mostly unsuccessful (Chapter 7). One interviewee pointed out that some demonstrably effective strategies such as fostering a culture of conservation and promoting more studies on viability and compatibility for new technologies have been greatly overlooked.

The major differences in the findings associated to this main criteria category are greatly related to technical development and the political context. On the one hand, Ontario has made relevant advancements in developing technical options for conservation and demand response, compared to other provinces in Canada. However, as mentioned earlier, the changing political environment, with oscillating policy objectives depending on the political party that is elected to govern, has undermined the continuity of efficiency and conservation initiatives. On the other hand, Costa Rica needs to further advance the development of some innovative options that have not yet reached their full potential (Avendaño-Leadem & García-Sánchez, 2019). This entails enhancing the capacity for incorporating emerging trends in the global market, including new market models, to facilitate the widespread adoption of technological advancements such as distributed generation, energy storage, and demand response options (Chapter 7). One favourable aspect, according to one interviewee, is that Costa Rica has the management experience in incorporating new system components and energy resources to the system (e.g., full adoption of renewable energies).

8.2.4. Democratic and participatory governance

Two notable similarities and two differences were found for democratic and participatory governance. First, both jurisdictions have failed to respect crucial requirements for public acceptance in project approval, such as respecting legislated milestones, conducting meaningful consultation with local communities and Indigenous groups, and providing transparency in decision making. In Ontario, for instance, a lack of transparency, disregard for public input processes, and decisions that mostly considered technical aspects caused the post-approval cancellation of two natural gas power plants (Winfield, 2016). Furthermore, some interviewees identified that decision makers in electricity-related projects usually prioritize economic stimulus over other meaningful interests of First Nations, and compensation to negatively affected groups are often insufficient (Chapter 6). In Costa Rica, the lack of participatory and democratic governance of hydroelectricity projects has been historically a serious issue that has created relevant tensions between governments and the communities (e.g., Arias, 2017; Carls & Haffar, 2010; Pérez, 2011). Some relevant failures have included lack of transparency, streamlining, violations to Indigenous and human rights, disruption of protected areas and insufficient consultation (Chapter 7).

Second, the two jurisdictions need to implement better efforts to foster the participation of key actors in the electrical energy system, especially of those with more limited resources. In Ontario, for example, some interviewees remarked that it is important to improve the inclusion of local utilities and distribution companies in official decision-making processes, as well as more effective community engagement (Chapter 6). In Costa Rica, some authors have pointed out that social mobilizations at a national scale, rather than governmental action, have pushed government and private actors to include community interests (e.g., Gutiérrez and Villalobos, 2020). Additionally, one interviewee stressed that rural electrification cooperatives are often not considered in official decision-making processes despite being essential for providing local services (Chapter 7).

The notable differences found in this regard are generally associated with the electrical energy system structures in each case. More specifically, the market models established in the jurisdictions determine greatly the managing structure, as well as the degree of participation and influence of key participants in the electrical energy system. Ontario's electricity market, on the one hand, is considered a hybrid model. That is, provincial authorities define overall energy systems planning and long-term objectives, and private actors can compete for contracts to build and operate related projects (Rivard & Yatchew, 2016). Some interviewees stressed that this model still has a highly centralized approach of management (Chapter 6). Costa Rica's electricity market model, on the other hand, is considered a monopsony. This means that the market is open for some private participation, but it is restricted to small- and medium-scale electricity generation projects (Asamblea Legislativa, 1995). Additionally, only the ICE, a government institution, can buy the electricity generated by private actors. According to different interviewees, however, this approach is expected to change eventually and be opened to include more private participation (Chapter 7).

8.2.5. Precaution, modularity, and resiliency

For precaution, modularity, and resiliency, two notable similarities and two differences were identified. First, some decisions made in both jurisdictions have reinforced path dependency on system design options with high socioecological and economic risks, as well as low capacity for flexibility, modularity, and adaptiveness to uncertain scenarios. One example is the provincial efforts in Ontario to maintain nuclear generation capacity. In this regard, nuclear power plants have been identified to have considerably high investment costs and lack flexibility for the incorporation of system components that can be cheaper and safer (Winfield, 2020a). In Costa Rica, decisions over time have contributed to strengthen a path dependency on large hydroelectricity projects (Avendaño-Leadem & García-Sánchez, 2019). One related consequence is the previously mentioned case of El Diquís hydroelectricity project with one of the cited causes for its cancellation being that electricity demand was not as high as the trends projected (Chacón, 2018).

Second, the two jurisdictions have made efforts to promote technologies to attain a more diversified electricity mix, with higher modularity and capacity for recovery. In both cases, for example, energy storage has been identified as a relevant option with the potential to increase system capacity for efficiency, demand response, and a widespread deployment of electric vehicles (Chapter 6; Chapter 7).

The two notable differences identified are directly related to the aspects mentioned above. Ontario’s unwillingness to look for alternatives to nuclear power raises concerns for intergenerational effects related to lack of long-term solutions for the disposal of radioactive by-products, permanent decommission after use, toxic waste in life-cycle processes, and high cost-related risks (Environmental Commissioner of Ontario, 2018). Additionally, according to one interviewee, base-load nuclear generation plants have very low capacity for incorporating demand response options as well as for more distributed generation. Costa Rica has a different issue that stems from a strong reliance on large hydroelectricity power plants. As mentioned in chapter 7, Costa Rica’s geographical context, which is favourable for hydroelectricity generation, also makes the electrical energy system vulnerable to increasing severe meteorological events that have already resulted in infrastructure damage, system failure, and blackouts (e.g., SICA, 2017; Teletica, 2020). In this regard, the country is paying more attention to alternative renewable sources for electricity generation due to the severity of the potential risks (Chapter 7).

8.2.6. Transformation, integration of multiple positive effects, and minimization of adverse effects

Four similarities and two differences associated to this main criteria category were found. First, it was recognized in the two jurisdictions that in many cases electrical energy system and sustainability-related policies and objectives are not coherent between institutions at different scales. In Ontario, for example, it has been identified that engaging with crucial actors such as local distribution companies, utilities, industry, and power consumers will be key to better aligning multi-scale objectives (e.g., Songsore et al., 2018).

Second, both jurisdictions have failed to establish effective long-term planning, which at the same time has hindered the capacity for implementing mutually reinforcing sustainability-contributing initiatives. In this regard, Ontario has opted for removing the provincial requirement to have a long-term plan (Chapter 6), while Costa Rica, according to one interviewee, needs a general law or independent planning entity that provides guidelines towards common goals.

Third, another similar aspect is the failure to broadly adopt policy-making tools that can help break path dependency and reverse negative trends. In both cases, approaches such as backcasting, scenario planning, and scenario visioning have been deemed as potentially-valuable options to help attain such goals.

Fourth, better efforts need to be made regarding the implementation of governance design options in order to facilitate electrical energy system transformations towards sustainability. In both cases, for instance, it has been recognized that better efforts to achieve effective consultation, engagement, and collaboration with the community and other key actors are required to promote complementarity of diverse approaches, innovation, and knowledge co-production.

Regarding the differences, one significant contextual consideration for Ontario is that the removal of the requirement for a long-term energy plan has left the province without a framework with officially approved and published sustainability-related criteria, requirements, or objectives (Winfield, 2020b). This in turn decreases the electrical energy system capacity to make broad contributions to positive sustainability effects and interactions. For Costa Rica, the probable increase of private participation in the electricity market has relevant implications for the near future. One key example is that authorities need to make sure that the influence of private actors does not lead to repeat the past pattern of electricity generation development without consultation (Chapter 7). Additionally, some interviewees have emphasized that a shift to more private participation may require the application of new policy, market strategies, and governance design options that align with national sustainability goals. These goals, at the same time, must promote an alignment with other countries that participate in Regional Electricity Market and the operations of the Central American Electrical Interconnection System.

8.3. Summary of notable similarities and differences from the specification to context and application of the sustainability-based assessment frameworks for electrical energy systems

This section summarizes the most notable similarities of, and differences between, the two cases that emerged from the application of the two specified frameworks. The main criteria categories and criteria developed for the sustainability-based assessment frameworks built in Chapters 6 and 7 were used to identify the background and context-specific characteristics relevant to electrical system management and design in Ontario and Costa Rica. At the same time, the application of the criteria helped to gather key insights for further specification to context. The comparison proved to be possible and fruitful, despite the application of somewhat different specified frameworks in the two cases. Arguably, the differences enabled a more insightful comparison than would have been possible using a single, less specific framework for the analysis of the cases.

A summary of the most notable similarities and differences can be found in Table 8.1 (see below). Table 8.1 shows in the first two columns the main criteria categories and the criteria that were included in the sustainability-based assessment framework specified to electrical energy systems developed in chapters 6 and 7. In the third and fourth columns, the table synthesizes the most notable similarities and differences discussed above.

Table 8.1. Most notable similarities and differences in the findings for electrical energy systems in Ontario and Costa Rica

Main criteria categories	**Sustainability-based criteria for electrical energy systems**	**Similarities in the specific framework applications**	**Differences in the specific framework applications**
Climate safety and social-ecological integrity	▪ Reducing harmful emissions to the atmosphere, including carbon and other substances that aggravate climate change ▪ Mitigating and adapting to already unavoidable social and ecological effects associated with climate change ▪ Enhancing human health by maximising	▪ Concerns about how to meet the electricity demand from an expected increase in electric vehicles ▪ Focus on incremental steps to mitigate and adapt to climate change effects, with less attention paid to transformative efforts	▪ Ontario: absence of provincial interest in pursuing net-zero emissions ▪ Costa Rica: strong focus on decarbonization goals – the electrical energy system is mostly powered by renewable energies (particularly, hydroelectricity)

	air quality, reducing toxic waste, and ensuring safe management in all life-cycle processes ▪ Minimizing threats to the biodiversity and ecological integrity, including toxic substances, resource depletion, animal and plant species extinction and pollution in all life-cycle processes ▪ Preserving main system characteristics that contribute to lasting socio-economic well-being and generate positive social-ecological system dynamics and effects	▪ Failure to respect some human rights, particularly Indigenous rights ▪ Failure to respect protected areas, and environmental regulations	
Intra- and inter-generational equity, accessibility, reliability, and affordability	▪ Favouring direct and indirect employment opportunities that are well paid, long lasting, conveniently located and otherwise accessible, fulfilling/challenging, etc. ▪ Promoting the just distribution of benefits and risks among present and future generations, regions, gender, race, Indigenous/non-	▪ Decision-making based on reliability with less attention paid to fair compensation and long-lasting community-oriented benefits ▪ Consistent annual increases in electricity prices ▪ Concerns about short-term costs of providing broad accessibility while maintaining a	▪ Ontario: Global Adjustment (the addition of the costs of providing and maintaining electrical energy system-related infrastructure and programs to the electricity bill) is a key consideration in electricity pricing and a concern for the implementation of renewable energy and efficiency and conservation options

	Indigenous people, poor and rich, and marginalised groups ▪ Favouring technical and policy options that maximize system capacity to provide electricity access and power essential human services for poor and remote areas ▪ Ensuring technical viability (e.g., reliability, resilience, safety, adaptive capacity, ease of repair, etc.) ▪ Ensuring economic viability (e.g., capital and operating costs, and risks in the short and long term, in comparison with other design options available)	renewable energy mix have delayed broader efforts to make positive contributions to overall sustainability	▪ Costa Rica: the solidarity model (electricity rates are equal in all areas with the support of governmental subsidies) has helped to maintain broad accessibility
Cost-effectiveness, resource efficiency, and conservation	▪ Increasing capacity for development and integration of reliable and affordable renewable-sourced energies that reduce negative climate change effects. ▪ Decreasing reliance on fossil fuels ▪ Enhancing technical demand management capacity to match electricity quality and	▪ Difficulties establishing decision-making approaches that focus on minimizing costs in generation, transmission, and distribution operations ▪ Need to take efficiency and other demand management strategies more seriously instead of	▪ Ontario: relevant progress in developing conservation and demand response options, but the changing political environment has undermined continuity ▪ Costa Rica: requires more development in conservation and demand response options, but has experience in managing

	quantity to end-user needs (e.g., storage, smart grid technologies, demand response options) ▪ Preserving and enhancing natural (and other meaningful) resources that are essential for community well-being ▪ Minimizing provision costs and socio-ecological costs, predominantly caused by life-cycle losses in generation and delivery activities	prioritizing increasing generation	a renewable electrical energy system
Democratic and participatory governance	▪ Maximizing capacity for democratic and participatory deliberation that facilitates public consultation and acceptance through explicit and transparent processes ▪ Building favourable conditions for open and informed discussion with integration of experts, stakeholders, Indigenous people, vulnerable groups and local knowledge	▪ Failure to attain broad public acceptance in project approval by respecting legislated milestones, conducting meaningful consultation with local communities and Indigenous groups, and providing transparency in decision-making ▪ Need to better promote the participation of key actors (e.g.,	▪ Ontario: the province's hybrid market model allows private actors to compete for contracts, while the government sets overall energy policy ▪ Costa Rica: the national monopsony-based market model is open for some private participation, but the ICE is the only buyer of the electricity generated nationally

	▪ Recognizing and addressing political barriers embedded in electrical energy systems that undermine democratic and participatory governance (e.g., powerful political and economic interests) ▪ Enhancing understanding and other capacities for just transitioning, opening windows of opportunity, and mobilizing key actors' influence for positive change ▪ Favouring policy-making design that clarifies the implications of attaining climate and associated social-ecological objectives	government institutions, NGOs, and private actors), especially those with more limited resources (e.g., local utilities, distribution companies, rural cooperatives)	
Precaution, modularity, and resiliency	▪ Favouring prudent and precautionary decision-making in consideration of unpredictability and incomplete understanding of complex dynamics ▪ Supporting design options that minimize vulnerability and maximize recovery	▪ Path dependency on large generation plants with low capacity for flexibility, modularity, and adaptiveness to different scenarios (e.g., climate change risks and unpredictable demand)	▪ Ontario: reliance on nuclear power has implications for long-lasting negative effects related to the disposal of radioactive by-products, permanent decommission after use, toxic waste in life-cycle processes, as well as high cost-related risks for future generations

	capacity to potential threats (e.g., natural disasters, accidents, system malfunctions, terrorist attacks, etc.) ▪ Favouring technology with high adaptive capacity for modifications over time, as well as design options for greater system compatibility ▪ Minimizing social, economic and biophysical risks in planning and decision-making for electrical energy systems of the future ▪ Avoiding planning and decision-making that increase path dependency (e.g., capital intensive, massive long-term projects with low capacity for modifications over time)	▪ Interest in some technologies that can be beneficial for resource diversification, and higher modularity and capacity of recovery (e.g., energy storage and smart grid tools)	▪ Costa Rica: reliance on large hydroelectricity generation has implications for vulnerability to adverse climate change effects like the increase in severe meteorological events resulting in infrastructure damage, system failure, and blackouts
Transformation, integration of multiple positive effects, and minimization of adverse effects	▪ Accumulating positive sustainability-oriented effects for desirable change through the implementation of multiple and mutually reinforcing sustainability-	▪ Sustainability-related policies and objectives are often misaligned between different institutions and jurisdictions at multiple scales ▪ A lack of effective long-term planning and absence of	▪ Ontario: the absence of a long-term energy plan undermines the development of policy pathways toward common requirements or objectives for the electrical energy system of the future

	contributing packages of initiatives ▪ Enhancing capacity for addressing governance challenges of transforming towards sustainability by incorporating governance design options that facilitate transformations ▪ Supporting just transitions to ensure that transformation planning and practice build the resilience of what is valuable and pay special attention to the interests of the most vulnerable ▪ Developing policy pathways to sustainability that aim to identify how can specific desirable targets be reached, instead of aligning decision-making to predictions based on current technical and economic trends ▪ Facilitating complementarity of different approaches to transformation by taking diverse knowledges seriously, accepting a	independent planning entities have hindered the capacity for implementation of mutually reinforcing sustainability-contributing initiatives ▪ Ongoing need to implement effective policy-making and planning tools (e.g., backcasting, scenario planning, prospective visioning) that can reduce path dependency and negative trends ▪ Need to implement governance options that facilitate transforming to sustainability (e.g., collaboration, knowledge integration and co-production with different key participants in the system, including community engagement)	▪ Costa Rica: the probable increase of private participation in the electricity market may require the application of new policy, market strategy, and governance design options that also consider the Regional Electricity Market and the operations of the Central American Electrical Interconnection System

	plurality of pathways to sustainability and embracing the political nature of transformations		

8.4. Main lessons learned

By specifying to context and applying the proposed sustainability-based assessment framework for electrical energy systems to two quite different jurisdictions – Ontario and Costa Rica – it was possible to draw important lessons. These key lessons are relevant to advancing knowledge on how best to design and evaluate electrical energy systems in a global context that demands prompt transformation due to pressing issues that imperil human and ecological well-being and at the same time also demands attention to and respect for the specific differences among local and regional contexts.

The main sustainability-based assessment criteria for electrical energy systems are useful for identifying different contextual characteristics in different jurisdictions that need to be considered and respected in sustainability-based assessment efforts. Hence, specification to context is crucial in any undertakings to design and evaluate jurisdictional electrical energy systems in attempts to tackle highly complex challenges that currently pose severe socioeconomic and ecological risks (e.g., climate change). While the criteria and sub-criteria for the frameworks specified to the two cases in this work did not need to be very different (see Chapters 6 and 7), they recognized key contextual characteristics in each case that are essential across the specific set of criteria. Not paying sufficient attention to the particular backgrounds and current context of the cases can undermine possibilities to maximize positive sustainability-related effects that electricity-related projects can generate. In fact, overlooking contextual scenarios can lead to increasing negative cumulative long-term effects – e.g., Ontario's long-lasting cost-related issues have hampered efforts to a greater adoption of renewable energy and other initiatives to reduce harmful emissions to the atmosphere. This also means that there is not, and there may not be, a single technological advancement, energy resource or initiative that can provide solutions to global energy needs.

In this thesis work, sustainability-based assessment frameworks specified to electrical energy systems, with further specification to particular contexts, were useful tools to identify decision-making options that can contribute positive effects to reduce and reverse global unsustainable trends. However, in order to achieve positive effects that accumulate to make contributions at larger scales, sustainability-based assessment frameworks must recognize the complexity of the world. This entails building specified frameworks with explicit consideration of not only the potential interlinked and non-linear effects among the criteria and sub-criteria, but also the potential interlinkages with other electricity-related initiatives as well as with other sectors and at multiple jurisdictional levels (e.g., the probable effects on electricity demand trends derived from efforts to lower harmful emissions from the transportation sector). To do so, the criteria and sub-criteria must be mutually reinforcing and approached as of equal importance, with unavoidable influence on each other. In this regard, clarifying key considerations for identifying and managing the possible trade-offs emerging from the application of the criteria is essential. Additionally, the specified sustainability-based assessment frameworks should be approached as packages of initiatives that leave room for compatibility with other similar initiatives through collaboration and co-production of knowledge.

The comparative analysis presented in this chapter suggests that the proposed sustainability-based assessment framework specified to electrical energy systems covered the basic suite of requirements for progress towards sustainability well enough to be relevant for both the Ontario and Costa Rica cases. At the same time, it provides an initial indication that the framework could be applicable to other jurisdictions with further development. That is, while these two cases are only a small sample of the many more possible cases for application, the findings from the application of the sustainability-based criteria for electrical energy systems helped in providing a common ground for a cross comparison of similarities and differences in two jurisdictions that are quite different in various aspects (e.g., geography, political and economic context, electrical energy system objectives and management). This suggests that the sustainability-based criteria not only helped to identify the most relevant electrical energy system-related debates and contextualities in each case, but also created opportunity for comparison in future applications. The analysis was also useful in revealing that the most notable similarities and differences from the findings on both cases were closely tied to contextual characteristics rather than to needs for very different criteria, or main criteria categories, in the two cases.

An additional insight revealed from the analysis is related to the criteria category on transformation, integration of multiple positive effects, and minimization of adverse effects. This criteria category is a new addition to sustainability-based assessments, needed to ensure explicit recognition and evaluation of the opportunities and barriers to transform, in this case, electrical energy systems to make broader contributions to sustainability. The analysis revealed that current central management approaches with insufficient implementation of effective openness and participatory governance design-options, for example, operate similarly in the two jurisdictions as salient barriers to positive change. At the same time, the proposed criteria, as specified and applied in both cases, were suitable to suggest actions needed to unlock opportunities for transformative effects that enhance the accumulation of sustainability-related benefits. These include, for instance, the adoption of policy-making approaches to break negative trends and path dependency, and collaboration to integrate and co-produce knowledge from diverse fields that usually work separately. Nonetheless, this is the first attempt to include this transformation category in sustainability-based assessments, and the category needs further testing and elaboration informed by being incorporated to more evaluation endeavors. At the same time, the novelty of the category creates opportunities to advance transformations towards sustainability through further contributions to the set of evaluation criteria by being applied to diverse contexts and changing energy scenarios.

More generally, it is important to emphasize that more insights from more specifications to context and applications will be necessary to test and improve the applicability of the framework as a valid generic tool. However, one overall lesson learned from the analysis presented in this work is that the process of specification to context did not undermine the capacity for the comparability of the two different jurisdictions. In fact, specification was useful to pinpoint critical factors (or similarities and differences) that should be considered to make more substantial comparisons between two cases that are considerably different. In other words, Table 8.1 and the subsequent analysis suggest that it is possible to have specification and comparability together in an effective approach to analyses.

Chapter 9 presents the conclusions for this thesis work, returning to the core research questions and considering the main insights drawn from the attempt to provide answers to the questions. The same chapter also includes concluding arguments concerning the lessons learned in this chapter and relevant implications for theory and practice, as well as directions for further research.

CHAPTER 9. CONCLUSIONS

This chapter presents the conclusions for the overall thesis work. The first section returns to the core research questions that were developed to approach the study. Afterwards, the chapter elaborates an overview of the theoretical foundations that the work was based on. These included relevant insights from three main areas of knowledge: sustainability in complexity, electrical energy systems and sustainability, and transformations towards sustainability. The following section introduces the major findings unveiled in the attempt to answer the core research questions. This includes the findings from the specification and application of the sustainability-based assessment framework for electrical energy systems developed in this study to two different jurisdictions: Ontario and Costa Rica. This chapter then identifies relevant implications for theory and practice in consideration of the findings. Finally, directions for further research stemming from the overall contributions of this study are provided.

9.1. Summary of the thesis

Table 9.1 provides a concise summary of this thesis work divided by chapter and into three columns. The first shows the chapter number and titles. The second provides a brief chapter description as a reminder of the chapter content. The third provides a summary of main considerations and findings. The summary of the main considerations and findings attempted to condense the main outcomes of each chapter in three or four bullet points, but the chapters can be consulted for a broader analysis.

Table 9.1. Summary of the thesis by chapters

Chapter (number and title)	**Chapter description**	**Summary of main considerations and findings**
1. Introduction	Presented the rationale for the thesis work.	▪ The chapter introduced the research context and a set of research questions and objectives to guide the thesis work.
2. Sustainability in complexity	Examined sustainability as an area of knowledge that has been adopted in efforts to pursue more prosperous social and ecological futures. This chapter also highlighted complex systems thinking as crucial to make progress towards sustainability.	▪ The main challenges that sustainability face are conceptual, ideological, and structural. ▪ Embracing the complexity of social and ecological systems is key to sustainability. ▪ Sustainability-based assessments can help to maximize positive social and ecological effects.
3. Electrical energy systems and sustainability	Electrical energy systems were introduced as relevant systems for advancing sustainability. In this chapter, electrical energy systems were examined as relevant	▪ Electrical energy systems can be designed to maximize positive contributions to sustainability.

	contributors of both positive and negative sustainability-associated effects. As a main outcome, this chapter proposed an initial sustainability-based assessment framework specified to electrical energy systems.	▪ A hybrid of conventional and new electrical energy system design options might be desirable. ▪ Five sustainability-based assessment criteria for electrical energy systems emerged from synthesizing key insights in the chapter (see section 3.4).
4. Directing transformations towards sustainability	Examined transformations as processes that can bee directed to make progress towards sustainability. Transitions and transformations were identified as key components in complex system change. Also, the chapter identified key governance challenges of transformations. Finally, the chapter proposed a main criterion for the sustainability-based assessment framework developed in Chapter 5.	▪ Transformations towards sustainability can be directed through the accumulation of effects that are desirable for human and environmental well-being. ▪ Governance design options that maximize transformative opportunities can be identified for moving towards sustainability (see section 4.2) ▪ Developing effective policy pathways is essential for directing systems to more desirable futures.
5. Research design and methods	Provided the design characteristics and methodological considerations for this thesis.	▪ The research is qualitative, transdisciplinary, and exploratory. ▪ A multiple case study approach was adopted, focusing on Ontario and Costa Rica as case studies. ▪ The case study methods selected were literature review, document research, and semi-structured interviews. ▪ The processes and steps for the specification of the proposed sustainability-based assessment framework for electrical energy systems were discussed.
6. Case study – Ontario	Examined Ontario's electrical energy system as the first case study for this thesis. The chapter provided the background and context for Ontario's electrical energy system, identifying key system change and system change characteristics. In this chapter, the sustainability-based assessment framework for electrical energy systems developed in Chapters 3 and 4 was further specified for	▪ Ontario's absence of long-term energy planning is an undermining factor for sustainability efforts. ▪ New electrical energy system planning should be developed as packages of initiatives that contribute to the accumulation of positive and mutually supportive effects. ▪ Ontario's electrical energy system has taken important steps towards sustainability but recent provincial decisions in policy and technical options have created challenging scenarios.

	application to Ontario's electrical energy system.	
7. Case study – Costa Rica	Examined Costa Rica's electrical energy system as the second case study for this thesis. In line with Chapter 6, the chapter provided the background and context for Costa Rica's electrical energy system and identified key system change and system change characteristics. Also, the sustainability-based assessment framework for electrical energy systems developed in Chapters 3 and 4 was further specified for application to Costa Rica's electrical energy system.	▪ While Costa Rica's electrical energy is almost entirely powered by renewable energy, governance-related issues have created social tensions. ▪ Costa Rica is experiencing relevant energy transitions that need to be managed justly and participatorily. ▪ Costa Rica can better manage the uncertain electricity demand trends by promoting the incorporation of promising technical options for conservation and demand response.
8. Framework analysis – comparing the case studies	Analyzed and provided main findings from the development and application of the sustainability-based assessment frameworks specified to the electrical energy systems of Ontario and Costa Rica. This chapter provided a comparison between the findings from the application of the sustainability-based assessment framework in the two case studies, including the main lessons learned.	▪ Sustainability-based assessments with sets of overarching criteria are useful tools for initial evaluation, but further specification to context is crucial in sustainability undertakings. ▪ Incorporating complexity thinking to sustainability-based assessment frameworks provides a lens for better understanding the potential interlinked effects of applying the criteria and sub-criteria. ▪ The comparative analysis between the cases revealed that the proposed sustainability-based assessment framework for electrical energy systems can be applicable to other jurisdictions with further development. ▪ The proposed framework can benefit more applications and theoretical contributions, and paying particular attention to directing system change to maximize positive effects is important.

9.2. Answering the research questions

This thesis work has gathered and synthesized main insights from the literature that can provide answers to the three research questions developed in Chapter 1. The research questions were developed in response to rising social and ecological issues, particularly stemming from electrical energy systems' operations, that threaten the capacity of the planet to avoid irreparable damages. As noted in Table 9.1, the three areas of knowledge adopted as theoretical foundations for this thesis are sustainability in complexity, electrical energy systems and sustainability, and transformations towards sustainability. This section shows how the main findings from this thesis work have informed the answers for the three research questions developed in Chapter 1. The research questions are revisited below, each with an answer built from the main insights from the thesis.

Question 1: What can be learned from the literature on sustainability-in-complexity, electrical energy systems and sustainability, and transformations towards sustainability about how best to specify sustainability-based assessment criteria for designing and evaluating electrical energy systems in the complex context of climate change and other pressing social and ecological issues that demand transformation?

The literature review conducted on the three fields of knowledge selected as theoretical foundations for this study, and the resulting syntheses, provided relevant lessons in this regard. First, sustainability-based assessment criteria for electrical energy systems must consider the complexity of the world. Complexity thinking suggests that sustainability-based assessment efforts must consider the context-specific characteristics of the venue of application and at the same time must be compatible and mutually reinforcing to other similar efforts in the same and different sectors. In this sense, complexity thinking can provide a lens to better understand the interlinked effects, and to identify the possible trade-off scenarios, of specifying and applying the criteria. Second, electrical energy systems are relevant venues for the application of sustainability-based assessment frameworks because they can contribute greatly to both positive and negative sustainability-associated effects. Therefore, one challenge for sustainability-based assessment criteria for electrical energy systems is to focus on the incorporation of promising technical and policy options while maintaining the characteristics that have provided essential services for human well-being. Third, sustainability-based assessment criteria for electrical energy systems must approach transformation as an accumulation of positive effects that can lead to the transformation of the system. For instance, the criteria must pay attention technical, governance, and policy options that have demonstrated the capacity for positive contributions to the context of application.

Question 2: What framework of sustainability-based assessment criteria for evaluation of existing electrical energy systems emerges from the learning in response to question 1?

The sustainability-based assessment framework specified to electrical energy systems elaborated in this thesis has been a relevant outcome to answer this research question (see Table 9.2). The initially proposed framework was developed in consideration of Gibson's (2005) basic requirements for progress towards sustainability and more recent contributions, overall accepted sustainability objectives for electrical energy systems, and governance options for directing change towards maximizing positive effects and avoiding adverse effects. The sustainability-based assessment framework provides a normative compass for decision-making regarding design options that are best suited to advance sustainability in electrical energy systems at different jurisdictions. The findings from the literature review provided a foundation for building a set of mutually reinforcing criteria for assessing electrical energy systems at the jurisdiction level. The criteria, divided in six main criteria categories, were developed in consideration of complex systems' dynamics and context-specific sustainability. The framework is potentially applicable to electrical energy system-related plans and projects in different regions, with further specification to the context of particular regional applications. In this sense, this dissertation has taken a further important step by examining the applicability of the framework in the electrical energy systems of Ontario and Costa Rica.

Question 3: What can be learned from applying this framework, with further specification for context, in case studies of two quite different jurisdictions with electrical energy systems in need of transformation? In particular, what can be learned about the utility of the framework and its specification for context, and about the barriers to and opportunities for transforming the electrical energy systems of the two jurisdictions?

The electrical energy systems of Ontario and Costa Rica have experienced relevant transitions in their recent history, partly in efforts to make more positive contributions to sustainability. Although Ontario and Costa Rica are different in many aspects, the study of these two regions has drawn general lessons for the present and future of electrical energy systems. From an individual perspective, this study has suggested that both jurisdictions have had some success in providing broad electricity access and incorporating renewable energy options but still need to make considerable improvements in different areas. Some of the main findings suggest that it is crucial for electrical energy systems to be supported by effective tools for official electrical energy system planning and project approval processes. Equally important, key participants in the electrical energy system need to demonstrate the capacity to respect Indigenous rights, environmental regulations, and natural protected areas, and to include local community needs in decision-making. Finally, the lessons learned from these cases indicate that sustainability-based assessments that focus on maximizing contributions to positive effects can be useful tools by developing criteria that pays attention to transformative opportunities and seeks the maximization of positive effects that are mutually reinforcing to all the criteria categories.

Table 9.2. Sustainability-based assessment framework specified to electrical energy systems

Climate safety and social-ecological integrity
▪ Reduction of harmful emissions to the atmosphere, including carbon and other substances that aggravate global warming ▪ Mitigation and adaptation to already unavoidable social and ecological effects associated with climate change ▪ Enhancing human health by maximising air quality, reducing toxic waste and ensuring safe management in all life-cycle processes ▪ Minimizing threats to the biodiversity and ecological integrity, including toxic substances, resource depletion, animal and plant species extinction and pollution in all life-cycle processes ▪ Preserving main system characteristics that contribute to lasting socio-economic well-being and generate positive social-ecological system dynamics and effects
Intra- and inter-generational equity, accessibility, reliability, and affordability
▪ Favouring direct and indirect employment opportunities that are well paid, long lasting, conveniently located and otherwise accessible, fulfilling/challenging, etc. ▪ Promoting distributional justice related to the benefits and risks of electrical energy system operations and addressing energy poverty by avoiding the creation of negative effects, and ensuring the fair provision of positive effects, among present and future generations across regions, gender, race, Indigenous/non-Indigenous people, poor and rich, and marginalized groups ▪ Favouring technical and policy options that maximize system capacity to provide electricity access and power essential human services for poor and remote areas ▪ Ensuring technical viability (e.g., reliability, resilience, safety, adaptive capacity, ease of repair, etc.) ▪ Ensuring economic viability (e.g., capital and operating costs, and risks in the short and long term, in comparison with other design options available)
Cost-effectiveness, resource efficiency and conservation
▪ Increasing capacity for development and integration of reliable and affordable renewable-sourced energies that reduce negative climate change effects.

- Decreasing reliance on fossil fuels
- Enhancing technical demand management capacity to match electricity quality and quantity to end-user needs (e.g., storage, smart grid technologies, demand response options)
- Preserving and enhancing natural (and other meaningful) resources that are essential for community well-being
- Minimizing provision costs and socio-ecological costs, predominantly caused by life-cycle losses in generation and delivery activities

Democratic and participatory governance

- Maximizing capacity for democratic and participatory deliberation that facilitates public consultation and acceptance through explicit and transparent processes
- Building favourable conditions for open and informed discussion with integration of experts, stakeholders, vulnerable groups and local knowledge, and ensuring particular attention to adequate representation of Indigenous peoples' rights and interests in decision-making
- Recognizing and addressing political barriers embedded in electrical energy systems that undermine democratic and participatory governance (e.g., powerful political and economic interests)
- Enhancing understanding and other capacities for just transitioning, opening windows of opportunity, and mobilizing key actors' influence for positive change
- Favouring policy-making design that clarifies the implications of attaining climate and associated social-ecological objectives

Precaution, modularity and resiliency

- Favouring prudent and precautionary decision-making in consideration of unpredictability and incomplete understanding on complex dynamics
- Supporting design options that minimize vulnerability and maximize recovery capacity to potential threats (e.g., natural disasters, accidents, system malfunctions, terrorist attacks, etc.)
- Favouring technology with high adaptive capacity for modifications over time, as well as design options for greater system compatibility
- Minimizing social, economic and biophysical risks in planning and decision-making for electrical energy systems of the future
- Avoiding planning and decision-making that increase path dependency (e.g., capital intensive, massive long-term projects with low capacity for modifications over time)

Transformation, integration of multiple positive effects, and minimization of adverse effects

- Accumulating positive sustainability-oriented effects for desirable change, while avoiding trade-off scenarios that pose risks to already disadvantaged groups, through the implementation of multiple and mutually reinforcing sustainability-contributing packages of initiatives
- Enhancing capacity for addressing governance challenges of transforming towards sustainability by incorporating governance design options that facilitate transformations (e.g., collaboration and multi-scale alignment, self-examination and clarification of political dynamics, adaptive capacity in policy- and decision-making for long-term considerations, specification to context).
- Supporting just transitions to ensure that transformation planning and practice build the resilience of what is valuable and pay special attention to the interests of the most vulnerable
- Developing pathways to sustainability that address combinations of policy and technical options, deliberative processes, and strategic approaches aim to identify how specific desirable targets can be reached, instead of aligning decision-making to predictions based on current technical and economic trends
- Facilitating complementarity of different approaches to transformation by taking diverse knowledges seriously, accepting a plurality of pathways to sustainability and embracing the political nature of transformations

9.3. Major findings

9.3.1. Learnings from the main areas of knowledge

Designing and evaluating electrical energy systems to minimize the negative effects and increase the positive contributions to human and environmental well-being cannot be achieved without recognizing that the world is made of complex systems. Complexity has a key role in the pursuit of sustainability since it leads to moving away from the idea that the sum of diverse sustainability-related efforts in separate social, ecological, and economic sectors will inherently result in global sustainability. The literature on sustainability in complexity suggests that the effects of implementing sustainability in different system components will not necessary align positively towards desirable overall effects. In fact, dealing with trade-offs has been an unavoidable consideration in this work given that non-linear dynamics often lead to seemingly positive interactions within one or multiple system components while simultaneously creating negative effects in unexpected points in space and time. However, the theory and practice suggested that it is possible to align sustainability efforts in diverse sectors by emphasizing the development of mutually reinforcing cumulative effects that are equally important to attain overall sustainability.

Electrical energy systems are unique and highly important venues for the application of sustainability. Building a sustainability-based assessment framework that is applicable to electrical energy systems entailed delving into scientific literature, global energy debates and overall accepted goals. One key finding is that electrical energy systems are ever evolving and that informed evaluation of potentially desirable options to power the most essential services for human well-being depends heavily on respect for the specific circumstances of the jurisdiction being examined. For instance, knowledge on sustainability and electrical energy systems suggests that no single energy resource or technological advancement can provide definitive global energy solutions. This is because: 1) contextualities determine the energy needs and possibilities of different jurisdictions; and 2) these contextualities can change constantly. Therefore, while it was possible to build a generic framework that recognizes core sustainability-related considerations that apply to all electrical energy systems, the framework must be specified for application to each particular system. Furthermore, while framework specification to two different systems – Ontario and Costa Rica – demonstrated the value of the generic framework, further specification to more electrical energy systems is necessary both for those particular applications and to hone the generic framework over time.

The design of sustainability-contributing electrical energy systems can have many forms. That is, there is a plurality of what is perceived as desirable electrical energy system design options, raising valid questions about the criteria that should be included in the generic sustainability-based assessment framework. While building the framework, there can be conflicting views about the main causes of electricity-related issues and the solutions that should be prioritized. The sustainability-in-complexity literature indicates in this sense that there are basic requirements for making progress towards sustainability that should not be overlooked in energy system decision making in any jurisdiction. Likewise, the literature on electrical energy systems and sustainability acknowledges overall targets to aim for in considering responses to pressing issues – e.g., lack of access to energy in poor and remote areas (Nathwani & Kammen, 2019), climate change and environmental impacts (UNEP, 2019), and unfair distribution of socioeconomic risks and benefits (Sovacool et al., 2017) – that stem from unsustainable energy practices. However, many pathways could be chosen to pursue such targets. The process of choosing the sustainability-based assessment framework generic criteria must therefore be encompassing and leave openings for discussion and deliberation.

The addition of a main criteria category that focuses on transformations towards sustainability in the generic framework is a new element in sustainability-based assessment frameworks. Chapter 4 has stressed that knowledge on transforming towards sustainability is often disjointed but there is recognition that different approaches to transformation provide insights that can be complementary in attempts to elicit change in entrenched systems (Patterson et al., 2016; Scoones et al., 2020). Considering this, the main criteria category entitled “Transformation, integration of multiple positive effects, and minimization of adverse effects" draws on relevant insights from diverse existing approaches. During this process, key elements that were identified in the literature to have the potential to stimulate desirable change appeared as suitable criteria for evaluation. One important lesson learned from this process is that diverse understandings of transformation can be complementary and mutually supportive to each other and to the rest of the criteria categories. However, while this is a step forward, it is crucial to recognize that there will still be debates about what needs to be transformed and what are the most effective ways to do it safely, fairly and promptly. This also means that, as the literature on transformations towards sustainability suggests, further works to question and test the effectiveness of the evaluation criteria will be essential.

9.3.2. Framework of sustainability-based assessment criteria for evaluation of existing electrical energy systems

The proposed sustainability-based assessment framework specified to electrical energy systems (Table 9.2) provided a favourable starting point for further specification and application to Ontario and Costa Rica's contexts. Accordingly, the criteria that stemmed from these considerations proved to be applicable to the two selected jurisdictions. In both cases, the framework criteria worked as an effective tool, or a map, to pinpoint in the literature and document research the most relevant sustainability-related considerations regarding the operations and management of electrical energy systems. Discussing these considerations generally with electrical energy system participants in the two jurisdictions helped to corroborate that the evaluation criteria included in the framework did encompass the contextual issues. The sustainability-based assessment framework, at the same time, benefitted from the data collection and specification processes by including contextualities and examples that reflect how the contextual issues are perceived in practice. Overall, the generic framework was appropriately designed to be applied for diverse applications so long as it is adjusted to the changing global energy scenarios and specified to respect local contexts.

9.4. Learnings from specifying and applying the framework to the case studies

9.4.1 Case comparison

The comparison of the Ontario and Costa Rica case studies revealed some key themes for a concise discussion on the most notable similarities identified between the electrical energy systems of the two jurisdictions. While Chapter 8 has already provided an extensive analysis of notable similarities and differences, this discussion emphasizes similarities that provide substantial themes for general comparison in this thesis work, and for further discussion in future studies. In general, three key comparable aspects related to cost-effectiveness, governance, and system rigidity can be identified.

Difficulties in minimizing costs

Minimizing costs has been a key theme in both case studies due to economic risks that undermine the systems' capacity to provide affordable electricity for all, in the present and in the future. For instance, the two cases have shown consistent increases in electricity prices in recent years partly because of financially risky decisions and insufficient support to options that can favour cost-effectiveness. Decision-making has generally favoured the approval of long-term and highly expensive electricity generation projects. This includes the construction of new, and renovation of already existing, large electricity generation projects with low capacity for modifications over time. As a result, the two jurisdictions have experienced some similar scenarios in their recent history, such as significant financial losses due to the cancellation of projects, as well as high expenses in refurbishment and repair costs. Additionally, both cases have shown potential for the wider adoption of efficiency and conservation technologies and programmes that has not been sufficiently developed yet. Increasing efforts to minimize costs may therefore be a relevant focal point for comparison in other applications of the sustainability-based assessment framework, and may draw increased attention as a key global objective to promote affordable electricity for all.

Insufficient efforts to meet democratic and participatory governance requirements
Electrical energy system planning in the two jurisdictions has demonstrated an insufficient capacity to effectively implement and respect official processes for public approval of electricity-related projects. As mentioned in Chapter 8, the two cases have faced similar issues related to lack of transparency in decision-making, insufficient consultation, violations of human rights and environmental regulations, misrepresentation of Indigenous and local community interests, and disruption of protected areas. Particularly, ignoring the interests of Indigenous communities and other disadvantaged social groups in official decision-making has created challenging contexts in both jurisdictions. The challenges have included social mobilizations that led to the cancellation of highly expensive projects resulting in considerable financial losses, and tensions between governments, local communities, and other participants in the electrical energy system. The analysis of both cases has suggested that recognizing democratic and participatory governance of electrical energy systems in different local jurisdictions as an unavoidable requirement for contributing to sustainability will be key to tackle energy poverty and unfair distribution of risks and benefits in the immediate jurisdictions as well as globally.

Path dependence on rigid systems
While their electricity mixes are different, the comparative analysis has shown that both jurisdictions have a generally rigid electrical energy system. That is, while some new options have been promoted in their recent history, the two jurisdictions have developed a path dependence on electrical energy system design options with low flexibility and high risks in failure. This includes long-term commitments to large, highly expensive, electricity generation plants with limited capacity for the incorporation of emerging options in the global energy landscape. According to the comparative analysis, system rigidity in the two jurisdictions has undermined the system capacity for cost-effectiveness, resource efficiency and conservation, as well as precaution, modularity and resiliency. For instance, system rigidity in both cases has contributed to a limited adoption of promising options such as alternative renewable energy,

energy storage, and demand response tools. This dissertation research has identified that tools to break negative trends (e.g., scenario planning and backcasting) can be key to building possible combinations of policy and technical pathways that can help to unlock path dependency to rigid electrical energy systems in both cases.

9.4.2. Main learnings

Applying sustainability-based assessment frameworks for electrical energy systems demands attention to and respect for the specific differences among local and regional contexts. The case studies revealed that overlooking the backgrounds and current contextualities of Ontario and Costa Rica could diminish positive outcomes and create further negative cumulative effects. Also, as mentioned earlier, embracing specification to context as a necessary step for electrical energy system evaluation and design in different jurisdictions recognizes that there is not now, and there may never be, a single technological advancement, energy resource or initiative that can provide solutions to global energy needs and issues.

Specification to context can also help to accelerate transformations towards more sustainable trends at a global scale. To do so, sustainability-based assessments should focus on maximizing the accumulation of beneficial effects from sustainability-related initiatives at multiple jurisdictional levels. It is crucial, however, to align efforts, as well as clarify the possible non-linear interactions derived from the initiatives, between and among scales. For these purposes, construction and application of the sustainability-based assessment framework involves three core tasks: a) develop criteria that is mutually reinforcing and of equal importance; b) identify and manage the possible trade-offs emerging from the application; and c) foster compatibility with other similar initiatives through collaboration and co-production of knowledge.

More specifically, the addition of transformation, integration of multiple positive effects, and minimization of adverse effects as a new criteria category for sustainability-based assessments has effectively drawn attention to barriers and opportunities to transforming electrical energy systems towards sustainability-contributing paths. This creates an initial opening for further developing attention to barriers and opportunities to transformation by honing the criteria through more applications in different jurisdictions and energy scenarios.

The application of the proposed sustainability-based assessment framework for electrical energy systems also unveiled opportunity for application to other jurisdictions with further specification. Ontario and Costa Rica are only a small sample, but the analysis of the findings from specification to context and application demonstrated that the proposed criteria provided a common ground for effectively comparing two jurisdictions that are considerably different. In fact, specification to context creates opportunity for more substantial comparisons in different applications by facilitating the identification of similarities and differences that are closely tied to contextual characteristics. Overall, as highlighted in chapter 8, this study has made an important contribution by suggesting that specification and comparability can work together in an effective approach to analyses.

9.5. Implications for theory

9.5.1. Moving towards next-generation sustainability-based assessments

First generation approaches to impact and environmental assessments at strategic and project levels usually have focused on how to best minimize adverse effects (Johnston, 2016). Instead, Canada's experience has suggested that official sustainability assessment endeavours can benefit from adopting approaches that seek to maximize the accumulation of positive sustainability gains in a context of complexity (Gibson, 2020). Studies have found, however, that more favourable policy-making regimes are necessary to facilitate the broad implementation of a next generation of sustainability-based assessments (Fonseca, 2020).

The findings from this thesis work can contribute to advancing a next generation of sustainability assessments through the development, specification, and application of a sustainability-based assessment framework to electrical energy systems. The application of the proposed framework to the contexts of Ontario and Costa Rica has revealed that next-generation sustainability-based assessments can be suitable for specification and application not only to different sectors (Chapter 2) but also to different jurisdictions. However, the case studies suggested that the current electrical energy system decision-making regimes need to pay more attention to aligning policy at different scales, and between different sectors, to facilitate rapid transitions and greater sustainability-related benefits. One essential consideration is developing sustainability-based assessment frameworks as packages of initiatives with high capacity for compatibility and improvements over time. For instance, the selection of the criteria has to promote positive interactions among the categories and the sub-criteria, and identify potential interactions with adjacent sectors and initiatives. An additional consideration is that sustainability-based assessment frameworks need to recognize jurisdictional political contexts as enablers or inhibitors of positive cumulative effects. This can be promoted through inclusion of the criteria category of transformation, integration of multiple positive effects, and minimization of adverse effects, with further theoretical contributions.

9.5.2. Designing sustainability-contributing electrical energy systems

One of the most relevant outcomes of this thesis work is the development of a sustainability-based assessment framework that can be used as a tool in the evaluation and design of electrical energy systems in different jurisdictions, with further specification to context. The specification to context and application processes revealed that complex systems thinking fits adequately into building a framework that is supportive to sustainability-contributing electrical energy system design.

Complex systems thinking suggests that electrical energy systems' change cannot be fully controlled, but it is possible to unlock barriers to and maximize stimulating effects for desirable change. In this sense, responses to pressing socioecological issues can be improved by shifting away from searching for feasible combinations that are less environmentally and socially harmful while still meeting basic energy needs, and towards designing electrical energy systems that contribute positively to maximizing mutually supportive sustainability gains (Chapter 3).

The case studies suggested that energy scenarios can change unpredictably, and therefore the design of electrical energy systems should not rely mostly on predictions based on current trends. Similarly, one ultimate preferred form of electrical energy system design should not be expected. Instead, promoting flexibility, or capacity for changes over time, in planning processes is key for addressing uncertain futures. Achieving collaboration of different actors, as well as broad approval of projects, plans and initiatives through inclusive and transparent deliberation, is also ideal since the participants in electrical energy systems have the capacity to facilitate or undermine sustainability-contributing efforts. At the same time, the contributions to sustainability must be fair to reduce burdens to electrical energy system participants who are already disadvantaged. Finally, while electrical energy systems have some capacity to recover from debilitating events (e.g., high financial losses, negative environmental impacts, and severe meteorological events), these can also create irreversible negative long-term effects (e.g., public health issues and social conflict). Therefore, designing electrical energy systems must emphasize precaution to avoid negative socioecological and economic risks that may be too severe for the system and social-ecological contexts to safely tolerate.

9.6. Implications for practice

Electrical energy systems can benefit greatly from effective long-term planning and decision making. This work suggests that increasing positive contributions to sustainability requires effective official planning processes, with publicly approved and published criteria towards long-term objectives, and clarifying the actions needed to attain them. Failure to do so, as this study demonstrates, can undermine responses to the most urgent issues that currently imperil human and environmental well-being. National and jurisdictional authorities therefore must ensure that the continuity and coherence of sustainability-related goals in electrical energy system planning is not undermined by deference to short-term political and economic pressures. In this regard, independent planning and regulating entities can be crucial components to preserve long-term goals and align efforts by different electrical energy system participants at different scales. Furthermore, backcasting and other scenario planning and visioning approaches have been identified as key to establish desirable objectives and clarify the policy required to attain them. This entails moving away from usual electrical energy system planning approaches that attempt to anticipate future energy needs based on extrapolating from current demand trends.

This thesis research has identified emerging options in the global energy context that are promising for making progress towards sustainability and are relevant for the design of future electrical energy systems (Chapter 3). Renewable energy alternatives, energy storage, smart grid tools, electric vehicles, and efficiency technologies and initiatives are some components that have gained increased attention. However, paired with the capacity for technical compatibility to incorporate the options reliably, public approval and social acceptance of new system design options need particular attention. Governing electrical energy systems democratically and participatively is crucial to enhance jurisdictional capacity for attaining broad public understanding and approval of promising options today and in the future. As revealed in the case studies, lacking effective processes, or ignoring established milestones, for public approval and social acceptance can lead to damaging conflict and the cancellation of electricity-related projects with severe financial losses and sociopolitical consequences. As mentioned earlier, jurisdictional authorities need to demonstrate that they can implement consultation, stakeholder participation and collaboration, assessment obligations at different stages, provide channels for public input, as well as deliver project-related information transparently and credibly.

The implementation of sustainability-based assessments will also require recognition of politically driven dynamics. In this case, this means that even with aligned efforts to implement sustainability-based assessments as mutually reinforcing packages of initiatives, there can also be particular divergent interests within and among assessment teams at different levels. Another relevant aspect is that institutional barriers rise only in part due to the motives and actions of political actors. Within government departments and utilities, important energy system officials may not be interested in or trained for unlocking entrenched pathways. Additionally, the idea of integrating a broad sustainability-based scope and transformative ambitions to electrical energy system planning can be perceived as too difficult to achieve. It is important that the application processes of sustainability-based assessments ensure openness for electrical energy system actors' and public contributions and review, as well as transparency. In this sense, independent planning and reviewing can also be relevant components to ensure that the different initiatives in the electricity sector foster maximum sustainability gains.

This thesis work has emphasized the relevance of specification to context in sustainability-based assessment efforts. Specification to context can be useful to identify the similarities and differences that will determine the development of effective criteria in different jurisdictions to make more substantial comparisons. However, it is crucial to carry out effective processes for defining meaningful criteria according to the characteristics and socially and ecologically valued components of the evaluated jurisdictions. This entails consulting different sources of knowledge and fostering contributions from diverse actors, especially from groups with less influence and limited resources, and ensuring that the diverse interests are well represented in the final assessment framework. Jurisdictional authorities and other key actors can contribute to specification processes by promoting tools for development and easy access to data in different sectors and disciplines, as well as knowledge integration and co-production.

9.6.1. Recommendations for policy-makers and sustainability proponents focused in Ontario's electrical energy systems

Policy-making for electrical energy systems in Ontario must acknowledge that the political context has a great influence in short- and long-term sustainability aspirations. One key recommendation is that electrical energy system policy should anticipate the changing political contexts, and the different sustainability-related goals depending on the political party that is in government. Since the current provincial government has shown a lack of interest in committing to electrical energy system-related sustainability goals, it is important that policy-makers and sustainability proponents focus on new planning tools at the provincial level. For instance, independent planning authorities that establish and oversee electrical energy system planning might be necessary to reinstate and avoid the absence of long-term planning requirements in the future. Additionally, it is important that policy-making pays attention to the cumulative effects of recent provincial decisions of removing official planning requirements and ignoring climate change commitments, and to the implications for long-term energy planning (e.g., expected increases in greenhouse gas emissions from the electricity sector).

One main finding in the Ontario case study is that establishing effective processes for attaining broad public approval in electrical energy system-related projects and initiatives has been a key challenge in the province. In this regard, one recommendation is that new electrical energy system planning efforts pay particular attention to ensuring that consultation obligations and public approval requirements are respected in electrical energy system projects. Particularly, planning efforts must ensure that projects and initiatives are better designed to deliver broader positive effects to First Nations and communities. Policy-makers must explicitly recognize that avoiding official requirements for project approval to favour short-term economic and political purposes has posed risky negative long-term social and ecological effects (e.g., social tension, climate change-associated risks, and cost-related issues). By strengthening electrical energy system planning processes and attaining broad public approval in electrical energy system design options, policy-making can at the same time take a step forward in advancing new technical options for efficiency, and conservation and demand response. In this sense, policy-making can promote a greater flexibility for changes over time to incorporate emerging renewable, efficient, and low-cost system options.

Ontario's electrical energy system has faced evident political challenges that are linked to emerging tendencies of right-wing populism and post-truth politics, and that have contributed to maintaining the gap between contribution-to-sustainability needs and current policy-making practices (Chapter 4). These political challenges include efforts to disregard climate change-related evidence, and the polarization of sustainability goals against aspirations for short-term socioeconomic well-being. In this regard, it is key that policy-making in Ontario pays attention to approaches to systemic human-induced change (Chapters 2 and 4). Provincial efforts may benefit from implementing approaches that seek targeted interventions for system innovation and looking for leverage points to unlock current entrenched practices that hinder the development of policy that deliver positive contributions to the provincial and multi-jurisdictional context (e.g., Abson et al., 2017). For instance, different works have highlighted strategies to create niches for innovation as protected spaces for policy development, experimentation, and eventual implementation as desirable tools to advance climate and other sustainability-related policies more effectively (e.g., Angheloiu & Tennant, 2020; Geels et al., 2017).

9.6.2. Recommendations for policy-makers and sustainability proponents focused in Costa Rica's electrical energy system

Similarly to Ontario, policy-making for Costa Rica's electrical energy system must pay particular attention to building effective processes for consultation and public approval processes. Due to the past pattern of large hydroelectricity development without consultation, electrical energy system authorities need to demonstrate that they can respect Indigenous groups interests, community needs, and environmental regulations. Particularly, during ongoing transitions in the national electrical energy system that can provide transformative opportunities. In this scenario, policy-makers and sustainability proponents can play a key role by promoting sustainability-based assessment efforts as requirements for current and future electricity-related plans, projects and initiatives (e.g., Gibson, 2017). This thesis work has proposed that sustainability-based assessment frameworks specified for application to electrical energy system plans, projects, and initiatives can help as tools to align policy-making at different scales, and between multiple projects related to ongoing transitions (e.g., Burch, 2017). In this sense, electrical energy system policy-making can contribute to avoiding a re-emergence of undesirable effects like strengthening path dependence on large hydroelectricity generation, avoiding consultation in electrical energy system operations, and increasing fossil fuels in the national electricity mix.

One threatening climate change-associated effect for the Costa Rican electrical energy system is that changing patterns in weather and water resources have affected the reliability of resources to power the system. In this sense, policy-making may need an increased focus on the further adoption of diversified electricity resources and technical system design options that promote efficiency, conservation, and greater capacity for demand response. For instance, smart grid and demand response tools, energy storage, as well as alternative renewable energy like smaller hydroelectricity, on- and off-shore wind, solar, and geothermal projects have been identified as viable alternatives that are getting increasing attention. At the same time, policy-makers and sustainability proponents need to emphasize the preservation of existing system characteristics that are desirable (see Chapter 4) – e.g., affordability, universal access, and financial stability. However, maintaining desirable characteristics will be especially challenging while also dealing with the lasting effects of the COVID-19 pandemic. In this regard, one recommendation for policy-makers and sustainability proponents is to focus on advancing initiatives for integrating and co-producing of knowledge to better understand and tackle pressing challenges and, as well as the uncertain and interlinked effects of ongoing crises (Romero-Lankao et al., 2017). At the same time, integration and knowledge co-production can promote the implementation of initiatives that are better suited theoretically to maximize the accumulation of positive sustainability-associated effects (Hacking, 2019; Kanie et al., 2020).

In the Costa Rican context, predominantly adopting technocentric approaches that emphasized large hydroelectricity development and overlooked community needs has contributed to social tension and financial challenges. Therefore, policy-making must identify and use emerging windows of opportunity from particular events in a transitioning energy context, and to steer desirable change towards more sustainable futures (Brundiers & Eakin, 2018). For instance, policy-makers find and push for the opportunities emerging in recent decisions to halt large hydroelectricity development and to focus on alternative renewable energy sources and other electrical energy system options that are less socially and environmentally disruptive (e.g., electric vehicles deployment, efficiency and demand response options). Additionally, community initiatives need to be advanced from the bottom-up, having top-down policy support, to disrupt management approaches that are path dependent on technocentric decisions (Johnstone et al., 2020). For example, the Costa Rican policy context should support, and effectively include in planning decision-making, the growing community movements in favour of protecting the rivers and respecting human rights and environmental legislation. As in the Ontario case, moving away from the usual practices and towards sustainability transformations may require the implementation of niches for innovation and human interventions for systemic change. This while advancing multi-scale initiatives as small transitioning steps that can be scaled up or down towards more desirable outcomes (Roberts & Geels, 2019; Scoones, 2020).

9.7. Directions for further research

The sustainability-based assessment framework for electrical energy systems resulting from this thesis work is a relevant contribution to better design electrical energy systems to deliver more positive and mutually supporting sustainability-related effects and to advance transformations towards sustainability. Further development and application of the framework, nonetheless, would benefit from contributions from more key participants in the electrical energy systems of Ontario and Costa Rica in order to carry out applications to particular plans, projects, and initiatives in each of the jurisdictions. For instance, works that seek better representation of Indigenous communities, industry actors, and local utilities and distribution companies would be helpful.

In order to test its validity as a generic tool, the sustainability-based assessment framework for electrical energy systems will also need specification to context and application to more different jurisdictions and at multiple levels. Future works can help to hone the framework by identifying strengths and weaknesses of the current form and criteria. Applications to more jurisdictions can also help to enrich the framework and reveal further opportunities for future research. As new system options emerge, electricity markets change, and current promising options move forward – e.g., further technological development and adoption of energy storage, renewable energy alternatives and smart grid tools – the framework will require modification to reflect more recent knowledge on energy scenarios.

Transformation, integration of multiple positive effects, and minimization of adverse effects as a new criteria category to evaluate and design electrical energy systems towards sustainability can be a relevant element to recognize political contexts more explicitly and ensure just transitions. Also, it can emphasize the need to approach sustainability as a maximization of broad positive effects in multiple complex systems, and as an interconnection of various initiatives that are compatible and mutually reinforcing. This criteria category, however, will require particular attention in future specification to context in new applications. While complexity thinking can to some extent provide a theoretical understanding of how complex systems transition and transform, approaches to transformation towards sustainability still need further development (Chapter 4). The literature is still somewhat disjointed and relatively new in terms of being incorporated to sustainability assessment endeavours. Future works must therefore pay attention to developing research in this regard and incorporate breakthroughs emerging in this area. This can help to enrich the criteria and to better unlock the potential for the accumulation of sustainability-based contributions for future electrical energy system-related plans, projects, and initiatives.

Emerging adverse political trends must also be considered in future research. Particularly, recent trends of right-wing populism and post-truth politics need to be examined in different contexts. While Chapter 4 has broadly addressed the rising political challenges in the global energy landscape, these may appear differently in particular jurisdictions. In Ontario, for instance, these have appeared as the provincial government disregarding climate change evidence and polarizing sustainability-associated goals against immediate socioeconomic benefits. In Costa Rica, the political context has traditionally relied on technocentric management approaches. Further sustainability-based assessment applications for electrical energy systems, and broader climate and sustainability goals, therefore, need to give more specific attention to how adverse political scenarios emerge in particular contexts. That is, further research needs to identify the political elements that oppose change and contribute to maintaining the gap between current practices and what is needed to taking steps towards sustainability transitions and transformations. Additionally, it is key that future works aim to provide theoretical contributions on possible steps needed to move away from adverse political trends (e.g., right-wing populism and post-truth politics in Ontario, and in other similar situations) to a more evidence and criteria-based system planning and decision-making process.

This dissertation research has identified needs to address politically driven dynamics that can affect sustainability-based assessment efforts at different stages of application, and between and within different jurisdictional levels. On this matter, section 9.6 has noted the relevance of promoting openness for participation, transparency, independent planning and reviewing. Future research can explore how to ensure that the full suite of criteria is applied as equally important and that the sustainability requirements are not undermined by divergent interests of participants in the application processes. One key aspect, for instance, can be focusing on the widespread mobilization of knowledge on the relevance of pursing sustainability as mutually supportive goals and cumulative gains since the early stages of sustainability-based assessment efforts. Further applications of the sustainability-based assessment framework for electrical energy systems to different jurisdictions can help to recognize emerging political challenges and possible viable solutions.

As suggested in Chapter 4, relevant approaches to human-induced change in complex systems can provide theoretical and practical foundations to closing such gap. While these have been addressed to some extent in the policy recommendations, implications for application of these approaches to the two case jurisdictions would benefit from further elaboration (e.g., to address deepening entrenchment of problematic directions in Ontario). Also needed are applications to other particular contexts, sectors, and initiatives, in future research to further advance knowledge on how to steer transitioning and transformative effects towards accumulating more positive, broad, and mutually reinforcing sustainability gains. For example, further research should pay attention to the application of approaches to human-induced change that seek transitioning steps that have positive influence at multiple scales, identify places or leverage points in the system to intervene and foster desirable change, like niches for policy and technological development, experimentation and innovation, as well as the incorporation of initiatives that can emerge from bottom-up and be supported by top-down scales, instead of relying mainly on technocentric, large-scale top-down full system change (e.g., Angheloiu & Tennant, 2020; Abson et al., 2017; Fischer & Riechers, 2019; Roberts & Geels, 2019; Westley & McGowan, 2017).

Finally, addressing the future research opportunities noted above can be relevant to identifying key needs and opportunities to make more positive sustainability contributions. For instance, the application of the sustainability-based assessment framework for electrical energy systems in further case studies can help to confirm the utility of the framework developed in this dissertation work and further hone it for future applications. Further applications to different jurisdictions can focus more closely on revealing what are the contextual dynamics that contribute to maintaining the existing gap between current practices and what is needed to make progress towards sustainability, according to the key elements proposed in the sustainability-based assessment framework for electrical energy systems. Future applications can also help to identify and assess particular initiatives that have succeeded in delivering broader contributions to positive sustainability-related effects through effectively implementing transitioning and transforming efforts. This can aid in advancing knowledge on the implications for directing transitions and transformations in electrical energy systems to contribute more positively to sustainability. At the same time, future works can address the elements above to develop sustainability-based assessment frameworks for application to other energy-related initiatives, and to other sectors, to advance a more general understanding on the implications for transitioning and transforming towards attaining broader sustainability objectives.

9.8. Concluding remarks

Basic human social and economic activities and governance practices can influence long-term, unpredictable, and sometimes irreversible changes in societies and the environment. Evidence shows, for example, that significant changes are needed rapidly in different socioeconomic sectors to avoid severe and irreversible risks of human-induced climate change (IPCC, 2021). Within this context, sustainability as a field of study can help to identify options for governing interlinked human and environmental systems to maximize their positive contributions to the broader socioecological context. This study has examined electrical energy systems as key contributors of positive and negative sustainability-related effects that induce broader social and ecological system change.

While electrical energy systems have provided essential services for human prosperity, they have also had impacts that undermine aspirations to attain widely accepted sustainability goals. This has led electrical energy system experts globally to pay more attention to new system design options with the potential to mitigate such impacts (e.g., smart grid tools, renewable energy, energy storage) (Castagneto Gissey et al., 2019; Lazowski et al., 2018; Tzankova, 2020). The theoretical analysis suggests in this regard that it is possible to design electrical energy systems to minimize the accumulation of negative effects and deliver more positive sustainability-associated effects. However, as stressed in Chapter 4, directing change is extremely difficult in complex socioecological systems (including energy systems) – e.g., non-linear dynamics happening at multiple scales (Keating & Katina, 2019) can lead to the accumulation of unexpected negative effects (Atlin & Gibson, 2017) and change systems unpredictably (Moore et al., 2018).

Ontario and Costa Rica face pressing challenges that have led to the recognition that electrical energy systems need to provide more positive contributions to sustainability-goals. While barriers to change were identified in both cases, ongoing transitions also provide opportunity for taking important steps towards sustainability. For both jurisdictions, improved efforts to evaluate and plan for electrical energy systems operations and initiatives more effectively may play key role in attaining (or not) climate change commitments and other sustainability-associated goals. However, this will require new sustainability-based assessment approaches that emphasize the complexity of the world and therefore aim to design electrical energy system projects, plans, and initiatives that are mutually reinforcing to other initiatives at multiple scales and through different sectors. In our pressing context, this task is daunting, but this thesis work has provided some important initial steps.

References

2050 Pathways Platform (2019). *Costa Rica launches decarbonization plan.* Retrieved from: https://2050pathways.org/costa-rica-launches-decarbonisation-plan/

Abson, D. J., Fischer, J., Leventon, J., Newig, J., Schomerus, T., Vilsmaier, U., … Lang, D. J. (2016). Leverage points for sustainability transformation. *Ambio,* 46, pp. 30-39.

Acar, C., Beskese, A., & Temur, G. T. (2019). A novel multicriteria sustainability investigation of energy storage systems. *International Journal of Energy Research*, 43(12), pp. 6419-6441.

Adachi, C., & Rowlands, I. H. (2010). The role of policies in supporting the diffusion of solar photovoltaic systems: Experiences with Ontario, Canada's Renewable Energy Standard Offer Program. *Sustainability*, 2(1), pp. 30-47.

Adger, W. N., Brown, K., Fairbrass, J., Jordan, A., Paavola, J., Rosendo, S. & Seyfang, G. (2003). Governance for sustainability: Towards a 'thick' analysis of environmental decisionmaking. *Environment and Planning A,* 35, pp. 1095-1110.

Adger, W. N., Jordan, & A. (2009). Sustainability: Exploring the processes and outcomes of governance. In W. N. Adger, Jordan & A. (Eds.), *Governing sustainability* (pp. 3-31). Cambridge: Cambridge University Press.

Adil, A. M. & Ko, Y. (2016). Socio-technical evolution of Decentralized Energy Systems: A critical review and implications for urban planning and policy. *Renewable and Sustainable Energy Reviews,* 57, pp. 1025-1037.

Ahlqvist, T. & Rhisiart, M. (2015) Emerging pathways for critical futures research: Changing contexts and impacts of social theory. *Futures,* 71, pp. 99-104

Akella, A. K., Saini, R. P. & Sharma, M. P. (2009). Social, economical and environmental impacts of renewable energy systems. *Renewable Energy,* 34, pp. 390-396.

Alanne, K., & Saari, A. (2006). Distributed energy generation and sustainable development. *Renewable and Sustainable Energy Reviews,* 10(6), pp. 539-558.

Aldarajee, A. H., Hosseinian, S. H., & Vahidi, B. (2020). A secure tri-level planner-disaster-risk-averse replanner model for enhancing the resilience of energy systems. *Energy,* p. 117916.

Allen, P. M. & Strathern, M. (2003). Evolution, emergence, and learning in complex systems. *Emergence,* 5(4), pp. 8-33.

Alshuwaikhat, H. M., Adenle, Y. A. & Saghir, B. (2016). Sustainability assessment of higher education institutions in Saudi Arabia. *Sustainability,* 8, p. 750.

Alstone, P., Gershenson, D. & Kammen, D. M. (2015). Decentralized energy systems for clean electricity access. *Nature Climate Change,* 5, pp. 305-314.

Amer, M., Daim, T.U. & Jetter, A. (2013) A review of scenario planning. *Futures,* 46, pp. 23-40.

Angheloiu, C., & Tennant, M. (2020). Urban futures: Systemic or system changing interventions? A literature review using Meadows' leverage points as analytical framework. *Cities*, *104*, 102808.

AMPCO (2019). *Ministry of Energy, Northern Development & Mines: Consultation on industrial electricity prices.* Submission of the Association of Major Power Consumers in

Ontario (AMPCO). Retrieved from: https://ampco.org/wp-content/uploads/AMPCO-Industrial-Rate-Consultations_june-14-2019.pdf.

Anastopoulou, A., Koutsopoulos, I., & Stamoulis, G. D. (2017). Optimal targeting and contract offering for load curtailment in Nega-Watt markets. *IEEE Transactions on Control of Network Systems*, 4(4), pp. 805-815.

Anaya, J. (2011). *La situación de los pueblos indígenas afectados por el proyecto hidroeléctrico El Diquís en Costa Rica.* United Nations Human Rights Office of the High Commissioner. Retrieved from: https://www2.ohchr.org/english/issues/indigenous/rapporteur/docs/proyectoElDiquis30-5-11.pdf.

Ander-Egg, E. (2011). *Aprender a investigar – Nociones básicas para la investigación social.* Córdoba, Argentina: Editorial Brujas.

Anderson, K. (2001). Reconciling the electricity industry with sustainable development: backcasting—a strategic alternative. *Futures*, *33*(7), 607-623.

Angel, J. (2016). Towards energy democracy: discussions and outcomes from an international workshop. *Work. Rep*, 11-12.

Arbabzadeh, M., Johnson, J. X., & Keoleian, G. A. (2017). Parameters driving environmental performance of energy storage systems across grid applications. *Journal of Energy Storage*, 12, pp. 11-28.

ARESEP (2019). *Anuario estadístico 2019.* Autoridad Reguladora de los Servicios Públicos. Retrieved from: https://aresep.go.cr/aresep/publicaciones/392-otras/3039-anuario-estadistico-2019.

ARESEP (2021). *Antecedentes e historia.* Autoridad Reguladora de los Servicios Públicos. Retrived from: https://aresep.go.cr/aresep/antecedentes-historia.

Arias, L. D. (2017). Conflictos en torno a la generación hidroeléctrica: el caso del Proyecto Hidroeléctrico San Rafael, Pérez Zeledón, Costa Rica. *Revista Nuevo Humanismo*, *5*(1).

Armstrong, J. H., & Kamieniecki, S. (2017). Strategic Adaptive Governance and Climate Change: Policymaking during Extreme Political Upheaval. *Sustainability*, *9*(7), 1244.

Arroyo, D., Astorga, A., Campos, C., Chang, G., Cortés, G., Madrigal, A. … & Monestel, H. (2012). *Estudio multidisciplinario: aproximaciones al Megaproyecto Hidroeléctrico El Diquís.* Kioscos Ambientales. Retrieved from: http://kioscosambientales.ucr.ac.cr/docs/publicaciones/diquis/EstudioDiquis.pdf.pdf.

Asamblea Legislativa (1995). *Reformas de la ley que autoriza la generación eléctrica autónoma o paralela, No. 7200.* Asamblea Legislativa de la República de Costa Rica. Retrieved from: http://www.asamblea.go.cr/sd/Documents/referencia%20y%20prestamos/BOLETINES/BOLETIN%2001/legislacion%20nacional/18093.%20%20Ley%20N%C2%B0%207508.pdf

Asamblea Legislativa de la República de Costa Rica (2010). *Proyecto de ley - ley general de electricidad.* Departamento de Servicios Parlamentarios. Retrieved from: http://proyectos.conare.ac.cr/asamblea/17812.pdf

Aschoff, J. (1967). Adaptive cycles: Their significance for defining environmental hazards. *International Journal of Biometeorology,* 11, pp. 255-278.

Atlin, C. (2019). *Pushing for better: Confronting conflict, unsustainability & colonialism through sustainability assessment and regional assessment in the Ring of Fire.* (Doctoral thesis) University of Waterloo, Waterloo, Canada.

Atlin, C., & Gibson, R. (2017). Lasting regional gains from non-renewable resource extraction: The role of sustainability-based cumulative effects assessment and regional planning for mining development in Canada. *The Extractive Industries and Society*, *4*(1), pp. 36-52.

Avelino, F., & Rotmans, J. (2011). A dynamic conceptualization of power for sustainability research. *Journal of Cleaner Production*, *19*(8), 796-804.

Avelino, F., Grin, J., Pel, B. & Jhagroe, S. (2016). The politics of sustainability transitions. Journal of Environmental Policy & Planning, 185(5), pp. 557-567.

Avendaño-Leadem, D. & García-Sánchez, D. (2019). Path dependence (trayectorias dependientes) en la matriz eléctrica de Costa Rica. *Geo UERJ*, (35), 44815.

Azungah, T. (2018). Qualitative research: deductive and inductive approaches to data analysis. *Qualitative Research Journal*, 18(4) pp. 383-400.

Baghwati, J. N. (1988). Poverty and public policy. *World Development,* 16(5), pp. 539-555.

Balachandra, P. (2011). Modern energy access to all in rural India: An integrated implementation strategy. *Energy Policy*, 39, pp. 7803-7814.

Baldwin, E., Rountree, V. & Jock, J. (2018). Distributed resources and distributed governance: Stakeholder participation in demand side management governance. *Energy Research & Social Science*, 39, pp. 37-45.

Ballestero, M., & López, T. (2017). El Nexo entre el agua, la energía y la alimentación en Costa Rica: el caso de la cuenca alta del río Reventazón.

Banco Interamericano de Desarrollo (2020). *Consultas públicas: el paso a paso – Marcos regulatorios y legales aplicables en Costa Rica.* Inter-American Development Bank. Retrieved from: https://publications.iadb.org/publications/spanish/document/Consultas-publicas-El-paso-a-paso-Marcos-regulatorios-y-legales-aplicables-en-Costa-Rica.pdf.

Bandura, A. (1977). *Social learning theory.* Englewood-Cliffs, N.J.: Prentice-Hall.

Banister, D., & Stead, D. (2004, March). Visioning and backcasting: desirable futures and key decisions. In *Stella Focus Group 4 Meeting, TU Delft, March*.

Bartram, L., Rodgers, J. & Muise, K. (2010). Chasing the Negawatt: Visualization for sustainable living. *IEEE Computer Graphics and Applications,* pp. 8-14.

Basit, T. (2003). Manual or electronic? The role of coding in qualitative data analysis. *Educational research*, *45*(2), pp. 143-154.

Bataille, C., Sawyer, D., & Melton, N. (2015). *Pathways to deep decarbonization in Canada*. Sustainable Development Solutions Network. Retrieved from: http://deepdecarbonization.org/wp-content/uploads/2015/09/DDPP_CAN.pdf.

Beckett, C., Dowdell, E., Monosky, M., & Keeling, A. (2020). Integrating socio-economic objectives for mine closure and remediation into impact assessment in Canada. Draft Report for the SSHRC Knowledge Synthesis Grant: Informing Best Practices in Environmental and Impact Assessment.

Beddoe, R., Costanza, R., Farley, J., Garza, E., Kent, J., Kubiszewski, I., … Woodward, J. (2008). Overcoming systemic roadblocks to sustainability: The evolutionary redesign of worldviews, institutions and technologies. *PNAS,*106(8), pp. 2483-2489.

Beland Lindahl, K., Baker, S., Rist, L., & Zachrisson, A. (2016). Theorising pathways to sustainability. *International Journal of Sustainable Development & World Ecology*, *23*(5), 399-411.

Bell, W. (1997) *Foundations of futures studies: Human science for a new era (Vol. 1).* New Brunswick (U.S.A.) and London (U.K.): Transaction Publishers.

Benevides, H., Kirchhoff, D., Gibson, R. B. & Doelle, M. (2009). *Law and policy options for strategic environmental assessment in Canada.* Submitted to the Canadian Environmental Assessment Agency in partial satisfaction of a Contribution Agreement dated July 2008 between the Canadian Environmental Assessment Agency and the University of Waterloo.

Bennett, N. J., Blythe, J., Cisneros-Montemayor, A. M., Singh, G. G., & Sumaila, U. R. (2019). Just transformations to sustainability. *Sustainability*, *11*(14), 3881.

Benton, T. G., Froggatt, A., Wellesley, L., Grafham, O., King, R., Morisetti, N., ... & Schröder, P. (2022). The Ukraine war and threats to food and energy security. *Chatham House—International Affairs Think Tank*.

Berg, B. L. & Lune H. (2012). *Qualitative research methods for the social sciences* (Eighth edition.). Boston: Pearson.

Berggren, J. (2018). Utilizing sustainability criteria to evaluate river basin decision-making: the case of the Colorado River Basin. *Regional Environmental Change,* 18, pp. 1621-1632.

Berkes, F. & Folke, C. (1998). *Linking ecological and social systems.* Cambridge, UK: Cambridge University Press.

Berkes, F. (2017). Environmental governance for the Anthropocene? Social-ecological systems, resilience, and collaborative learning. *Sustainability,* 9, 1232.

Bhattacharyya, S. C. (2012). Energy access programmes and sustainable development: A critical review and analysis. *Energy for Sustainable Development,* 16, pp. 260-271.

Bibri, S. E. (2018). Backcasting in futures studies: a synthesized scholarly and planning approach to strategic smart sustainable city development. *European Journal of Futures Research,* 6(1), p. 13.

Biermann, F. (2012). Planetary boundaries and Earth system governance: Exploring the links. *Ecological Economics*, *81*(1), pp. 4-9.

Bindé, J. (2000) Toward an ethics of the future. *Public Culture,* 12(1), pp. 51-72.

Blowers, A. (1987). Transition or Transformation?-Environmental Policy Under Thatcher. *Public Administration*, *65*(3), pp. 277-294.

Blythe, J., Silver, J., Evans, L., Armitage, D., Bennett, N. J., Moore, M. L., ... & Brown, K. (2018). The dark side of transformation: latent risks in contemporary sustainability discourse. *Antipode, 50*(5), 1206-1223.

Bobar, A., & Winder, G. M. (2017). Conceptualizing Resilience in Transformation Processes: Working with Context Resilience and Specifying Interrelated Systems in Bavaria’s Forest and Wood Use Systems. *GAIA-Ecological Perspectives for Science and Society*, *26*(1), pp. 191-198.

Bond, A., Morrison-Saunders, A. & Pope, J. (2012). Sustainability assessment: The state of art. *Impact Assessment and Project Appraisal*, 30(1), pp. 53-62.

Bonner, J. T. (2004). Perspective: The size-complexity rule. *Evolution: International Journal of Organic Evolution*, 58(9), pp. 1883-1890.

Börjeson, L., Höjer, M., Dreborg, K. H., Ekvall, T., & Finnveden, G. (2006). Scenario types and techniques: towards a user's guide. *Futures*, *38*(7), pp. 723-739.

Boyle, G., Everett, B., & Ramage, J. (2003). *Energy systems and sustainability: Power for a sustainable future*. Oxford: Oxford University Press.

Brand, U. (2016). "Transformation" as a new critical orthodoxy – The strategic use of the term "transformation" does not prevent multiple crises. *GAIA*, 25/1, pp. 23-27.

Brisbois, M. C. (2020). Shifting political power in an era of electricity decentralization: Rescaling, reorganization and battles for influence. *Environmental Innovation and Societal Transitions*, *36*, pp. 49-69.

Brown, K. (2014). Global environmental change I: A social turn for resilience? *Progress in Human Geography*, 38(1), pp. 107-117.

Brown, K. E., Henze, D. K. & Milford, J. B. (2014). How accounting for climate and health impacts of emissions could change the US energy system. *Energy Policy*, 102, pp. 396-405.

Brundiers, K. & Eakin, H. C. (2018). Leveraging post-disaster windows of opportunities for change towards sustainability: A framework. *Sustainability*, 10, 1390.

Buanes, A., & Jentoft, S. (2009). Building bridges: Institutional perspectives on interdisciplinarity. *Futures*, *41*(446-454).

Bulkeley, H. (2015). Can cities realise their climate potential? Reflections on COP21 Paris and beyond. *Local Environment*, *20*(11), 1405-1409.

Bull, B. (2005). *Aid, Power and Privatization: The Politics of Telecommunication Reform in Central America*. Cheltenham, UK. Northhampton, MA, USA: Edward Elgar.

Burawoy, M. (2001). Transition without transformation: Russia's involutionary road to capitalism. *East European Politics and Societies*, *15*(2), pp. 269-290.

Burch, S. (2017). The Governance of Transformative Change: Tracing the pathway of the sustainability transition in Vancouver, Canada. In *Urban Sustainability Transitions* (pp. 50-64). Routledge.

Burch, S. (2019). *The slow road through climate change*. Global Impact. Retrieved from: https://uwaterloo.ca/global-impact/slow-road-through-climate-change.

Burch, S., Shaw, A., Dale, A., & Robinson, J. (2014). Triggering transformative change: A development path approach to climate change response in communities. *Climate Policy*, *14*(4), pp. 467-487.

Burke, E. (1790). Reflections on the revolution in France. Retrieved from: https://socialsciences.mcmaster.ca/econ/ugcm/3ll3/burke/revfrance.pdf.

Burke, M. J., & Stephens, J. C. (2018). Political power and renewable energy futures: A critical review. *Energy Research & Social Science*, 35, pp. 78-93.

Burns, T. R. (2012). The sustainability revolution: A societal paradigm shift. *Sustainability,* 4, pp. 1118-1134.

Caddell, E. (2018). *Sustainability and indigenous interests in regional land use planning: Case study of the Peel Watershed Process in Yukon, Canada.* (Masters Thesis) University of Waterloo, Waterloo, Canada.

CalCCA (2021). *CCA Resources.* California Community Choice Association. Retrieved from: https://cal-cca.org/resources/#toggle-id-3.

Cámara de Industrias de Costa Rica (2021). *Oposición de la CICR al aumento tarifario propuesto por la CNFL.* Retrieved from: https://cicr.com/wp-content/uploads/2021/11/Oposicion-de-la-CICR-al-aumento-tarifario-propuesto-por-la-CNFL.pdf.

Cambronero, A. & Fernández, D. (2017). Afectividades en la defensa de los ríos Convento y Sonador (Zona Sur, Costa Rica). *Rev. Rupturas*, 8(1), pp. 227-242.

Canales, D. (2021). *Amplio consenso sobre urgencia de modernizar el sistema eléctrico.* La República. Retrieved from: https://www.larepublica.net/noticia/amplio-consenso-sobre-urgencia-de-modernizar-el-sistema-electrico.

Capra, F. (1996). *The web of life.* New York, London, Toronto, Sydney, Auckland: Anchor Books Doubleday.

Carazo, E. (2001). Después del combo qué? *Revista Costarricense de Trabajo Social*, 12, pp. 5-12.

Carbone, C. (2018). Paisaje y movimientos sociales, la identidad cultural y las injusticias espaciales internas en los territorios indígenas: El caso de la comunidad de Terrabá, Costa Rica. *Revista Conjeturas Sociológicas*, pp. 95-113.

Carls, J. & Haffar, W. R. (2010). *Conflict resolution of the Boruca Hydro-Energy Project – Renewable energy production in Costa Rica.* New York; London: The Continuum International Publishing Group Ltd.

Carlson, R., Martin, E., Nowina, P., & Richardson, M. E. (2013). *Getting the Green Light: The Path to Public Support for Ontario's Power Plans*. Mowat Centre for Policy Innovation.

Carpenter, S. R. & Gunderson, L. H. (2001). Coping with collapse: Ecological and social dynamics in ecosystem management. *BioScience*, 51(6), pp. 451-457.

Cartagena, R. E. (2010). El ambientalismo y la lucha contra el combo del sector eléctrico (1998-2001). *Revista de Ciencias Sociales (Cr), 2*(128-129), pp. 49-61.

Carver, D., Gibson, R.B., Irving, J., Kennan, H. & Burbidge, E. (2010). *Inter-jurisdictional coordination of EA: Challenges and opportunities arising from differences among provincial and territorial assessment requirements and processes.* Report for the Environmental Planning and Assessment Caucus, Canadian Environmental Network. East Coast Environmental Law Association.

Casillas, C. E. & Kammen, D. M. (2010). The energy-poverty-climate nexus. *Science*, 330(6008), pp. 1181-1182

CENCE (2021). *Informe anual de la operación del sistema eléctrico nacional 2021.*

CEPAL (2018). *Informe nacional de monitoreo de eficiencia energética de Costa Rica.* Naciones Unidas CEPAL.

CEPAL (2020). *Estadísticas de producción de electricidad de los países del Sistema de la Integración Centroamericana (SICA) – datos preliminares a 2019.* Naciones Unidas CEPAL.

Ćetković, S., & Hagemann, C. (2020). Changing climate for populists? Examining the influence of radical-right political parties on low-carbon energy transitions in Western Europe. *Energy Research & Social Science*, *66*, 101571.

Cha, J. M. (2020). A just transition for whom? Politics, contestation, and social identity in the disruption of coal in the Powder River Basin. *Energy Research & Social Science*, *69*, 101657.

Chacón, V. (2018). *ICE sepulta el proyecto hidroeléctrico el Diquís.* Semanario Universidad. Retrieved from: https://semanariouniversidad.com/pais/ice-sepulta-el- proyecto-hidroelectrico-diquis/.

Chaffin, B. C., & Gunderson, L. H. (2016). Emergence, institutionalization and renewal: rhythms of adaptive governance in complex social-ecological systems. *Journal of Environmental Management*, *165*, pp. 81-87.

Chan, D., Cameron, M., & Yoon, Y. (2017). Implementation of micro energy grid: A case study of a sustainable community in China. *Energy and Buildings*, 139, pp. 719-731.

Chanto, L. F. (2011). *Informe: Diagnóstico del PRONACE 2003-2008 y aportes para*

Chaplin, C. (2016). *Future drivers and trends affecting energy development in Ontario – A literature review.* Toronto, ON: Mowat Centre.

Chavez, D., & Ramos, A. C. (2013). Una empresa pública excepcional en una socialdemocracia en crisis: el Instituto Costarricense de Electricidad. *Revista de Gestión Pública*, *2*(1), pp. pp. 67-106.

Chen, T. Y., & Huang, C. J. (2019). A two-tier scenario planning model of environmental sustainability policy in Taiwan. *Sustainability*, *11*(8), 2336.
Chicago and London: University of Chicago Press.

Child, M. & Breyer, C. (2017). Transition and transformation: A review of the concept of change in the progress towards future sustainable energy systems. *Energy Policy*, 107, pp. 11-26.

Chu, S., Cui, Y., & Liu, N. (2017). The path towards sustainable energy. *Nature materials*, 16(1), pp. 16-22.

Cilliers, P. (2005). Complexity, deconstruction and relativism. *Theory, Culture & Society*, 22(5), pp. 255-267.

City of London (2013). *Community Energy Action Plan.* Retrieved from: https://questcanada.org/wp-content/uploads/2018/08/City-of-London-Community-Energy-Action-Plan.pdf.

Clapp, J. & Fuchs, D. (2009) *Corporate power in global agrifood governance.* Cambridge, Massachusetts; London, England: The MIT Press.

Cohen, M. (2017). A systematic review of urban sustainability assessment literature. *Sustainability*, 9(11), pp. 2048.

Colloff, M. J., Martín-López, B., Lavorel, S., Locatelli, B., Gorddard, R., Longaretti, P., . . . Murphy, H. T. (2017). An integrative research framework for enabling transformative adaptation. *Environmental Science and Policy, 68*, pp. 87-96.

Comisión Defensora de los Ríos Convento y Sonador (2016). *Defensa de los ríos Convento y Sonador: la historia de nuestra lucha*. Universidad de Costa Rica, Vicerrectoría de Acción Social, Programa Kioscos Socioambientales para la Organización Comunitaria.

Conca, J. (2017). The biggest power plants in the world – Hydro and nuclear. Forbes. Retrieved from: https://www.forbes.com/sites/jamesconca/2017/08/10/the-biggest-power-plants-in-the-world-hydro-and-nuclear/#50c5c7cf2c88.

Cornish, E. (2004). *Futuring: The exploration of the future*. World Future Society.

Cortés, M. E. & Iglesias, M. (2004). *Generalidades sobre metodología de la investigación.* México: Universidad Autónoma del Carmen.

Costanza, R. & Patten, B. C. (1995). Defining and predicting sustainability. *Ecological Economics*, 15, pp. 193-196.

Costanza, R. (2008). Stewardship for a "full" world. *Current History*, pp. 30-35.

Costanza, R., Graumlich, L.J. & Steffen, W. (2007). *Sustainability or collapse? An integrated history and future of people on Earth.* Cambridge, MA: MIT Press.

Cowie, W. (2006). *Assessing Trinidad's energy security vulnerability: Threats and responses.* Canadian Centre of Intelligence and Security Studies Vol. 1.

Craig, P. P., Gadgil, A., & Koomey, J. G. (2002). What can history teach us? A retrospective examination of long-term energy forecasts for the United States. *Annual Review of Energy and the Environment*, 27(1), pp. 83-118.

Cresswell, J. W. (2013). *Qualitative inquiry and research design: Choosing among five approaches.* Thousand Oaks: SAGE.

Creswell, J. W. (2009). *Research design: Qualitative, quantitative, and mixed methods approach* (3rd edition ed.). Los Angeles, London, New Delhi, Singapore: SAGE.

Creutzig, F., Breyer, C., Hilaire, J., Minx, J., Peters, G. P., & Socolow, R. (2019). The mutual dependence of negative emission technologies and energy systems. *Energy & Environmental Science*, 12(6), pp. 1805-1817.

Creutzig, F., Fernandez, B., Haberl, H., Khosla, R., Mulugetta, Y., & Seto, K. C. (2016). Beyond technology: demand-side solutions for climate change mitigation. *Annual Review of Environment and Resources*, 41, pp. 173-198.

Croal, P., Gibson, R. B., Alton, C., Brownlie, S & Windibank, E. (2010). A decision-maker's tool for sustainability-centred strategic environmental assessment. *Journal of Environmental Assessment Policy and Management*, 12(1), 1-27.

Csereklyei, Z., Qu, S., & Ancev, T. (2019). The effect of wind and solar power generation on wholesale electricity prices in Australia. *Energy Policy*, 131, pp. 358-369.

Cunha, J. (2015). How sustainability concerns have been taken into account on electricity systems regulation policy? Some insights from four European countries. In *2015 12th International Conference on the European Energy Market (EEM)* (pp. 1-5). IEEE.

Dalal-Clayton, B. & Sadler, B. (2012). *Sustainability appraisal: A sourcebook and reference guide to international experience.* London and New York: Routledge, Taylor & Francis Group.

Dale, A., Burch, S, Robinson, J. & Strashok, C. (2018) Multilevel governance of sustainability transitions in Canada: policy alignment, innovation, and evaluation. In S. Hughes et al. (eds.), *Climate Change in Cities* (pp. 343-358), The Urban Book Series.

Daly, H. E. (2005). Economics in a full world. *Scientific American*, pp. 100-107.

DCC (2021). *Contribución nacionalmente determinada de Costa Rica 2020.* Dirección de Cambio Climático. Retrieved from: https://cambioclimatico.go.cr/wp-content/uploads/2021/01/Contribucion-Nacionalmente-Determinada-de-Costa-Rica-2020-Version-Completa.pdf?x25339.

De Pascali, P., Santangelo, S., Perrone, F. & Bagaini, A. (2020). Territorial energy decentralisation and ecosystem services in Italy: Limits and potential. *Sustainability,* 12, p. 1424.

Dekker, S. W. A., Hancock, P. A. & Wilkin, P. (2013). Ergonomics and sustainability: Towards an embrace of complexity and emergence. *Ergonomics,* 56(3), pp. 357-364.

Delina, L. L. & Sovacool, B. K. (2018) Of temporality and plurality: an epistemic and governance agenda for accelerating just transitions for energy access and sustainable development. *Current Opinion in Environmental Sustainability,* 34, pp. 1-6

Derbyshire, J. (2016) The implications, challenges and benefits of a complexity-orientated futures studies. *Futures*, 77, pp. 45-55.

Devuyst, D. (2000). Linking impact assessment and sustainable development at the local level: the introduction of sustainability assessment systems. *Sustainable Development*, 8, pp. 67-78.

Diefenback, T. (2009). Are case studies more than sophisticated storytelling? Methodological problems of qualitative empirical research mainly based on semi-structured interviews. *Quality and Quantity Journal 43.* 875-894. doi: 10.1007/s11135-008-9164-0

Diefenderfer, H. L., Johnson, G. E., Thom, R. M., Buenau, K. E., Weitkamp, L. A., Woodley, C. M., ... & Kropp, R. K. (2016). Evidence-based evaluation of the cumulative effects of ecosystem restoration. *Ecosphere*, *7*(3), e01242.

Dinçer, İ., & Bicer, Y. (2019). *Integrated energy systems for multigeneration*. Elsevier.

Do, T. H., & Hoffmann, C. (2019). Estimation of the future electricity price surcharge for the integration of wind and solar power into the Vietnamese electricity system. In *2019 IEEE Asia Power and Energy Engineering Conference (APEEC)* (pp. 263-268). IEEE.

Dobles, R. (n.d.). *Costa Rica's commitment: on the path to becoming carbon-neutral.* United Nations; UN Chronicle. Retrieved from: https://www.un.org/en/chronicle/article/costa-ricas-commitment-path-becoming-carbon-neutral.

Doelle, M. & Sinclair, J. (2010). Mediation in Environmental assessments in Canada: Unfulfilled promise? *Dalhousie Law Journal*, 33(1), pp. 117-152.

Doelle, M. (2012). *The role of EA in achieving a sustainable energy future in Canada: A case study of the Lower Churchill Panel Review*. JELP Conference. Doern, B. & Gattinger, M. (2003) *Power switch: Energy regulatory governance in the twenty-first century.* Toronto: University of Toronto Press.

Doelle, M. (2017). The Lower Churchill Panel Review: Sustainability assessment under legislative constraints in Canada. In R. B. Gibson (Ed.), *Sustainability assessment: Applications and opportunities* (pp. 110-126). London and New York: Routledge/Earthscan.

Doern, G. B., & Gattinger, M. (2003). *Power switch: energy regulatory governance in the twenty-first century*. University of Toronto Press.

Dorninger, C., Abson, D. J., Apetrei, C. I., Derwort, P., Ives, C. D., Klaniecki, K., ... & von Wehrden, H. (2020). Leverage points for sustainability transformation: a review on interventions in food and energy systems. *Ecological Economics*, *171*, 106570.

Dow, K., Berkhout, F., Preston, B. L., Klein, R. J. T., Midgley, G., & Shaw, M. R. (2013). Limits to adaptation. *Nature Climate Change, 3*(4), pp. 305-307.

Drauz, S. R., Spalthoff, C., Würtenberg, M., Kneikse, T. M., & Braun, M. (2018, April). A modular approach for Co-simulations of integrated multi-energy systems: Coupling multi-energy grids in existing environments of grid planning & operation tools. In *2018 Workshop on Modeling and Simulation of Cyber-Physical Energy Systems (MSCPES)* (pp. 1-6). IEEE.

Dreborg, K. H. (1996) Essence of backcasting. *Futures*, 28(9), pp. 813-828.

Dryzek, J. S. & Stevenson, H. (2011). Global democracy and earth system governance. *Ecological Economics*, 70, pp. 1865-1874.

Du Pisani, J.A. (2006) Sustainable development – Historical roots of the concept. *Environmental Sciences*, 3(2), pp. 83-96.

Dukert, J. M. (2009). *Energy*. Westport, CT-London: Greenwood Press.

Dunlap, R. E., & Olsen, M. E. (1984). Hard-path versus soft-path advocates: a study of energy activists. *Policy Studies Journal*, 13(2), pp. 413.

Dunlop, T. (2019). Mind the gap: A social sciences review of energy efficiency. *Energy Research & Social Science*, 56, p. 101216.

Echevarría, C. & Monge, G. (2017). Generación distribuida para autoconsumo en Costa Rica: Oportunidades y desafíos. *Banco Interamericano de Desarrollo.*

EIA (2019). *Construction cost data for electric generators installed in 2017.* U.S. Energy Information Administration. Retrieved from: eia.gov/electricity/generatorcosts/#top

Elahi, S. (2011) Here be dragons… exploring the 'unknown unknowns'. *Futures*, 43, pp. 196-201.

Energéticos.

Environment and Climate Change Canada (2020). *National Inventory Report 1990 – 2018: Greenhouse gas sources and sinks in Canada – Canada's submission to the United Nations Framework Convention on Climate Change.* Executive summary. Retrieved from: http://publications.gc.ca/collections/collection_2020/eccc/En81-4-1-2018-eng.pdf.

Environmental Commissioner of Ontario (ECO) (2018). *Making connections – Straight talk about electricity in Ontario*. 2018 Energy Conservation Progress Report, Volume One.

Environmental Defence (2020). *Ontario climate – Yours to recover: A progress report on Ontario's Climate Actions.* Retrieved from: https://environmentaldefence.ca/report/yours-to-recover-a-progress-report-on-ontarios-climate-change-actions/.

ESPH (2020). *Historia de la empresa.* Empresa de Servicios Públicos de Heredia. Retrieved from: https://www.esph-sa.com/sobre-la-esph/historia.

Espinosa, R. (2020). Modelación econométrica de la eco-eficiencia en las empresas eléctricas de Costa Rica utilizando smart grid. *Revista Fidélitas*, *1*(2).

Espinoza-Carvajal, G. (2017). Propuesta de mejora de los procedimientos en la gestión de proyectos en JASEC: Caso de proyecto de generación termoeléctrica impulsada con biodiesel (Master's thesis, Tecnológico de Costa Rica).

Etzion, D., Gehman, J., Ferraro, F., & Avidan, M. (2017). Unleashing sustainability transformations through robust action. *Journal of Cleaner Production, 140*, pp. 167-178. *Evaluation* (2nd ed.). San Francisco: Jossey-Bass.

Evans, G., & Phelan, L. (2016). Transition to a post-carbon society: Linking environmental justice and just transition discourses. *Energy Policy*, *99*, pp. 329-339.

Fahrioglu, M. (2016). Effect of demand management on regulated and deregulated electricity sectors. *Energy Policy*, 90, pp. 115-120.

Fahrmeir, A. (2020). Democracies, change, sustainability, and transformation: historical perspectives. *Sustainability: Science, Practice and Policy*, *16*(1), pp. 74-82.

Fairchild, D., & Weinrub, A. (2017). Energy democracy. In *The Community Resilience Reader* (pp. 195-206). Island Press, Washington, DC.

Fam, D., Palmer, J., Riedy, C. & Mitchell, C. (2017). *Transdisciplinary research and practice for sustainability outcomes.* Oxon and New York: Earthscan.

Fang, K., Heijungs, R. & De Snoo, G. R. (2015). Understanding the complementary linkages between environmental footprints and planetary boundaries in a footprint-boundary environmental sustainability assessment framework. *Ecological Economics,* 114, pp. 218-226.

Farah-Pérez, A., Umaña-Villalobos, G., Picado-Barboza, J., & Anderson, E. P. (2020). An analysis of river fragmentation by dams and river dewatering in Costa Rica. *River Research and Applications, 36*(8), pp. 1442-1448.

Farrell, A. E., Zerriffi, H., & Dowlatabadi, H. (2004). Energy infrastructure and security. *Annu. Rev. Environ. Resour.*, *29*, 421-469.

Feindt, P. H., & Weiland, S. (2018). Reflexive governance: exploring the concept and assessing its critical potential for sustainable development. Introduction to the special issue.

Feola, G. (2015). Societal transformation in response to global environmental change: A review of emerging concepts. *Ambio, 44*(5), pp. 376-390.

Financial Accountability Office of Ontario (2017). *Nuclear refurbishment – An assessment of the financial risks of the Nuclear Refurbishment Plan.* Retrieved from: https://www.brucepower.com/wp-content/uploads/2020/01/Nuclear-Refurb-EN.pdf.

Financial Accountability Office of Ontario (2022). *Ontario's energy and electricity subsidy programs – Cost, recent changes and the impact on electricity bills.* Retrieved from: https://www.fao-on.org/web/default/files/publications/FA1907%20Electricity%20Sector%20Review/Ontario's%20Energy%20and%20Electricity%20Subsidy%20Programs-EN.pdf.

Fine, J. D. & Owen, D. (2004). Technocracy and democracy: Conflicts between models and participation in environmental law and planning. *Hastings Law Journal,* 56(5), pp. 901-982.

Fischer, J., & Riechers, M. (2019). A leverage points perspective on sustainability. *People and Nature*, *1*(1), pp. 115-120.

Flint, R. W. & Danner, M. J. E. (2001). The nexus of sustainability & social equity: Virginia's Eastern Shore (USA) as a local example of global issues. *International Journal of Economic Development*, 3(2).

Flint, R. W. (2013). *Practice of sustainable community development.* New York: Springer Science, Business Media.

Folke, C., Carpenter, S. R., Walker, B., Scheffer, M., Chapin, T., & Rockström, J. (2010). Resilience thinking: Integrating resilience, adaptability and transformability. *Ecology and Society, 15*(4), 20.

Folke, C., Polaski, S., Rockström, J., Galaz, V., Westley, F., Lamont, M. … Walker, B. (2020). *Our Future in the Anthropocene Biosphere: Global Sustainability and Resilient Societies.* Beijer Discussion Paper Series No. 272.

Fonseca, A. & Gibson, R. B. (2020). Testing an ex-ante framework for the evaluation of impact assessment laws: Lessons from Canada and Brazil. *Environmental Impact Assessment Review,* 81, pp. 1-12.

Francis, G. (2006). "Models" for sustainability emerge in an open systems context. *The Integrated Assessment Journal,* 6(4), pp. 59-77.

Fraune, C., & Knodt, M. (2018). Sustainable energy transformations in an age of populism, post-truth politics, and local resistance. *Energy Research & Social Science, 43*, pp. 1-7.

Fuenfschilling, L., & Truffer, B. (2016). The interplay of institutions, actors and technologies in socio-technical systems—An analysis of transformations in the Australian urban water sector. *Technological Forecasting and Social Change, 103*, 298-312.

Fylan, F. (2005). Semi-Structured Interviewing. In J. Miles and P. Gilbert. *A handbook of research methods for clinical and health psychology*. New York: Oxford University Press.

Gaede, J., & Rowlands, I. H. (2018). How 'transformative' is energy storage? Insights from stakeholder perceptions in Ontario. *Energy research & social science, 44*, 268-277.

Gahm, C., Denz, F., Dirr, M., & Tuma, A. (2016). Energy-efficient scheduling in manufacturing companies: A review and research framework. *European Journal of Operational Research*, 248(3), pp. 744-757.

Galaz, V., Biermann, F., Crona, B., Loorbach, D., Folke, C., Olsson, P. … Reischl, G. (2012). ‘Planetary boundaries – exploring the challenges for global environmental governance. *Current Opinion in Environmental Sustainability,* 4, pp. 80-87.

Galgóczi, B. (2020). Just transition on the ground: Challenges and opportunities for social dialogue. *European Journal of Industrial Relations*, *26*(4), pp. 367-382.

Gangas, P. & Retana, J. (2006). Ciudadanos críticos: las movilizaciones contra el “combo ICE” en Costa Rica. *América Latina Hoy*, 42, pp. 93-108.

García-Sánchez, D. & Avendaño-Leadem, D. (2018). Energy transition and path dependence: the case of Costa Rica. *Revista Geográfica de América Central*, *3*(61E), pp. 281-295.

García-Sánchez, D. (2012). Decision making and the energy path towards carbon neutrality: the case of Costa Rica. In *Berlin Conference on Evidence for Sustainable Development*.

Gatto, A., & Busato, F. (2020). Energy vulnerability around the world: The global energy vulnerability index (GEVI). *Journal of Cleaner Production*, 253, p. 118691.

Gaudreau, K. (2013). Sustainability assessment of energy systems. (Doctoral thesis), University of Waterloo, Waterloo, Canada.

Geels, F. W. (2004). From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory. *Research policy*, 33(6-7), pp. 897-920.

Geels, F. W. (2011). The multi-level perspective on sustainability transitions: Responses to seven criticisms. *Environmental Innovation and Societal Transitions,* 1, pp. 24-40.

Geels, F. W., Sovacool, B. K., Schwanen, T., & Sorrell, S. (2017). Sociotechnical transitions for deep decarbonization. *Science*, *357*(6357), pp. 1242-1244.

Ghalehkhondabi, I., Ardjmand, E., Weckman, G. R. & Young II, W. A. (2017). An overview of energy demand forecasting methods published in 2005-2015. *Energy Syst,* 8, pp. 411-447.

Ghassemi, M., Andersen, P. K., Ghassemi, A. & Chianelli, R. R. (2004). Hazardous waste from fossil fuels. *Encyclopedia of Energy,* 3, pp. 119-239.

Gibson, R. (1991). Should environmentalists pursue sustainable development? *Probe Post,* 22–25.

Gibson, R. B. (2011). Application of a contribution to sustainability test by the Joint Review Panel for the Canadian Mackenzie Gas Project. *Impact Assessment and Project Appraisal,* 29(3), pp. 231-244.

Gibson, R. B. & Collins, A. (2016). ERS 680/701 Sustainability foundations – Week 3: Sustainability [PowerPoint Slides].

Gibson, R. B. (2006). Sustainability assessment: Basic components of a practical approach. *Impact Assessment and Project Appraisal*, 24(3), pp. 170-182.

Gibson, R. B. (2011). Application of a contribution to sustainability test by the Joint Review Panel for the Canadian Mackenzie Gas Project. *Impact Assessment and Project Appraisal,* 29(3), pp. 231-244.

Gibson, R. B. (2017). *Sustainability assessment: Applications and opportunities.* London: Earthscan.

Gibson, R. B. (2020). An evaluation of Canada’s new, sustainability-based Impact Assessment Act. *Journal of Environmental Law and Practice*, 33(1), pp. 1-34.

Gibson, R. B., Doelle, M. & Sinclair, A. J. (2016). Fulfilling the promise: Basic components of Next Generation Environmental Assessment. *Journal of Environmental Law and Practice,* 29, pp. 251-276.

Gibson, R. B., Hassan, S., Holtz, S., Tansey, J., & Whitelaw, G. (2005). *Sustainability assessment*. London [u.a.]: Earthscan.

Gibson, R. B., Péloffy, K., Greenford, D. H., Doelle, M., Matthews, H. D., Holz, C… Grenier, F. (2018). *From Paris to projects – Clarifying the implications of Canada’s climate change mitigation commitments for the planning and assessment of projects and strategic undertakings.* Summary Report.

Gibson, R. B., Péloffy, K., Horen Greenford, D., Doelle, M., Matthews, H. D., Holz, C., ... & Grenier, F. (2019). From Paris to Projects: Clarifying the Implications of Canada’s Climate Change Mitigation Commitments for the Planning and Assessment of Projects and Strategic Undertakings (Full Report).

Gissey, G. C., Subkhankulova, D., Dodds, P. E., & Barrett, M. (2019). Value of energy storage aggregation to the electricity system. *Energy policy*, *128*, 685-696.

Gobierno de Costa Rica (2018). *Plan Nacional de Descarbonización 2018-2050.* Dirección de Cambio Climático. Retrieved from: https://cambioclimatico.go.cr/wp-content/uploads/2019/11/PLAN-NACIONAL-DESCARBONIZACION.pdf?x25339.

Goddard, G., & Farrelly, M. A. (2018). Just transition management: Balancing just outcomes with just processes in Australian renewable energy transitions. *Applied Energy*, *225*, pp. 110-123.

Godet, M. (2010) Future memories. *Technological Forecasting & Social Change*, 77, pp. 1457-1463.

Goldthau, A. (2014). Rethinking the governance of energy infrastructure: Scale, decentralization and polycentrism. *Energy Research & Social Science,* 1, pp. 134-140.

Golubchikov, O., & Deda, P. (2012). Governance, technology, and equity: An integrated policy framework for energy efficient housing. *Energy policy*, *41*, 733-741.

Goulding, A. J. (2013). A New Blueprint for Ontario's Electricity Market. *Commentary-CD Howe Institute*, (389).

Government of Canada (2019). *Impact Assessment Act*, Statutes of Canada, 2019, c 28, s 1. Retrieved from: https://laws-lois.justice.gc.ca/eng/acts/I-2.75/.

Government of Canada (2020). Electricity facts. Retrieved from: https://www.nrcan.gc.ca/science-data/data-analysis/energy-data-analysis/energy-facts/electricity-facts/20068.

Government of Canada (2021). *Constitution Acts, 1867 to 1982.* Justice Laws Website. Retrieved from: https://laws-lois.justice.gc.ca/eng/const/page-4.html?wbdisable=true.

Government of Ontario (2004). *Electricity Restructuring Act, S.O. 2004, c. 23 – Bill 100.* Retrieved from: https://www.ontario.ca/laws/statute/s04023.

Government of Ontario (2009). *Green Energy and Green Economy Act, 2009, S.O. 2009, c. 12 – Bill 150.* Retrieved from: https://www.ontario.ca/laws/statute/s09012.

Government of Ontario (2010). *Ontario's Long-Term Energy Plan – Building our clean energy future.*

Government of Ontario (2013). *Ontario's Long-Term Energy Plan – Achieving balance.*

Government of Ontario (2017). *Ontario's Long-Term Energy Plan – Delivering fairness and choice.*

Government of Ontario (2018) *Green Energy Repeal Act, 2018, S.O., c. 16 – Bill 34.* Retrieved from: https://www.ontario.ca/laws/statute/s18016.

Government of Ontario (2019). *About Ontario.* Retrieved from: ontario.ca/page/about-ontario#section-3.

Government of Ontario (2020). *Removing the time requirements for releasing Ontario's next long-term energy plan by revoking Ontario Regulation 355/17.* Environmental Registry of Ontario. Retrieved from: https://ero.ontario.ca/notice/019-2149.

Government of Ontario (2021). *Published plans and annual reports 2021-2022: Ministry of Energy, Northern Development and Mines - Plans for 2021-2022, and results and outcomes of all provincial programs delivered by the Ministry of Energy, Northern Development and Mines in 2020-2021.* Retrieved from: https://www.ontario.ca/page/published-plans-and-annual-reports-2021-2022-ministry-energy-northern-development-and-mines.

Government of Western Australia (2003) *Hope for the future: The Western Australian State Sustainability Strategy,* Perth, Western Australia: Department of the Premier and Cabinet.

Gowdy, J. M. (1994). The social context of natural capital: The social limits to sustainable development. *International Journal of Social Economics,* 21(8), pp. 43-55.

Grober, U. (2012). *Sustainability: A cultural history.* Totnes, Devon: Green Books (Original work published 2010).

Grupo Banco Mundial (2021). *PIB (US$ a precios actuales) – Costa Rica*. Retrieved from: https://datos.bancomundial.org/indicador/NY.GDP.MKTP.CD?locations=CR.

Grupo ICE (2020). *Somos electricidad renovable y solidaria.* Retrieved from: https://www.grupoice.com/wps/wcm/connect/85a8f53b-e1a5-4348-b913-dddf0150c2ad/Fasciculo_Electricidad_2020_compressed.pdf?MOD=AJPERES&CACHEID=ROOTWORKSPACE-85a8f53b-e1a5-4348-b913-dddf0150c2ad-nDk1jn4.

Grupo ICE (2021). *Más de 475.000 clientes del ICE y la CNFL ya tienen medidores eléctricos inteligentes.* Sala de Prensa. Retrieved from: https://www.grupoice.com/wps/portal/ICE/quienessomos/sala-prensa/sala-de-prensa/!ut/p/z0/fY29DsIwDIRfJUvHKq5oKjGCQJUYqgILZEGu66BASUp_EI9Pihg6sd2dP99JLU9SO3zZKw7WO2yCP-vskpdJlqwhKUGpDeyX22NR5IcFKJA7qf8DocHenk-

9kpq8G_g9yJMlFtxHYEbuUNQs2rFqLCGF0Qh6bFC0HbseY_KP0YVL7Xt-t7abxI-Y3r5QBDNKeGPJYjPVz-IIUgKjFFUxklJxagzGWLMKNiFjaEEpZ7K96_MHj-WTdQ!!/.

Guerrero, L. (2015). UCR se adentra en el estudio del cambio climático desde diferentes disciplinas. *Revista Crisol*, 29, pp. 20-24.

Gunderson, L. H. & Holling, C. S. (2002). *Panarchy: Understanding transformations in human and natural systems.* Washington, DC; London: Island Press.

Guo, Z., Ge, S., Yao, X., Li, H., & Li, X. (2020). Life cycle sustainability assessment of pumped hydro energy storage. *International Journal of Energy Research*, 44(1), pp. 192-204.

Gürtler, M., & Paulsen, T. (2018). The effect of wind and solar power forecasts on day-ahead and intraday electricity prices in Germany. *Energy Economics*, 75, pp. 150-162.

Gutiérrez, A. (2020). Capitalismo verde y energías" limpias": Costa Rica como laboratorio mundial de descarbonización. *Anuario del Centro de Investigación y Estudios Políticos*, ISSN: 2215-2873, 11, pp. 195-227.

Gutiérrez, A., & Villalobos, D. (2020). Proyectos hidroeléctricos y resistencias comunitarias en defensa de los ríos en Costa Rica: un análisis geográfico. *Cuadernos de Geografía: Revista Colombiana de Geografía*, *29*(1), pp. 133-151.

Guzmán-Hernández, T. D. J., Araya-Rodríguez, F., Castro-Badilla, G., & Obando-Ulloa, J. M. (2016). Uso de la energía solar en sistemas de producción agropecuaria: producción más limpia y eficiencia energética. *Revista Tecnología en Marcha*, *29,* pp. 46-56.

Hacking, T. (2019). The SDGs and the sustainability assessment of private-sector projects: Theoretical conceptualisation and comparison with current practice using the case study of the Asian Development Bank. *Impact Assessment and Project Appraisal,* 37(1), pp. 2-16.

Hadorn, H., Bradley, D., Pohl, C., Rist, S., & Wiesmann, U. (2006). Implications of transdisciplinarity for sustainability research. *Ecological Economics,* 60, pp. 119-128.

Haggerty, J. H., Haggerty, M. N., Roemer, K., & Rose, J. (2018). Planning for the local impacts of coal facility closure: Emerging strategies in the US West. *Resources Policy*, *57*, pp. 69-80.

Harris, M., Beck, M., & Gerasimchuk, I. (2015). *The end of coal: Ontario's coal phase-out*. Winnipeg (CAN): International Institute for Sustainable Development.

Head, B. W. (2008). Wicked problems in public policy. *Public Policy,* 3(2), pp. 101-118.

Healy, N., & Barry, J. (2017). Politicizing energy justice and energy system transitions: Fossil fuel divestment and a “just transition”. *Energy Policy*, *108*, pp. 451-459.

Heffron, R. J., & McCauley, D. (2017). The concept of energy justice across the disciplines. *Energy Policy*, *105*, pp. 658-667.

Henry, M. S., Bazilian, M. D., & Markuson, C. (2020). Just transitions: Histories and futures in a post-COVID world. *Energy Research & Social Science*, *68*, 101668.

Hernandez, R. R., Easter, S. B., Murphy-Mariscal, M. L., Maestre, F. T., Tavassoli, M., Allen, E. B., ... & Allen, M. F. (2014). Environmental impacts of utility-scale solar energy. *Renewable and sustainable energy reviews*, 29, pp. 766-779.

Hernández, R., Fernández, C. & Baptista, P. (2010). *Metodología de la investigación.* México: McGraw-Hill/Interamericana Editores.

Hill, D. (1998) Sustainable development – Tools and techniques for action, proceeding of

Hiremath, R. B., Shikha, S. & Ravindranath, N. H. (2007). Decentralized energy planning; modeling and application – a review. *Renewable & Sustainable Energy Reviews,* 11, pp. 729-752.

Hochrainer-Stigler, S., Colon, C., Boza, G., Poledna, S., Rovenskaya, E., & Dieckmann, U. (2020). Enhancing resilience of systems to individual and systemic risk: Steps toward an integrative framework. *International Journal of Disaster Risk Reduction*, *51*, 101868.

Hodbod, J., & Adger, W. N. (2014). Integrating social-ecological dynamics and resilience into energy systems research. *Energy Research & Social Science*, 1, pp. 226-231.

Hoffmann, B. (2008). Why reform fails: The 'politics of policies' in Costa Rican telecommunications liberalization. *Revista Europea de Estudios Latinoamericanos y del Caribe/European Review of Latin American and Caribbean Studies*, pp. 3-19.

Holland, R. A., Scott, K., Agnolucci, P., Rapti, C., Eigenbrod, F. & Taylor, G. (2019). The influence of the global electric power system on terrestrial biodiversity. *PNAS,* 116(51), pp. 26078-26084.

Holling, C. S. (1996). Engineering resilience versus ecological resilience. In P. C. Schulze (Ed.) *Engineering Within Ecological Constraints* (pp. 31-44). Washington, DC: National Academy Press.

Holling, C. S. (2001). Understanding the complexity of economic, ecological, and social systems. *Ecosystems,* 4(5), pp. 390-405.

Hölscher, K., Wittmayer, J. M., & Loorbach, D. (2018). Transition versus transformation: what's the difference? *Environmental Innovation and Societal Transitions*, *27*, pp. 1-3.

Hong, P., Jagani, S., Kim, J., & Youn, S. H. (2019). Managing sustainability orientation: An empirical investigation of manufacturing firms. *International Journal of Production Economics*, *211*, 71-81.

Horn, R., Dahy, H., Gantner, J., Speck, O., Leistner, P. (2018). Bio-inspired sustainability assessment for building product development – Concept and case study. *Sustainability,* 10(1), p. 130.

Hornborg, A., McNeill, J. R. & Martinez-Alier, J. (2007). *Rethinking environmental history: World system history and global environmental change.* Plymouth, UK: AltaMira Press.

Houldin, R. W. (2017). Ontario electricity: When prophecy failed but rent collection succeeded. *The Electricity Journal*, *30*(3), pp. 10-14. https://intranetsp.bournemouth.ac.uk/documentsrep/PGR%20Workshop%20-%20Interviews%20Dec%202014.pdf.

Hwang, J. Y., Myung, S. T., & Sun, Y. K. (2017). Sodium-ion batteries: present and future. *Chemical Society Reviews*, 46(12), pp. 3529-3614.

Hydro One Limited (2021). *Energizing life for people & communities – 2021 annual report.*

Ibarra, J. T., Cockle, K., Altamirano, T., van der Hoek, Y., Simard, S., Bonacic, C., & Martin, K. (2020). Nurturing resilient forest biodiversity: nest webs as complex adaptive systems. *Ecology and Society*, *25*(2), 27.

ICE (2017). *Plan de expansión de la generación eléctrica 2016-2035.* Instituto Costarricense de Electricidad; Planificación y desarrollo eléctrico – proceso expansión del sistema. Retrieved from: https://www.grupoice.com/wps/wcm/connect/beb21101-9c67-4acf-964e-c7a00f682040/PEG+2016-2035.pdf?MOD=AJPERES&CVID=lPcDy1N&CVID=lPcDy1N&CVID=lPcDy1N.

ICE (2019). *Índice de cobertura eléctrica.* Instituto Costarricense de Electricidad – Dirección Corporativa de Electricidad; Planificación y Desarrollo Eléctrico – Expansión del Sistema. Retrieved from: https://www.grupoice.com/wps/wcm/connect/10261169-f251-465d-9b95-0b17c7baa49e/I%CC%81ndice+de+Cobertura+Ele%CC%81ctrica+2019.pdf?MOD=AJPERES&CVID=n1u6RVf.

ICE (2021). *Plan de expansión de la generación eléctrica 2020-2035.* Instituto Costarricense de Electricidad – Gerencia de electricidad; Planificación y desarrollo eléctrico – proceso expansión del sistema. Retrieved from: https://www.grupoice.com/wps/wcm/connect/741c8397-09f0-4109-a444-bed598cb7440/PLAN+DE+EXPANSI%C3%93N+DE+LA+GENERACI%C3%93N+EL%C3%89CTRICA+2020%E2%80%932035_compressed.pdf?MOD=AJPERES&CVID=nJADNyi.

IEA (2019a), *World Energy Outlook 2019*. IEA, Paris. Retrieved from: https://www.iea.org/reports/world-energy-outlook-2019.

IEA (2019b), *Global Energy & CO2 Status Report 2019*. IEA, Paris. Retrieved from: https://www.iea.org/reports/global-energy-co2-status-report-2019.

IEA (2022). *For the first time in decades, the number of people without access to electricity is set to increase in 2022.* IEA, Paris. Retrieved from: https://www.iea.org/commentaries/for-the-first-time-in-decades-the-number-of-people-without-access-to-electricity-is-set-to-increase-in-2022.

IESO (2009) Integrated Power System Plan I. Retrieved from: https://cms.powerauthority.on.ca/integrated-power-system-plan.

IESO (2015). *The Independent Electricity System Operator and Ontario Power Authority amalgamate.* News releases. Retrieved from: https://www.ieso.ca/corporate-ieso/media/news-releases/2015/01/the-independent-electricity-system-operator-and-ontario-power-authority-amalgamate.

IESO (2020a). *Reliability Outlook – An adequacy assessment of Ontario's electricity system.* From October 2020 to March 2022. Retrieved from: https://www.ieso.ca/en/Sector-Participants/Planning-and-Forecasting/Reliability-Outlook.

IESO (2020b). *Annual Planning Outlook, January 2020.* Retrieved from: ieso.ca/en/Sector-Participants/Planning-and-Forecasting/Annual-Planning-Outlook.

IESO (2021). *About regional planning.* Retrieved from: https://www.ieso.ca/en/Get-Involved/Regional-Planning/About-Regional-Planning/Overview.

IESO (2022a). *Annual planning outlook – Ontario's electricity system needs 2024-2043.*

IESO (2022b). *Ontario's electricity grid.* Retrieved from: https://www.ieso.ca/en/Learn/Ontario-Electricity-Grid/Supply-Mix-and-Generation.

IIASA (2012). *Global energy assessment*. Cambridge [u.a.]: Cambridge University Press. Retrieved from: http://www.iiasa.ac.at/web/home/research/Flagship-Projects/Global-Energy-Assessment/Global_Energy_Assessment_FullReport.pdf.

Imbault, F., Swiatek, M., De Beaufort, R., & Plana, R. (2017). The green blockchain: Managing decentralized energy production and consumption. In *2017 IEEE International Conference on Environment and Electrical Engineering and 2017 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe)* (pp. 1-5). IEEE.

IMO (2002). Market Surveillance Panel Monitoring Report on the IMO-Administered Electricity Markets for the First Four Months, May to August 20020. Retrieved from: https://www.oeb.ca/documents/msp/panel_mspreport_imoadministered_071002.pdf.

Inayatullah, S. (2008) Six pillars: futures thinking for transforming. *Foresight,* 10(1), pp. 4-21.

Inayatullah, S. (2018) Foresight in challenging environments. *Journal of Futures Studies,* 22(4), pp. 15-24

INEC (2021). *Costa Rica en cifras 2021.* Instituto Nacional de Estadística y Censos. Retrieved from: https://www.inec.cr/sites/default/files/documetos-biblioteca-virtual/recostaricaencifras2021_0.pdf.

Innerarity, D. (2012) The future and its enemies – In defense of political hope. Stanford, California: Stanford University Press.

International Panel on Climate Change. (2018). *Global warming of 1.5℃ ─ an IPCC special report on the impacts of global warming of 1.5℃ above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.* Retrieved from https://www.ipcc.ch/sr15/.

IPBES (2019). *Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.* S. Díaz, J. Settele, E. S. Brondízio, E.S., H. T. Ngo, M. Guèze, J. Agard, A. Arneth, P. Balvanera, K. A. Brauman, S. H. M. Butchart, K. M. A. Chan, L. A. Garibaldi, K. Ichii, J. Liu, S. M. Subramanian, G. F. Midgley, P. Miloslavich, Z. Molnár, D. Obura, A. Pfaff, S. Polasky, A. Purvis, J. Razzaque, B. Reyers, R. Roy Chowdhury, Y. J. Shin, I. J. Visseren-Hamakers, K. J. Willis, and C. N. Zayas (eds.). IPBES secretariat, Bonn, Germany.

IPCC (2018). *Global warming of 1.5℃ - An IPCC Special report on the impacts of global warming of 1.5℃ above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate* *change, sustainable development, and efforts to eradicate poverty.* Summary for Policy Makers.

Jacobs, M. (1999). Sustainable development as a contested concept. In A. Dobson (Ed.), *Fairness and Futurity: Essays on Environmental Sustainability and Social Justice* (pp. 21-45). Oxford: Oxford University Press.

Jastremski, K. (2017). *Governance for sustainability in forest communities: Case study of the Antoine-Labelle regional county municipality in Quebec.* (Doctoral thesis, University of Waterloo, Waterloo, Canada). Retrieved from: http://hdl.handle.net/10012/12763.

Jeffs, E. (2012). *Greener energy systems: Energy production technologies with minimum environmental impact*. Boca Raton, FL: Taylor & Francis Group, LLC.

Jenkins, K. (2018). Setting energy justice apart from the crowd: lessons from environmental and climate justice. *Energy Research & Social Science*, 39, pp. 117-121.

Jenkins, K. E., Sovacool, B. K., Błachowicz, A., & Lauer, A. (2020). Politicising the Just Transition: Linking global climate policy, Nationally Determined Contributions and targeted research agendas. *Geoforum*, 115, pp. 138-142.

Jesse, B. J., Heinrichs, H. U., & Kuckshinrichs, W. (2019). Adapting the theory of resilience to energy systems: a review and outlook. *Energy, Sustainability and Society*, 9(1), p. 27.

Jiménez, R., Serebrisky, T. & Mercado, J. (2014). *Electricidad Perdida – Dimensionando las pérdidas de electricidad en los sistemas de transmisión y distribución en América Latina y el Caribe.* Banco Interamericano de Desarrollo.

Johnson, S. (2012). *UNEP The first 40 years – A narrative.* Nairobi: UNON/Publishing Section Services.

Johnston, A. (2016). *Federal environmental assessment reform summit – Executive summary.* West Coast Environmental Law.

Johnstone, P., Rogge, K. S., Kivimaa, P., Fratini, C. F., Primmer, E., & Stirling, A. (2020). Waves of disruption in clean energy transitions: Sociotechnical dimensions of system disruption in Germany and the United Kingdom. *Energy Research & Social Science*, *59*, 101287.

Jones, B. R., Sovacool, B. K., & Sidortsov, R. V. (2015). Making the ethical and philosophical case for "energy justice". *Environmental Ethics*, *37*(2), pp. 145-168.

Jones, F. C. (2016). Cumulative effects assessment: theoretical underpinnings and big problems. *Environmental Reviews*, *24*(2), pp. 187-204.

Jones, W. D. (2007) Ontario quits coal. *IEEE Spectrum.* March 2007, pp. 12-13.

Jørgensen, S. E. & Fath, B. D. (2004). Application of thermodynamic principles in ecology. *Ecological Complexity*, 1(4), pp. 267-280.

Kaika, M. (2017). 'Don't call me resilient again!': The New Urban Agenda as immunology… or… what happens when communities refuse to be vaccinated with 'smart cities' and indicators. *Environment & Urbanization, 29*(1), pp. 89-102.

Kainiemi, L., Eloneva, S., & Levänen, J. (2019). Transition towards a decentralised energy system: analysing prospects for innovation facilitation and regime destabilisation in Finland. *Technology Analysis & Strategic Management*, 31(9), pp. 1003-1015.

Kakwani, N. & Pernia, E. M. (2000). What is pro-poor growth? *Asian Development Review*, 18.

Kallis, G. (2011). Degrowth. *Newsletter for the European Society of Ecological Economics*, 5.

Kanie, N., Griggs, D., Young, O., Waddell, S., Shrivastava, P., Haas, P. M., ... & Kőrösi, C. (2019). Rules to goals: emergence of new governance strategies for sustainable development. *Sustainability Science*, *14*(6), pp. 1745-1749.

Kantor, I., Rowlands, I. H., & Parker, P. (2017). Aggregated and disaggregated correlations of household electricity consumption with time-of-use shifting and conservation. *Energy and Buildings*, 139, pp. 326-339.

Karanasios, K., & Parker, P. (2016). Recent developments in renewable energy in remote aboriginal communities, Ontario, Canada. *Papers in Canadian Economic Development*, *16*, pp. 82-97.

Kates, R. W., Parris, M. T. & Leiserowitz, A. A. (2005). What is sustainable development? Goals, indicators, values, and practice. *Environment: Science and Policy for Sustainable Development,* 47(3), pp. 1-10.

Kates, R. W., Travis, W. R., & Wilbanks, T. J. (2012). Transformational adaptation when incremental adaptations to climate change are insufficient. *Proceedings of the National Academy of Sciences of the United States of America*, *109*(19), pp. 7156-7161.

Katre, A., & Tozzi, A. (2018). Assessing the sustainability of decentralized renewable energy systems: a comprehensive framework with analytical methods. *Sustainability*, *10*(4), p.1058.

Katz, D. & Kahn, R. L. (1978). *The social psychology of organizations.* New York: Wiley.

Kay, J. J. & Schneider, E. (1994). Embracing complexity: The challenge of ecosystem approach. *Alternatives*, 20(3), pp. 32-38.

Keating, C. B., & Katina, P. F. (2019). Complex system governance: Concept, utility, and challenges. *Systems Research and Behavioral Science*, *36*(5), pp. 687-705.

Kemp, R., & Loorbach, D. (2005). Dutch policies to manage the transition to sustainable energy. *Jahrbuch Okologische Okonomik, 4*, pp. 123-151.

Kemp, R., Loorbach, D. & Rotmans, J. (2007). Transition management as a model for managing processes of co-evolution towards sustainable development. *The International Journal of Sustainable Development & World Ecology*, 14(1), pp. 78-91.

Kemp, S. (2009). Unpredictability and nonlinearity in complexity theory: A critical appraisal. *Emergence: Complexity & Organization,* 11(1), pp. 84-93.

Kerlinger, F. N. & Lee, H. B. (2002). *Investigación del comportamiento: Métodos de investigación en ciencias sociales.* McGraw-Hill.

Khan, I. (2020). Impacts of energy decentralization viewed through the lens of the energy cultures framework: Solar home systems in the developing economies. *Renewable and Sustainable Energy Reviews,* 119, pp. 1-11.

Kim, S. H. (2007). Evaluation of negative environmental impacts of electricity generation: Neoclassical and institutional approaches. *Energy Policy*, *35*(1), pp. 413-423.

Kirkby, J., O'Keefe, P. & Timberlake, L. (1995). *The Earthscan reader in sustainable development.* London: Earthscan.

Kirsch, S. (2010). Sustainable mining. *Dialect Anthropol*, 34, pp. 87-93.

Kirwan, J., Maye, D., & Brunori, G. (2017). Reflexive governance, incorporating ethics and changing understandings of food chain performance. *Sociologia Ruralis*, *57*(3), pp. 357-377.

Kooiman, J. (2003) *Governing as governance.* London, Thousand Oaks, New Delhi: SAGE.

Kosoy, N., Brown, P. G., Bosselmann, K., Duraiappah, A., Mackey, B., Martinez-Alier, J., … Thomson, R. (2012). Pillars for a flourishing Earth: planetary boundaries, economic growth delusion and green economy. *Current Opinion in Environmental Sustainability,* 4, pp. 74-79.

Kothari, C. R. (2004). *Research methodology – Methods and techniques.* New Delhi: New Age International.

Kroposki, B., Johnson, B., Zhang, Y., Gevorgian, V., Denholm, P., Hodge, B. M., & Hannegan, B. (2017). Achieving a 100% renewable grid: Operating electric power systems with extremely high levels of variable renewable energy. *IEEE Power and Energy Magazine*, 15(2), pp. 61-73.

Kruyt, B., van Vuuren, D. P., de Vries, H. J., & Groenenberg, H. (2009). Indicators for energy security. *Energy policy*, 37(6), pp. 2166-2181.

Kubli, M., & Ulli-Beer, S. (2016). Decentralisation dynamics in energy systems: A generic simulation of network effects. *Energy Research & Social Science*, *13*, 71-83.

Kumagai, Y. (2017). Applying a sustainability assessment framework to recovery plans in eastern Tohoku, Japan. In R. B. Gibson (Ed.) *Sustainability Assessment: Applications and Opportunities* (pp. 194-224). London and New York: Routledge/Earthscan.

Kuosa, T. (2011) Evolution of futures studies. *Futures,* 43, pp. 327-336.

Kuzdas, C., Warner, B. P., Wiek, A., Vignola, R., Yglesias, M. & Childers, D. L. (2016). Sustainability assessment of water governance alternatives: the case of Guanacaste Costa Rica. *Sustain Sci,* 11, pp. 231-247.

Kuzemko, C., Lockwood, M., Mitchell, C., & Hoggett, R. (2016). Governing for sustainable energy system change: Politics, contexts and contingency. *Energy Research & Social Science*, 12, pp. 96-105.

LaBelle, M. C. (2017). In pursuit of energy justice. *Energy Policy*, 107, pp. 615-620.

Laird, F. N. (1990). Technocracy revisited: knowledge, power and the crisis in energy decision making. *Industrial Crisis Quarterly*, 4(1), pp. 49-61.

Lamorgese, L. & Geneletti, D. (2013). Sustainability principles in strategic environmental assessment: A framework for analysis and examples from Italian urban planning. *Environmental Impact Assessment Review,* 42, pp. 116-126.

Lange, P., Driessen, P. P. J., Sauer, A., Bornemann, B., & Burger, P. (2013). Governing towards sustainability — conceptualizing modes of governance. *Journal of Environmental Policy & Planning, 15*(3), pp. 403-425.

Laughlin, R. C. (1991). Environmental disturbances and organizational transitions and transformations: some alternative models. *Organization studies*, *12*(2), 209-232.

Lazowski, B., Parker, P. & Rowlands, I. H. (2018) Towards a smart and sustainable residential energy culture: assessing participant feedback from a long-term smart grid pilot. *Energy, Sustainability and Society,* 8:27.

Leach, M., Nisbett, N., Cabral, L., Harris, J., Hossain, N., & Thompson, J. (2020). Food politics and development. *World Development*, *134*, 105024.

Leach, M., Rockström, J., Raskin, P., Scoones, I., Stirling, A., Smith, A., . . . Olsson, P. (2012). Transforming innovation for sustainability. *Ecology and Society, 17*(2), 11.

Leach. M., Scoones, I. and Stirling, A. (2007). *Pathways to sustainability: an overview of the STEPS Centre approach.* STEPS Approach Paper, Brighton: STEPS Centre.

Lebel, L., Anderies, J. M., Campbell, B., Folke, C., Hatfield-Dodds, S., Hughes, T. P., & Wilson, J. (2006). Governance and the capacity to manage resilience in regional social-ecological systems. *Ecology and Society*, *11*(1).

Leftwich, A. (1983/2010). Redefining politics. People, resources and power. New York, NY: Routledge (Republished edition of the 1983 original).

Lélé, S. M. (1991). Sustainable development: a critical review. *World Development,* 19 (6), pp. 607 – 621.

Levin, S. A. (1999). Fragile dominion: Complexity and the commons. Reading, MA: Perseus Books.

Levin, S., Xepapadeas, T., Crépin, A., Norberg, J., de Zeeuw, A., Folke, C., . . . Walker, B. (2013). Social-ecological systems as complex adaptive systems: Modeling and policy implications. *Environment and Development Economics*, 18, pp. 111-132.

Lewis-Beck, M.S., Bryman, A., Liao, F. T. (2004). *The sage encyclopedia of social science.* Sage Publications.

Li, M. J., & Tao, W. Q. (2017). Review of methodologies and polices for evaluation of energy efficiency in high energy-consuming industry. *Applied Energy*, 187, pp. 203-215.

Li, X. (2005). Diversification and localization of energy systems for sustainable development and energy security. *Energy Policy*, *33*(17), pp. 2237-2243.

Lieu, J., Sorman, A. H., Johnson, O. W., Virla, L. D., & Resurrección, B. P. (2020). Three sides to every story: Gender perspectives in energy transition pathways in Canada, Kenya and Spain. *Energy Research & Social Science,* 68, p. 101550.

Lilliestam, J., & Hanger, S. (2016). Shades of green: Centralisation, decentralisation and controversy among European renewable electricity visions. *Energy Research & Social Science*, 17, pp. 20-29.

Lin, Y., & Bie, Z. (2016). Study on the resilience of the integrated energy system. *Energy Procedia*, 103(1), pp. 171-176.

Lin, Y., Jia, Y., Alva, G., & Fang, G. (2018). Review on thermal conductivity enhancement, thermal properties and applications of phase change materials in thermal energy storage. *Renewable and sustainable energy reviews*, 82, pp. 2730-2742.

Linden-Fraser, R. (2020). *Bill C-12: An act respecting transparency and accountability in Canada's efforts to achieve net-zero greenhouse gas emissions by the year 2050*. Publication No. 43-2-C12-E. Parliamentary Information and Research Service.

Lockwood, M., Davidson, J., Curtis, A., Stratford, E., & Griffith, R. (2010). Governance Principles for Natural Resource Management. *Society and Natural Resources,* 23(10), pp. 986-1001.

Loorbach, D. (2010). Transition management for sustainable development: A prescriptive, complexity-based governance framework. *Governance: An International Journal of Policy, Administration, and Institutions*, 23(1), pp. 161-183.

Love, P. (2017). *Fundamentals of energy efficiency – Policy, programs and best practices.* Retrieved from: http://energyefficiencyfundamentals.org/.

Lovins, A. B. (1977). Energy strategy: The road not taken? *Not Man Apart*, 6(20).

Lovins, A. B. (1990). The negawatt revolution. *Across the board*, 27(9), 18-23.

Lovins, A. B. (2018). How big is the energy efficiency resource? *Environmental Research Letters*, 13(9), p. 090401.

Luederitz, C., Lang, D. J. & Von Wehrden, H. (2013). A systematic review of guiding principles for sustainable urban neighborhood development. *Landscape and Urban Planning,* 118, pp. 40-52.

Luederitz, C., Schäpke, N., Wiek, A., Lang, D. J., Bergmann, M., Bos, J. J., ... & Farrelly, M. A. (2017). Learning through evaluation–A tentative evaluative scheme for sustainability transition experiments. *Journal of Cleaner Production*, *169*, pp. 61-76.

Lujano-Rojas, J. M., Yusta, J. M., & Domínguez-Navarro, J. A. (2019). Mitigating energy system vulnerability by implementing a microgrid with a distributed management algorithm. *Energies*, 12(4), p. 616.

Lund, P. D., Lindgren, J., Mikkola, J., & Salpakari, J. (2015). Review of energy system flexibility measures to enable high levels of variable renewable electricity. *Renewable and Sustainable Energy Reviews*, 45, pp. 785-807.

Macdonald, D. (2012). State interest as an explanatory factor in the failure of the soft-path energy vision. *Energy Policy*, 43, pp. 92-101.

Machi, L. A. & McEvoy, B. T. (2009). *The literature review.* Thousand Oaks: Corwin Press.

MacLaren, O. (2021). *Cancellation of renewable energy contracts disproportionately hits First Nations and local communities.* Olthuis Kleer Townshend – LLP. Retrieved from: https://www.oktlaw.com/cancellation-of-renewable-energy-contracts-disproportionately-hits-first-nations-and-local-communities/.

Mang-Benza, C., & Hunsberger, C. (2020). Wandering identities in energy transition discourses: Political leaders' use of the "we" pronoun in Ontario, 2009–2019. *The Canadian Geographer/Le Géographe canadien*, *64*(3), pp. 516-529.

Marín, C. (2019). *Bloque Verde califica de 'aburguesado, descontextualizado y grosero' Plan de Descarbonización.* Retrieved from: https://www.elmundo.cr/costa-rica/bloque-verde-califica-de-aburguesado-descontextualizado-y-grosero-plan-de-descarbonizacion/.

Markard, J., Raven, R., & Truffer, B. (2012). Sustainability transitions: An emerging field of research and its prospects. *Research Policy, 41*(6), pp. 955-967.

Masini, E. (2006) Rethinking futures studies. *Futures*, 38, pp. 1158-1168.

Masten, A. S. (2001). Ordinary magic: Resilience processes in development. *American Psychologist*, 56(3), pp. 227-238.

Mayer, A. (2018). A just transition for coal miners? Community identity and support from local policy actors. *Environmental Innovation and Societal Transitions*, *28*, pp. 1-13.

Mazmanian, D. A., & Kraft, M. E. (Eds.). (2009). *Toward sustainable communities: Transition and transformations in environmental policy*. MIT Press.

McCrory, G., Schäpke, N., Holmén, J., & Holmberg, J. (2020). Sustainability-oriented labs in real-world contexts: An exploratory review. *Journal of Cleaner Production*, 123202.

McDaniel, R. R. Jr., Jordan, M. E. & Fleeman, B. F. (2003). Surprise, surprise, surprise! A complexity science view of the unexpected. *Health Care Management Review*, 28(3), pp. 266-278.

McKenna, R. (2018). The double-edged sword of decentralized energy autonomy. *Energy Policy*, 113, pp. 747-750.

McNeill, J. R. & McNeill, W. H. (2003). *The human web: A bird's eye view of the world history.* New York: Norton.

Meadowcroft, J. (2007). Who is in charge here? Governance for sustainable development in a complex world**.** *Journal of Environmental Policy & Planning*, 9(3-4), pp. 299-314.

Meadows, D. H. (1999). *Leverage points – Places to intervene in a system.* Hartland, VT: The Sustainability Institute.

Meadows, D. H., Meadows, D. L., Randers, J. & Behrens, W. W. (1972). *The limits to growth: A report for the Club of Rome's project on the predicament of mankind.* New York: Potomac Associates.

Mebratu, D. (1998). Sustainability and sustainable development: historical and conceptual review. *Environmental Impact Assessment*, 18, pp. 493-520.

Méndez, P. F., Amezaga, J. M., & Santamaría, L. (2019). Explaining path-dependent rigidity traps: increasing returns, power, discourses, and entrepreneurship intertwined in social-ecological systems. *Ecology and Society*, 24(2), 30.

Mendizabal, M., Heidrich, O., Feliu, E., García-Blanco, G & Mendizabal, A. (2018). Stimulating urban transition and transformation to achieve sustainable and resilient cities. *Renewable and Sustainable Energy Reviews*, 94, pp. 410-418.

Mengelkamp, E., Gärttner, J., & Weinhardt, C. (2018, March). Decentralizing energy systems through local energy markets: The LAMP-Project. In *Multikonferenz Wirtschaftsinformatik* (pp. 924-930).

Menjívar, M. (2005). Acciones colectivas en Costa Rica al final del siglo XX: entre la continuidad y el orden. *Rev. Ciencias Sociales*, 106, pp. 55-67.

Metzger, J. P. & Muller, E. (1996). Characterizing the complexity of landscape boundaries by remote sensing. *Landscape Ecology*, 11(2), pp. 65-77.

Miller, C. A., & Richter, J. (2014). Social planning for energy transitions. *Current Sustainable/Renewable Energy Reports*, 1(3), pp. 77-84.

Miller, G. F. (1997). Protean primates: The evolution of adaptive unpredictability in competition and courtship. In A. Whiten & R. W. Byrne (Eds.), *Machiavellian Intelligence II: Extensions and Evaluations* (pp. 312-340). Cambridge, UK: Cambridge University Press.

Miller, J. G. (1965). Living systems: Basic concepts. *Behavioral Science*, 10(3), pp. 193-237.

MINAE (2015). *VII Plan Nacional de Energía 2015-2030.* Ministerio de Ambiente y Energía; Programa de las Naciones Unidas para el Desarrollo PNUD. San José, C.R.: PNUD.

MINAE (2020a). *Datos oficiales sobre la superficie marina y terrestre de Costa Rica.* Centro Nacional de Información Geoambiental. Retrieved from: https://ceniga.go.cr/datos-oficiales-sobre-la-superficie-marina-y-terrestre-de-costa-rica/.

MINAE (2020b). *Guía para la prevención y mitigación de la electrocución de la fauna silvestre por tendidos eléctricos en Costa Rica.* Grupo de Trabajo Electrificación Sostenible 2020.

MINAE, Instituto Meteorológico Nacional & Dirección de Cambio Climático (2019). *Costa Rica: 2do. Informe Bienal de Actualización ante la Convención Marco de Naciones Unidas sobre el Cambio Climático.* Primera Edicion.

MINAE, SINAC, CONAGEBIO & FONAFIFO (2018) *Sexto Informe Nacional de Costa Rica ante el Convenio de Diversidad Biológica. Programa de Naciones Unidas para el Desarrollo* - Apoyo técnico para que las Partes Elegibles desarrollen el Sexto Informe Nacional para el CDB (6NR-LAC, SecCDB, GEF, PNUD), Costa Rica.

Minister of the Environment (2020). *Bill C-12 – An act respecting transparency and accountability in Canada's efforts to achieve net-zero greenhouse gas emissions by the year 2050.* First reading, November 19, 2020. House of Commons Canada. Retrieved from: https://parl.ca/Content/Bills/432/Government/C-12/C-12_1/C-12_1.PDF.

Ministerio de Hacienda (2018). *Ministerio de Ambiente y Energía.* Retrieved from: https://www.hacienda.go.cr/docs/59a5ef55ce2d7_219%20c.pdf.

Ministerio de Relaciones Exteriores y Culto (2008). *Informe del Estado Costarricense con respecto a la Resolución 7/23 del Consejo de Derechos Humanos – "Los derechos humanos y el cambio climático".* United Nations Human Rights Office of the High Commissioner. Retrieved from: https://www.ohchr.org/documents/issues/climatechange/submissions/costa_rica.pdf.

Ministry of Energy (2015). Electricity Power System Planning. In Office of the Auditor General of Ontario, *2015 Annual Report* (pp. 206-242).

Ministry of Finance (2020). *2020-2021 First quarter finances.* Retrieved from: https://www.fin.gov.on.ca/en/budget/finances/2020/ofin20_1.html#secB.

Ministry of Finance (2021). *Ontario fact sheet.* Retrieved from: https://www.fin.gov.on.ca/en/economy/ecupdates/factsheet.pdf.

Ministry of the Environment, Conservation and Parks (2018a). *Bill 4, Cap and Trade Cancellation Act, 2018.* Environmental Registry of Ontario. Retrieved from: https://ero.ontario.ca/notice/013-3738.

Ministry of the Environment, Conservation and Parks (2018b). *Preserving and protecting our environment for future generations – A Made-in-Ontario Environment Plan.*

Mitchell, C. (2016). Momentum is increasing towards a flexible electricity system based on renewables. *Nature Energy*, 1(2), pp. 1-6.

Mittlefehldt, S. (2018). Wood Waste and Race: The Industrialization of Biomass Energy Technologies and Environmental Justice. *Technology and Culture*, 59(4), pp. 875-898.

Mizuno, Y., Kishita, Y., Wada, H., Kobayashi, K., Fukushige, S., & Umeda, Y. (2012, August). Proposal of design support method of sustainability scenarios in backcasting manner. In *International Design Engineering Technical Conferences and Computers and Information in Engineering Conference* (Vol. 45042, pp. 767-776). American Society of Mechanical Engineers.

Moghaddam, N. B., Nasiri, M., & Mousavi, S. M. (2011). An appropriate multiple criteria decision making method for solving electricity planning problems, addressing sustainability issue. *International Journal of Environmental Science & Technology*, 8(3), pp. 605-620.

Molyneaux, L., Brown, C., Wagner, L., & Foster, J. (2016). Measuring resilience in energy systems: Insights from a range of disciplines. *Renewable and Sustainable Energy Reviews*, 59, pp. 1068-1079.

Moon, K., & Blackman, D. (2014). A guide to understanding social science research for natural scientists: Social science for natural scientists. *Conservation Biology*, *28*(5), pp. 1167–1177.

Moore, M. L., Olsson, P., Nilsson, W., Rose, L., & Westley, F. R. (2018). Navigating emergence and system reflexivity as key transformative capacities. *Ecology and Society*, *23*(2), 38.

Mora, S. (2019). *Comentarios al Plan Nacional de Descarbonización, Costa Rica 2018-2050.* ResearchGate. Retrieved from: https://www.researchgate.net/publication/344243361_Comentarios_al_Plan_Nacional_de_Descarbonizacion_Costa_Rica_2018-2050.

Morrison, D. E., & Lodwick, D. G. (1981). The social impacts of soft and hard energy systems: the Lovins' claims as a social science challenge. *Annual Review of Energy*, 6(1), pp. 357-378.

Morrow, A. (2015). *Ontario liberals' gas-plants scandal: Everything you need to know.* The Globe and Mail. Retrieved from: https://www.theglobeandmail.com/news/politics/ontario-liberals-gas-plants-scandal-everything-you-need-to-know/article23668386/.

Moses, J. W. & Knutsen, T. L. (2012). *Ways of knowing – Competing methodologies in social and political research.* Hampshire and New York: Palgrave Macmillan.

Moslehi, S. & Arababadi, R. (2016). Sustainability assessment of complex energy systems using life cycle approach- Case study: Arizona State University Tempe Campus. *Procedia Engineering*, 145, pp. 1096-1103.

Mqadi, L. J., Musango, J. K., & Brent, A. C. (2018). Rethinking strategic sustainability planning for the electricity sector in South Africa. *South African Journal of Industrial Engineering*, 29(1), pp. 63-73.

Mulvihil, P. R. & Kramkowski, V. (2010) Extending the influence of scenario development in sustainability planning and strategy. *Sustainability,* 2, pp. 2449-2466.

Murillo, A. (2020). *Almacenamiento energético: Cómo maximizar su aprovechamiento?* Delfino. Retrieved from: https://delfino.cr/2020/10/almacenamiento-energetico-como-maximizar-su-aprovechamiento.

Nash, H. (1979). *The Energy Controversy.* San Francisco: Friends of the Earth Inc.

Nathwani, J. & Kammen, D. M. (2019). Affordable energy for humanity: A global movement to support universal clean energy access. *Proceedings of the IEEE*, 107(9), pp. 1780-1789.

National Research Council Committee on Health (NRC) (2010). Environmental, and other external costs and benefits of energy production and consumption. Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use. The National Academies Press, Washington, D.C.

Natural Resources Canada (NRCAN) (2020). Energy fact book 2019-2020. Government of Canada.

Navarro-Picado, J., Spínola-Parallada, M., Madrigal-Mora, A., & Fonseca-Sánchez, A. (2017). Selección de hábitat de Lontra longicaudis (Carnivora, Mustelidae) bajo la influencia de la represa hidroeléctrica del río Peñas Blancas y sus tributarios, Alajuela, Costa Rica. *Uniciencia*, *31*(1), pp. 73-84.

Nayan Yadava, R. & Sinha, B. (2019). Developing energy access index for measuring energy poverty in forest fringe villages of Madhya Pradesh, India. *Sustainable Energy Technologies and Assessments*, 31, pp. 167-178.

Nelson, C. (2007). *Thomas Paine – enlightenment, revolution, and the birth of modern nations*. New York: Penguin Books.

Nelson, V., & Phillips, D. (2018). Sector, landscape or rural transformations? Exploring the limits and potential of agricultural sustainability initiatives through a cocoa case study. *Business Strategy and the Environment*, *27*(2), pp. 252-262.

Newell, P., & Mulvaney, D. (2013). The political economy of the 'just transition'. *The Geographical Journal*, *179*(2), pp. 132-140.

Newcomer, K. E., Hatry, H. P., & Wholey, J. S. (Eds.). (2015). *Handbook of practical program evaluation* (p. 492). USA: John Wiley & Sons.

Newman, L., & Brooks, D. B. (2004). The soft path holds up: efficient technologies and renewable sources will bring a cheaper, more reliable energy future. *Alternatives Journal*, 30(1), pp. 10-14.

Ngonghala, C. N., Pluciński, M. M., Murray, M. B., Farmer, P. E., Barrett, C. B., Keenan, D. C., & Bonds, M. H. (2014). Poverty, disease, and the ecology of complex systems. *PLoS Biol*, *12*(4), e1001827.

Nikolakis, W. (2020). Participatory backcasting: Building pathways towards reconciliation? *Futures*, *122*, 102603.

Nock, D., Levin, T., & Baker, E. (2020). Changing the policy paradigm: A benefit maximization approach to electricity planning in developing countries. *Applied Energy*, 264, p. 114583.
Norton, B. G. (2005) *Sustainability: A Philosophy of Adaptive Ecosystem Management*.
Novakovic, B., & Nasiri, A. (2015). Introduction to electrical energy systems. In M. H. Rashid (Ed.), *Electrical renewable energy systems* (pp. 1-20). London, UK: Academic Press
NRCAN (2002). *Political map Ontario.* Retrieved from: nrcan.gc.ca/maps-tools-publications/tools/geodetic-reference-systems/reference-maps/16846.
NRi (2018). *Project profile: El Dabaa nuclear power plant, Egypt.* Future Power Technology. Retrieved on July 2020 from: https://power.nridigital.com/power_technology_nov18_special/project_profile_el_dabaa_nuclear_power_plant_egypt
O'Brien, G., & Hope, A. (2010). Localism and energy: Negotiating approaches to embedding resilience in energy systems. *Energy policy*, 38(12), pp. 7550-7558.
O'Brien, K. (2012). Global environmental change II: From adaptation to deliberate transformation. *Progress in Human Geography,* 36(5), pp. 667-676.
Oberle, B., Bringezu, S., Hatfield-Dodds, S., Hellweg, S., Schandl, H., Clement, J., ... & Ekins, P. (2019). Global resources outlook 2019: natural resources for the future we want.
Obregón, C. M. (2014). *Visión retrospectiva y modelo de Desarrollo eléctrico de Costa Rica.* Retrieved from: https://www.ucr.ac.cr/medios/documentos/2014/carlos_obregon.pdf.
Ohashi, H. (2012). Power devices now and future, strategy of Japan – Role of power electronics for a low carbon society. *Proceedings of the 2012 24th International Symposium on Power Semiconductor Devices and ICs,* pp. 9-12.
Olsson, P., Galaz, V. & Boonstra, W. J. (2014). Sustainability transformations: A resilience perspective. *Ecology and Society,* 19(4): 1.
Olsson, P., Moore, M. L., Westley, F. R., & McCarthy, D. D. (2017). The concept of the Anthropocene as a game-changer: a new context for social innovation and transformations to sustainability. *Ecology and Society*, *22*(2).
Ontario Energy Board (2022). *Overview of energy sector.* Retrieved from: https://www.oeb.ca/ontarios-energy-sector/overview-energy-sector.
Ontario Energy Board (2023). *Mission and mandate.* Retrieved from: https://www.oeb.ca/about-oeb/mission-and-mandate.
Ontario Power Generation (2021). Small modular reactors. Retrieved from: https://www.opg.com/innovating-for-tomorrow/small-modular-nuclear-reactors/.
Onwuegbuzie, A. J. & Frels, R. (2015). *Seven steps to a comprehensive literature review.* Los Angeles, CA: Sage.
OPA/IESO (2013). *Engaging local communities in Ontario's electricity planning continuum – Enhancing regional electricity planning and sitting.* Report prepared for the Minister of Energy by the Ontario Power Authority and the Independent Electricity System Operator, August 1, 2013.
Orr, D. W. (1979). US energy policy and the political economy of participation. *The Journal of Politics*, 41(4), pp. 1027-1056.

Österlin, C. (2020). *Nature conservation, landscape change and indigenous rights: The role of Sámi reindeer herding for environmental objectives in the Swedish mountain landscape* (Doctoral dissertation, Department of Physical Geography, Stockholm University).

Ostrom, E. (2009). A general framework for analyzing sustainability of socio-ecological systems. *Science,* 325, pp. 419-422.

Our Energy Gueph (2018). *Community Energy Initiative Update*. Retrieved from: https://www.ourenergyguelph.ca/community-energy-initiative-cei-update-2018.

Papaefthymiou, G. & Dragoon, K. (2016). Towards 100% renewable energy systems: Uncapping power system flexibility. *Energy Policy*, 92, pp. 69-82.

Parisi, A. J. (1977). 'Soft' energy, hard choices. *The New York Times.* Retrieved from https://search.proquest.com/docview/123493303.

Partidário, M. R. (2017). Using strategic thinking and critical decision factors to achieve sustainability – Three cases in Portugal. In R. B. Gibson (Ed.), *Sustainability Assessment – Applications and opportunities* (pp. 169-193). London and New York: Routledge/Earthscan.

Pascale, A. (2017) *The links between energy and human welfare.* (Doctoral thesis). University of Queensland, Australia.

Patterson, J., Schulz, K., Vervoort, J., van der Hel, S., Widerberg, O., Adler, C., . . . Barau, A. (2016). Exploring the governance and politics of transformations towards sustainability. *Environmental Innovation and Societal Transitions*.

Patterson, W. C. (1999). *Transforming electricity*. London: The Royal Institute of International Affairs/Earthscan.

Patterson, W. C. (2007). *Keeping the lights on*. London: Earthscan.

Peano, C., Tecco, N., Dansero, E., Girgenti, V. & Sottile, F. (2015). Evaluating the sustainability in complex agri-food systems: The SAEMETH framework. *Sustainability,* 7, pp. 6721-6741.

Pearse, G., Burton, B., & McKnight, D. (2013). *Big Coal: Australia's Dirtiest Habit*. NewSouth.

Pelling, M. (2011). *Adaptation to climate change – from resilience to transformation*. London and New York: Routledge.

Pelling, M., O’Brien, K., & Matyas, D. (2015). Adaptation and transformation. *Climatic Change, 133*(1), pp. 113-127.

Pereira, L., Karpouzoglou, T. D., Doshi, S., & Frantzeskaki, N. (2015). Organising a safe space for navigating social-ecological transformations to sustainability. *International Journal of Environmental Research and Public Health, 12*(6), pp. 6027-6044.

Pérez, B. (2011). Reflexiones sobre el proyecto hidroeléctrico el Diquís y sus impactos sociales en las comunidades de Térraba, Buenos Aires y Ceibo. *Reflexiones*, 90(2), pp. 9-25.

Phdungsilp, A. (2011) Futures studies’ backcasting method used for strategic sustainable city planning. *Futures,* 43, pp. 707-714.

Pinker, A., Argüelles, L., Fischer, A. & Becker, S. (2020). Between straitjacket and possibility: Energy initiatives and the politics of regulation. *Geoforum*, 113, pp. 14-25.

Pohl, C. (2010). From transdisciplinarity to transdisciplinary research. *Transdisciplinary Journal of Engineering & Science*, 1, pp. 65-73.

Pollin, R., & Callaci, B. (2016). A just transition for US fossil fuel industry workers. *The American Prospect*, *6*.

Pop, I. G., Văduva, S. & Talpoş, M-F. (2017). Energetic sustainability and the environment: A transdisciplinary, economic-ecological approach. *Sustainability*, 9, p. 873.

Pope, J., Bond, A., Hugé, J. & Morrison-Saunders, A. (2017). Reconseptualising sustainability assessment. *Environmental Impact Assessment Review*, 62, pp. 205-215.

Poschen, P. (2017). *Decent work, green jobs and the sustainable economy: Solutions for climate change and sustainable development*. Routledge.

Potvin, C., Burch, S., Layzell, D., Meadowcroft, J., Mousseau, N., Dale, A… Slawinski, N. (2017). *Re-energizing Canada – Pathways to a low-carbon future.* Sustainable Canada Dialogues.

Pratama, Y. W., Purwanto, W. W., Tezuka, T., McLellan, B. C., Hartono, D., Hidayatno, A., & Daud, Y. (2017). Multi-objective optimization of a multiregional electricity system in an archipelagic state: The role of renewable energy in energy system sustainability. *Renewable and Sustainable Energy Reviews*, 77, pp. 423-439.

Purcell, B. (2022). *Ontario's next gas plant scandal.* The Atmospheric Fund. Retrieved from: https://taf.ca/ontarios-next-gas-plant-scandal/#:~:text=These%20new%20gas%20plants%20are,emissions%20from%20Ontario's%20electricity%20system.

Rakshit, R., Shahi, C., Smith, M. A., & Cornwell, A. (2019). Energy transition complexities in rural and remote Indigenous communities: a case study of Poplar Hill First Nation in northern Ontario. *Local Environment*, *24*(9), pp. 809-824.

Raman, S. (2013). Fossilizing renewable energies. *Science as Culture*, 22(2), pp. 172-180.

Rapid Transition Alliance (2019). *Can Costa Rica's path to cabron neutrality be replicated by other countries?* Retrieved from: https://www.rapidtransition.org/stories/can-costa-ricas-path-to-carbon-neutrality-be-replicated-by-other-countries/.

Ravetz, J. R. (2006) Post-normal science and the complexity of transitions towards sustainability. *Ecological Complexity*, 3, pp. 275-284.Raworth, K. (2012). *A safe and just space for humanity: Can we live within the doughnut?* Oxfam Discussion Paper. Cowley, Oxford: Oxfam GB.

Raworth, K. (2012). *A safe and just space for humanity: Can we live within the doughnut?* Cowley, Oxford: Oxfam GB.

Raymond, L. (2020). Carbon pricing and economic populism: the case of Ontario. *Climate Policy*, *20*(9), pp. 1127-1140.

Redclift, M. (2005). Sustainable development (1987-2005): An oxymoron comes of age. *Sustainable Development*, 13, pp. 212-227.

Ren, J., & Ren, X. (2018). Sustainability ranking of energy storage technologies under uncertainties. *Journal of cleaner production*, 170, pp. 1387-1398.

REN21 (2014). *Renewables 2014 – Global Status Report.* Retrieved from: https://www.ren21.net/wp-content/uploads/2019/05/GSR2014_Full-Report_English.pdf. *research methods.* Thousand Oaks: Sage Publications.

Reyes, V. & Tabora, F. (2016). *Situación de los recursos hídricos en Centroamérica – Costa Rica.* Global Water Partnership Central America.

Richardson, K. A. & Lissack, M. R. (2001). On the status of boundaries, both natural and organizational: A complex systems perspective. *Emergence,* 3(4), pp. 32-49.

Rittel, H. W., & Webber, M. M. (1973). Dilemmas in a general theory of planning. *Policy Sciences*, *4*(2), pp. 155-169.

Rivard, B. (2019). Don't leave me stranded: *What to do with Ontario's Global Adjustment?* Policy brief, July 2019. Ivey Business School – Energy Policy and Management Centre. Western University, Canada. Retrieved from: https://www.ivey.uwo.ca/cmsmedia/3787293/dont-leave-me-stranded-what-to-do-with-ontario-s-global-adjustment.pdf.

Rivard, B., & Yatchew, A. (2016). Integration of renewables into the Ontario electricity system. *The Energy Journal*, *37*.

Roberts, C., & Geels, F. W. (2019). Conditions for politically accelerated transitions: Historical institutionalism, the multi-level perspective, and two historical case studies in transport and agriculture. *Technological Forecasting and Social Change*, *140*, 221-240.

Robin, L., & Steffen, W. (2008). The 'Big Here and the Long Now': Agendas for history and sustainability. *History Compass, 5,* pp. 1694-719.

Robinson, J. (1990). Futures under glass – a recipe for people who hate to predict. *Futures,* 22, pp. 820-842.

Robinson, J. B. (1982) Energy backcasting – A proposed method of policy analysis. *Energy Policy,* 10(4), pp. 337-344

Robinson, J. B. (2004). Squaring the circle? Some thoughts on the idea of sustainable development. *Ecological Economics,* 48, pp. 369-384.

Robinson, J. B., Francis, G., Legge, R. & Lerner, S. (1990). Defining a sustainable society – Values, principles and definitions. *Alternatives,* 17(2), pp. 36-46.

Rocchetta, R. & Patelli, E. (2018). Assessment of power grid vulnerabilities accounting for stochastic loads and model imprecision. *Electrical Power and Energy systems,* 98, pp. 219-232.

Rockström, J., Steffen, W., Noone, K., Persson, A, Chapin III, F. S., Lambin, E., … Foley, J. A. (2009). A safe operating space for humanity. *Nature*, *461*, pp. 472–475.

Rodríguez, G. & Sáez, E. (2020). *Ríos limpios – Estrategia nacional para la recuperación de cuencas urbanas 2020-2030.* Costa Rica – Gobierno del Bicentenario 2018-2022; Ministerio de Ambiente y Energía. Retrieved from: http://www.da.go.cr/wp-content/uploads/2020/02/Estrategia-Nacional-Rios-Limpios_Recuperacion-de-Cuencas-Urbanas-2020-2030.pdf.

Rogge, K. S., & Reichardt, K. (2016). Policy mixes for sustainability transitions: An extended concept and framework for analysis. *Research Policy*, 45(8), pp. 1620-1635.

Roggema, R., Vermeend, T., & Dobbelsteen, A. V. D. (2012). Incremental change, transition or transformation? Optimising change pathways for climate adaptation in spatial planning. *Sustainability*, *4*(10), pp. 2525-2549.

Roinioti, A., & Koroneos, C. (2019). Integrated life cycle sustainability assessment of the Greek interconnected electricity system. *Sustainable Energy Technologies and Assessments*, 32, pp. 29-46.

Rojas, J. R. (2016). Perspectiva energética en Costa Rica: análisis de situación, retos y oportunidades. *Revista Centroamericana de Administración Pública*, (71), pp. 148-167.

Romero-Lankao, P., Bulkeley, H., Pelling, M., Burch, S., Gordon, D. J., Gupta, J., ... & Tozer, L. (2018). Urban transformative potential in a changing climate. *Nature Climate Change*, *8*(9), pp. 754-756.

Rosa, E. A., Machlis, G. E., & Keating, K. M. (1988). Energy and society. *Annual review of sociology*, 14(1), pp. 149-172.

Rosemberg, A. (2010). Building a just transition: The linkages between climate change and employment. *International Journal of Labour Research*, *2*(2), 125.

Rosenau, J. (2003). Globalization and governance: Bleak prospects for sustainability. *Internationale Politik und Gesellschaft*, 3, pp. 11-29.

Rosenbloom, D. (2019). A clash of socio-technical systems: Exploring actor interactions around electrification and electricity trade in unfolding low-carbon pathways for Ontario. *Energy Research & Social Science*, *49*, pp. 219-232.

Rosenbloom, D., & Meadowcroft, J. (2014). The journey towards decarbonization: Exploring socio-technical transitions in the electricity sector in the province of Ontario (1885–2013) and potential low-carbon pathways. *Energy Policy*, *65*, pp. 670-679.

Rossin, A. D. (1980). The soft energy path: where does it really lead? [Alternative energy sources]. *Futurist*.

Rovira Mas, J. (2001). *La democracia en Costa Rica ante el siglo XXI.* San José, Costa Rica: Editorial de la Universidad de Costa Rica.

Rowlands, I. H. (2007). The development of renewable electricity policy in the province of Ontario: the influence of ideas and timing. *Review of Policy Research*, *24*(3), pp. 185-207.

Rowlands, I. H. (2008). *Demand response in Ontario: Exploring the issues.* A report prepared for the Independent Electricity System Operator (IESO), Toronto, Ontario.

Rutter, M. (1993). Resilience: Some conceptual considerations. *Journal of Adolescent Health,* 14(8), pp. 626-631.

Rutter, P., & Keirstead, J. (2012). A brief history and the possible future of urban energy systems. *Energy Policy*, *50*(1), 72-80.

Saldaña, J. (2014). Coding and analysis strategies. In *The Oxford handbook of qualitative research*.

Sánchez Úbeda, E. F., Portela González, J., Muñoz San Roque, A., Chueca, E., & Hallack, M. (2021). *Impacto del COVID-19 en la demanda de energía eléctrica en Latinoamérica y el Caribe.* Banco Interamericano de Desarrollo.

Sandí Meza, V., & Recinos Carvajal, S. (2022). *Efectos de la pandemia en Costa Rica – Retos y oportunidades para el Desarrollo económico y social.* Friedrich-Ebert-Stiftung. Retrieved from: https://library.fes.de/pdf-files/bueros/fesamcentral/19398.pdf.

Santos, I. T. (2020). Confronting governance challenges of the resource nexus through reflexivity: A cross-case comparison of biofuels policies in Germany and Brazil. *Energy Research & Social Science*, *65*, p. 101464.

Santos, S. A., Póvoas de Lima, H., Massruhá, S.M.F.S., de Abreu, U. G. P., Tomás, W. M., Salis, S. M., … Pellegrin, L. A. (2017). A fuzzy logic-based tool to assess beef cattle ranching sustainability in complex environmental systems. *Journal of Environmental Management,* 198, pp. 95-106.

Santoyo-Castelazo, E., & Azapagic, A. (2014). Sustainability assessment of energy systems: integrating environmental, economic and social aspects. *Journal of Cleaner Production*, 80, pp. 119-138.

Sawyer, S. W., & Feldman, S. L. (1981). Technocracy versus reality: perceptions in solar policy. *Policy Sciences*, 13(4), pp. 459-472.

Schaaf, W., Bens, O., Fischer, A., Gerke, H. H., Gerwin, W., Grünewald, U., ... & Schulin, R. (2011). Patterns and processes of initial terrestrial-ecosystem development. *Journal of Plant Nutrition and Soil Science*, *174*(2), pp. 229-239.

Schelly, C., Bessette, D., Brosemer, K., Gagnon, V., Arola, K. L., Fiss, A., ... & Halvorsen, K. E. (2020). Energy policy for energy sovereignty: Can policy tools enhance energy sovereignty?. *Solar Energy*, 205, pp. 109-112.

Schmeck, H. (2016, November). *Lessons from European German energy transition: Is the disruption potential real?* Presented at the Technology Innovation & Policy Forum, Waterloo, Ontario.

Schneider, S. H., Turner, B. L. & Morehouse Garriga, H. (1998). Imaginable surprise in global change science. *Journal of Risk Research,* 1(2), pp. 165-185.

Schot, J., Kanger, L., & Verbong, G. (2016). The roles of users in shaping transitions to new energy systems. *Nature energy*, 1(5), pp. 1-7.

Schulz, K. A., & Siriwardane, R. (2015). *Depoliticised and technocratic? normativity and the politics of transformative adaptation.* Earth System Governance Working Paper No. 33. Lund and Amsterdam: Earth System Governance Project.

Schwartz, P. (1991). *The art of the long view.* New York: Doubleday.

SCIJ (1990). *Ley que autoriza la generación eléctrica autónoma o paralela.* Sistema Costarricense de Información Jurídica. Retrieved from:

http://www.pgrweb.go.cr/scij/Busqueda/Normativa/Normas/nrm_texto_completo.aspx?param1=NRTC&nValor1=1&nValor2=7591&nValor3=8139&strTipM=TC.

SCIJ (2008). *Declara de conveniencia nacional e interés público los estudios y las obras del Proyecto Hidroeléctrico El Diquís y sus obras de transmisión, en adelante el Proyecto, las que serán construidas por el Instituto Costarricense de Electricidad.* Sistema Costarricense de Información Jurídica. Retrieved from: http://www.pgrweb.go.cr/scij/Busqueda/Normativa/Normas/nrm_texto_completo.aspx?param1=NRTC&nValor1=1&nValor2=62425&nValor3=89875&strTipM=TC.

SCIJ (2019). *Aplicación del impuesto al valor agregado (IVA) en tarifas de las empresas distribuidoras de electricidad públicas, municipales y cooperativas de electrificación rural, correspondiente al segundo semestre de 2019.* Sistema Costarricense de Información Jurídica. Retrieved from: http://www.pgrweb.go.cr/scij/Busqueda/Normativa/Normas/nrm_texto_completo.aspx?param1=NRTC&nValor1=1&nValor2=90300&nValor3=118858&strTipM=TC.

Scoones, I. (2016). The politics of sustainability and development. *Annual Review of Environment and Resources, 41*(1), pp. 293-319.

Scoones, I., Leach, M., & Newell, P. (2015). *The politics of green transformations*. London and New York: Routledge.

Scoones, I., Stirling, A., Abrol, D., Atela, J., Charli-Joseph, L., Eakin, H., … Yang, L. (2020). Transformations to sustainability: Combining structural, systemic and enabling approaches. *Current Opinion in Environmental Sustainability,* 42, pp. 65-75.

Seme, S., Sredenšek, K., Praunseis, Z., Štumberger, B., & Hadžiselimović, M. (2018). Optimal price of electricity of solar power plants and small hydro power plants–Technical and economical part of investments. *Energy*, 157, pp. 87-95.

Sen, A. (2017). Peak power problems: How Ontario’s industrial electricity pricing system hurts consumers. *The Electricity Journal*, *30*(1), pp. 62-67.

SEPSE (2021). *Estrategia nacional de redes eléctricas inteligentes 2021-2031*. Secretaría Planificación Subsector Energía. Retrieved from: https://sepse.go.cr/wp-content/uploads/2021/08/ENREI-FINAL.pdf.

Sequeira, T. N., & Santos, M. S. (2018). Renewable energy and politics: A systematic review and new evidence. *Journal of Cleaner Production*, 192, pp. 553-568.

Serwaa Mensah, G., Kemausuor, F. & Brew-Hammond, A. (2014). Energy access indicators and trends in Ghana. *Renewable and Sustainable Energy Reviews*, 30, pp. 317-323.

Shah , Y. T. (2020). *Modular systems for energy usage management.* Boca Raton, London, New York: CRC Press.

Shah, S. H. & Gibson, R. B. (2013). Large dam development in India: Sustainability criteria for the assessment of critical river basin infrastructure. *International Journal of River Basin Management,* 11(1), pp. 33-53.

Sharma B. D. (1994). On sustainability. In M. Tobias and G. Cowan (Eds.), *The Soul of Nature – Visions of a Living Earth* (pp. 271-278). New York: Continuum.

Sharma, T., & Balachandra, P. (2015). Benchmarking sustainability of Indian electricity system: An indicator approach. *Applied Energy*, 142, pp. 206-220.
Sharma, T., & Balachandra, P. (2018). Will the integration of renewable energy enable sustainable transition of Indian electricity system?. *Energy strategy reviews*, 21, pp. 137-148.
Sharma-Wallace, L., Velarde, S. J., & Wreford, A. (2018). Adaptive governance good practice: Show me the evidence! *Journal of Environmental Management*, *222*, pp. 174-184.
Sharmina, M. (2017). Low-carbon scenarios for Russia's energy system: A participative backcasting approach. *Energy Policy*, 104, pp. 303-315.
Shen, Y., Gu, C., & Zhao, P. (2019). Structural vulnerability assessment of multi-energy system using a PageRank algorithm. *Energy Procedia*, 158, pp. 6466-6471.
Shin, C. H., Taehyung, K. I. M., Lee, S., Kim, J., Nam, H. S., & Jeong, Y. K. (2019). A study on the effects of economic zero energy town according to the Korea's renewable energy support policies. In *2019 International Conference on Information and Communication Technology Convergence (ICTC)* (pp. 1204-1207). IEEE.
Shove, E., & Walker, G. (2010). Governing transitions in the sustainability of everyday life. *Research policy*, *39*(4), pp. 471-476.
SICA (2017). *ICE activa sistema para desconectar a Costa Rica de Panamá en caso de sobrecarga eléctrica.* Sistema de Integración Centroamericana. Retrieved from: https://www.sica.int/busqueda/Noticias.aspx?IDItem=108860&IDCat=3&IdEnt=1225&Idm=1&IdmStyle=1.
Singh, A. K., Khatoon, I. S., Muazzam, Md. & Chaturvedi, D. K. (2013). An overview of electricity demand forecasting techniques. *Network and Complex systems,* 3(2), pp. 38-48.
Sjöstedt, M. (2019). Governing for sustainability: How research on large and complex systems can inform governance and institutional theory. *Environmental Policy and Governance*, *29*(4), pp. 293-302.
Slocombe, D. S. (1993). Implementing ecosystem-based management. *BioScience*, 43(9), pp. 612-622.
Smit, B., & Pilifosova, O. (2003). Adaptation to climate change in the context of sustainable development and equity. *Sustainable Development*, *8*(9), 9.
Smith, A. F. M., Fressoli, M., Abrol, D., Arond, E., & Ely, A. (2016). *Grassroots innovation movements*. London and New York: Routledge.
Smith, A., & Stirling, A. (2010). The politics of social-ecological resilience and sustainable socio-technical transitions. *Ecology and Society*, *15*(1 art 11), pp. 1-13.
Sneddon, C., Howarth, R.B. & Norgaard, R.B. (2005). Sustainable development in a post-Bruntland world. *Ecological Economics*, 57, pp. 253-268.
Snell, D. (2018) 'Just Transition'? Conceptual challenges meet stark reality in a 'transitioning' coal region in Australia. *Globalizations,* 15 (4), pp. 550-564

SolarShare (2015). Who manages our electricity in Ontario: A brief history. Retrieved from: https://www.solarbonds.ca/news-events/blog/solarshare-blog/2015/11/06/who-manages-our-electricity-in-ontario-a-brief-history.

Sommerville, P., Carlson, R. & Prazic, P. (2016). *Emerging energy trends – Regulatory responses to Ontario's energy future.* Toronto, ON: Mowat Centre.

Son, H. (2015). The history of Western futures studies: an exploration of the intellectual traditions and three-phase periodization. *Futures,* 66, pp. 120-137.

Songsore, E., Buzzelli, M., & Baxter, J. (2018). Understanding developer perspectives and experiences of wind energy development in Ontario. *Environment and Planning C: Politics and Space*, *36*(4), pp. 649-668.

Sovacool, B. K., & Valentine, S. V. (2011). Bending bamboo: Restructuring rural electrification in Sarawak, Malaysia. *Energy for Sustainable Development*, 15(3), pp. 240-253.

Sovacool, B. K., Burke, M., Baker, L., Kotikalapudi, C. K., & Wlokas, H. (2017). New frontiers and conceptual frameworks for energy justice. *Energy Policy,* 105, pp. 677-691.

Spang, A., Saw, J. H., Jørgensen, S. L., Zaremba-Niedwiedzka, K., Martijn, J., Lindl, A. E., … Ettema, T. J. G. (2015). Complex archaea that bridge the gap between prokaryotes and eukaryotes. *Nature,* 521, pp. 173-179.

Stadler, K., Wood, R., Bulavskaya, T., Södersten, C. J., Simas, M., Schmidt, S., ... & Giljum, S. (2018). EXIOBASE 3: Developing a time series of detailed environmentally extended multi-regional input-output tables. *Journal of Industrial Ecology*, 22(3), pp. 502-515.

Stern, P. C., & Gardner, G. T. (1981). Psychological research and energy policy. *American psychologist*, 36(4), p. 329.

Stevis, D., & Felli, R. (2020). Planetary just transition? How inclusive and how just?. *Earth System Governance,* 100065.

Stirling, A. (2014a). Emancipating transformations: From controlling the 'transition' to culturing plural radical progress. STEPS Working Paper 64. Brighton: STEPS Centre.

Stirling, A. (2014b). Transforming power: Social science and the politics of energy choices. *Energy Research & Social Science*, *1*, pp. 83-95.

Stirling, A. (2015). From controlling 'the transition'to culturing plural radical progress. *The politics of green transformations*, pp. 54-67.

Stuart, J., Collins, P., Alger, M. & Whitelaw, G. (2014). Embracing sustainability: The incorporation of sustainability principles in municipal planning and policy in four mid-sized municipalities in Ontario, Canada. *Local Environment: The International Journal of Justice and Sustainability.*

Sun, X., Zhang, B., Tang, X., McLellan, B. C., & Höök, M. (2016). Sustainable energy transitions in China: Renewable options and impacts on the electricity system. *Energies*, 9(12), p. 980.

Suprayoga, G. B., Bakker, M., Witte, P. & Spit, T. (2020). A systematic review of indicators to assess the sustainability of road infrastructure projects. *European Transport Research Review,* 12:19.

Sutherland, G. D., Waterhouse, F. L., Smith, J., Saunders, S. C., Paige, K., & Malt, J. (2016). Developing a systematic simulation-based approach for selecting indicators in strategic cumulative effects assessments with multiple environmental valued components. *Ecological Indicators*, *61*, pp. 512-525.

Svenfelt, Å., Engström, R., & Svane, Ö. (2011). Decreasing energy use in buildings by 50% by 2050—A backcasting study using stakeholder groups. *Technological Forecasting and Social Change*, *78*(5), pp. 785-796.

Swart, R. J., Raskin, P. & Robinson, J. (2004) The problem of the future: sustainability science and scenario analysis. *Global Environmental Change*, 14, pp. 137-146.

Swennenhuis, F., Mabon, L., Flach, T. A., & de Coninck, H. (2020). What role for CCS in delivering just transitions? *An evaluation in the North Sea region. International Journal of Greenhouse Gas Control*, 94, 102903.

Tainter, J. A. (2000). Problem solving: Complexity, history, sustainability. *Population and Environment: A Journal of Interdisciplinary Studies*, 22(1), pp. 3-40.

Tainter, J. A. (2006). Social complexity and sustainability. *Ecological Complexity*, 3, pp. 91-103.

Taljegard, M. (2019). Impact of vehicle-to-grid on the European electricity system – The electric vehicle battery as a storage option. In *2019 IEEE Transportation Electrification Conference and Expo (ITEC)* (pp. 1-5). IEEE.

Talukder, B. & Hipel, K. W. (2020). Diagnosis of sustainability of trans-boundary water governance in the Great Lakes basin. *World Development*, 129, pp. 1-12.

Tamayo y Tamayo, M. (2003). *El proceso de la investigación científica.* México: Editorial Limusa.

Teletica (2020). *Lluvia, rayería y vientos han provocado gran cantidad de averías eléctricas.* Retrieved from: https://www.teletica.com/multimedia/lluvia-rayeria-y-vientos-han-provocado-gran-cantidad-de-averias-electricas_1051388.

Temper, L., Walter, M., Rodriguez, I., Kothari, A., & Turhan, E. (2018). A perspective on radical transformations to sustainability: resistances, movements and alternatives. *Sustainability Science*, *13*(3), pp. 747-764.

Teske, S. (2010). *Energy [r]evolution: A sustainable energy outlook for Canada* Greenpeace International, European Renewable Energy Council. Retrieved from http://www.greenpeace.org/canada/Global/canada/report/2010/9/E%5BR%5Dcanada.pdf.

Tester, J. W., Drake, E. M., Driscoll, M. J., Golay, M. W., & Peters, P. W. (2005). *Sustainable energy – choosing among options*. Cambridge, MA: MIT Press.
the Institute of Civil Engineers. *Municipal Engineers*, 127, pp. 168-169.

Thomson, G., Ny, H., Nikulina, V., Borén, S., Ayers, J., & Bryant, J. (2020). 'Rapid Scenario Planning'to Support a Regional Sustainability Transformation Vision: A Case Study from Blekinge, Sweden. *Sustainability*, *12*(17), 6928.

Thomson, I. T .D., Fagan, D., & Speer, S. (2021). *Reforming provincial energy planning: Summary and analysis from Ontario 360's expert roundtable.* Retrieved from:

https://on360.ca/policy-papers/reforming-provincial-energy-planning-summary-and-analysis-from-ontario-360s-expert-roundtable/.

Timmons, D., Elahee, K., & Lin, M. (2020). Microeconomics of electrical energy storage in a fully renewable electricity system. *Solar Energy*, 206, pp. 171-180.

Ton, D. T., & Smith, M. A. (2012). The US department of energy's microgrid initiative. *The Electricity Journal*, 25(8), pp. 84-94.

Trebilcock, M. J., & Hrab, R. (2005). Electricity restructuring in Ontario. *The Energy Journal*, *26*(1).

Trochim, W. M., Cabrera, D. A., Milstein, B., Gallagher, R. S. & Leischow, S. J. (2006). Practical challenges of systems thinking and modeling in public health. *American Journey of Public Health,* 96 (3), pp. 538-546.

Trotter, P. A., & Maconachie, R. (2018). Populism, post-truth politics and the failure to deceive the public in Uganda’s energy debate. *Energy Research & Social Science*, *43*, pp. 61-76.

Truffer, B., Voß, J. -., & Konrad, K. (2008). Mapping expectations for system transformations – lessons from Sustainability Foresight in German utility sectors. *Technological Forecasting & Social Change, 75*(9), pp. 1360-1372.

Tukker, A., Bulavskaya, T., Giljum, S., De Koning, A., Lutter, S., Simas, M., ... & Wood, R. (2014). The global resource footprint of nations. *Carbon, water, land and materials embodied in trade and final consumption calculated with EXIOBASE*, *2*(8).

Tzankova, Z. (2020). Public policy spillovers from private energy governance: New opportunities for the political acceleration of renewable energy transitions. *Energy Research & Social Science*, 67, p. 101504.

Tziogas, C., Georgiadis, P., & Papadopoulos, A. (2019). Fostering the transition to sustainable electricity systems: A hierarchical analysis framework. *Journal of Cleaner Production*, 206, pp. 51-65.

Ulloa, A., Camacho, D., Arias, D., & Valverde, J. C. (2018). Análisis del mercado de biomasa forestal con fines energéticos en la zona de Guanacaste, Costa Rica. *Revista Forestal Mesoamericana Kurú*, *15*, pp. 45-52.

Umaña, J. (2017). *Experto del SES-Lab resalta cómo el precio del almacenamiento de energía sostenible es cada vez más asequible.* Hoy en el Tec. Retrieved from: https://www.tec.ac.cr/hoyeneltec/2017/05/22/experto-ses-lab-resalta-precio-almacenamiento-energia-sostenible-cada-vez-mas-asequible.

Umar, M., Riaz, Y., & Yousaf, I. (2022). Impact of Russian-Ukraine war on clean energy, conventional energy, and metal markets: Evidence from event study approach. *Resources Policy*, *79*, 102966.

UN (2020). *Ensure access to affordable, reliable, sustainable and modern energy.* Sustainable Development Goals. Retrieved from: https://www.un.org/sustainabledevelopment/energy/. *un nuevo PRONACE.* San José, Costa Rica: Consultores en Ingeniería y Recursos.

UNEP (2019). *Emissions Gap Report 2019.* UNEP, Nairobi.

Ungar, M. (2008). Resilience across cultures. *The British Journal of Social Work,* 38(2), pp. 218-235.

United Nations (UN) (2016). Affordable and clean energy: Why it matters? Retrieved from http://www.un.org/sustainabledevelopment/wp-content/uploads/2016/08/7_Why-it-Matters_Goal-7_CleanEnergy_2p.pdf.

UNRISD (2016). *Policy innovations for transformative change – Implementing the 2030 agenda for sustainable development.* UNRISD Flagship Report 2016.

Urbinatti, A. M., Dalla Fontana, M., Stirling, A., & Giatti, L. L. (2020). 'Opening up'the governance of water-energy-food nexus: Towards a science-policy-society interface based on hybridity and humility. *Science of The Total Environment*, 140945.

Valverde, G., Arguello, A., González, R., & Quirós-Tortós, J. (2017). Integration of open source tools for studying large-scale distribution networks. *IET Generation, Transmission & Distribution*, *11*(12), pp. 3106-3114.

van Riet, R., Skowron, A. & Teske, S. (2020). *Escenario: 100% energía renovable para Costa Rica*. World Future Council/La Ruta del Clima.

van Teijlingen, E. (2014). Semi-structured interviews. *Bournemouth University.* Retrieved from:

Vegh, G. (2016). Learning from mistakes: improving governance in the Ontario electricity sector. *CD Howe Institute E-Brief*, *230*.

Vegh, G. (2017). *Report on Energy Governance in Ontario – To the Ontario Energy Association and the Association of Power Producers of Ontario.* McCarthy Tetrault.

Velasco, H. (2009). Complexity, sustainability, justice, and meaning: Chronological versus dynamical time. *Cosmos and History: The Journal of Natural and Social Philosophy*, 5(2), pp. 108-133.

Venda, F. V. & Venda, Y. V. (1991). Transformation dynamics in complex systems. *Journal of the Washington Academy of Sciences*, 81(4), pp. 163-184.

Verbong, G. P. J., & Geels, F. W. (2010). Exploring sustainability transitions in the electricity sector with socio-technical pathways. *Technological Forecasting & Social Change*, *77*(8), pp. 1214-1221.

Vergragt, P. J., & Quist, J. (2011). Backcasting for sustainability: Introduction to the special issue.

Vigni, F. L. (2020). Five anticipation communities in complex systems sciences: Complexity science and its visions of the future. *Futures*, *120*, pp. 1-15

Villa-Arrieta, M., & Sumper, A. (2019). Contribution of smart cities to the energy sustainability of the binomial between city and country. *Applied Sciences*, *9*(16), p. 3247.

von Bertalanffy, L. (1956). General systems theory. *General Systems,* 1, pp. 1-10.

Vos, R. O. (2007) Defining sustainability: A conceptual orientation. *Journal of Chemical Technology and Biotechnology,* 82, pp. 334-339.

Voß, J. P. & Bornemann, B. (2011). The politics of reflexive governance: Challenges for designing adaptive management and transition management. *Ecology and Society*, 16(2): 9.

Wächter, P., Ornetzeder, M., Rohracher, H., Schreuer, A., & Knoflacher, M. (2012). Towards a sustainable spatial organization of the energy system: Backcasting experiences from Austria. *Sustainability*, 4(2), pp. 193-209.

Walker, B. & Salt, D. (2006). *Resilience thinking – Sustaining ecosystems and people in a changing world.* Washington, DC: Island Press.

Walker, B., Holling, C. S., Carpenter, S. R., & Kinzig, A. (2004). Resilience, adaptability and transformability in social–ecological systems. *Ecology and society*, *9*(2), 5.

Walker, G., & Cass, N. (2007). Carbon reduction, 'the public' and renewable energy: engaging with socio-technical configurations. *Area*, 39(4), pp. 458-469.

Ward, B. & Dubos, R. (1972). *Only one Earth – The care and maintenance of a small planet.* Harmondsworth: Penguin Books Ltd.

Weaver P. M. & Rotmans, J. (2006). Integrated sustainability assessment: What is it, why do it and how? *International Journal of Innovation and Sustainable Development*, 1(4), pp. 284-303.

Weber, E. P., & Khademian, A. M. (2008). Wicked problems, knowledge challenges, and collaborative capacity builders in network settings. *Public Administration Review*, *68*(2), pp. 334-349.

Weber, J. A. (1979). *Power grab: The conserver cult and the coming energy catastrophe*. New Rochelle, NY: Arlington House.

Weis, T., Stensil, S. P., & Harti, J. (2013). *Renewable is doable: Affordable and flexible options for Ontario's long-term energy plan*. Pembina Institute for Appropriate Development.

Westley, F., & McGowan, K. (Eds.). (2017). *The evolution of social innovation: building resilience through transitions*. Edward Elgar Publishing.

Westley, F., Olsson, P., Folke, C., Homer-Dixon, T., Vredenburg, H., Loorbach, D. … & van der Leeuw (2011). Tipping toward sustainability: Emerging pathways of transformation. *AMBIO*, 40, pp. 762-780.

White, D. (2020). Just transitions/design for transitions: preliminary notes on a design politics for a green new deal. *Capitalism Nature Socialism*, *31*(2), pp. 20-39.

White, M. A. (2013). Sustainability: I know it when I see it. *Ecological Economics*, 86, pp. 213-217.

Wickson, F., Carew, A. L. & Russell, A. W. (2006). Transdisciplinary research: characteristics, quandaries and quality. *Futures*, 38, pp. 1046-1059.

Wiek, A. & Iwaniec, D. (2014) Quality criteria for visions and visioning in sustainability science. *Sustain Sci*, 9, pp. 497-512.

Wiek, A. & Larson, K. L. (2012). Water, people, and sustainability – A systems framework for analyzing and assessing water governance regimes. *Water Resources Management*, 26, pp. 3153-3171.

Wiese, F. (2016). Resilience thinking as an interdisciplinary guiding principle for energy system transitions. *Resources*, 5(4), p. 30.

Williams, L., & Sovacool, B. K. (2020). Energy democracy, dissent and discourse in the party politics of shale gas in the United Kingdom. *Environmental Politics*, pp. 1-25.

Williams, M., & Moser, T. (2019). The art of coding and thematic exploration in qualitative research. *International Management Review*, *15*(1), 45-55.

Winfield, M. (2005). *Power for the future – Towards a sustainable electricity system for Ontario.* Pembina Institute.

Winfield, M. (2016). *A new era of environmental governance in Canada: Better decisions regarding infrastructure and resource development projects.* Canada: Metcalf Foundation.

Winfield, M. (2017). Electricity system planning and sustainability assessment in Ontario, Canada. In R. B. Gibson (Ed.) *Sustainability Assessment: Applications and Opportunities* (pp. 146-168). London and New York: Routledge/Earthscan.

Winfield, M. (2020a). *Canada's newest nuclear industry dream is a potential nightmare.* Policy Options. Retrieved from: https://policyoptions.irpp.org/magazines/november-2020/canadas-newest-nuclear-industry-dream-is-a-potential-nightmare/.

Winfield, M. (2020b). *Has Ontario made itself an "innovation wasteland" for energy?* LinkedIn. Retrieved from: https://www.linkedin.com/pulse/has-ontario-made-itself-innovation-wasteland-energy-mark-winfield/?trackingId=iDZq2quAAXpIafLLiKNEaw%3D%3D.

Winfield, M., & Weiler, S. (2018). Institutional diversity, policy niches, and smart grids: A review of the evolution of Smart Grid policy and practice in Ontario, Canada. *Renewable and Sustainable Energy Reviews*, *82*, pp. 1931-1938.

Winfield, M., Gibson, R. B., Markvart, T., Gaudreau, K., & Taylor, J. (2010). Implications of sustainability assessment for electricity system design: The case of the Ontario Power Authority's integrated power system plan. *Energy Policy*, 38(8), pp. 4115-4126.

Winkler, H. (2020). Towards a theory of just transition: A neo-Gramscian understanding of how to shift development pathways to zero poverty and zero carbon. *Energy Research & Social Science*, *70*, 101789.

Winzer, C. (2012). Conceptualizing energy security. *Energy policy*, 46, pp. 36-48.

Woods, G. J., Ormerod, K. J., Bailey, C. J., Kang, D., Quintanar, D. R., Curley, E. F., ... & Arnold, R. G. (2012). Scenario planning for robust water supply infrastructure design. In *World Environmental and Water Resources Congress 2012: Crossing Boundaries* (pp. 2838-2845).

World Commission on Environment and Development (WCED) (1987). *Our common future.* New York: Oxford University Press.

Worster D. (1993). *The wealth of nature: environmental history and the ecological imagination.* New York: Oxford University Press.

Xu, L., Marinova, D. & Guo, X. (2015). Resilience thinking: a renewed system approach for sustainability. *Sustain Sci*, 10, pp. 123-138.

Yang, Y., Li, Y., Chen, F., Zhang, S., & Hou, H. (2019). Regime shift and redevelopment of a mining area's socio-ecological system under resilience thinking: a case study in Shanxi Province, China. *Environment, Development and Sustainability*, *21*(5), pp. 2577-2598.

Yasmin, T., Farrelly, M., & Rogers, B. C. (2020). Adaptive governance: a catalyst for advancing sustainable urban transformation in the global South. *International Journal of Water Resources Development*, *36*(5), pp. 818-838.

Yaylaci, E. D. (2015) *A sustainability assessment framework for evaluation of coal mining sector plans in Afşin-Elbistan coal basin with a special emphasis on land disturbance.* (Doctoral Thesis) Middle East Technical University, Ankara, Turkey.

Yergin, D. (2006). Ensuring energy security. *Foreign affairs*, pp. 69-82.

Yi, H., & Feiock, R. C. (2014). Renewable energy politics: policy typologies, policy tools, and state deployment of renewables. *Policy Studies Journal*, 42(3), pp. 391-415.

Yin, R. K. (2003). *Case study research, design and methods* (3rd Edition ed.). Thousand Oaks, London, New Delhi: SAGE.

Yoffee, N. & Cowgill, G. L. (1991). *The collapse of ancient states and civilizations.* Tucson: The University of Arizona Press.

Young, O. R. (2017). Beyond regulation: Innovative strategies for governing large complex systems. *Sustainability*, *9*(6), 938.

Yulish, C. B. (1977). Soft vs. hard energy paths: 10 critical essays on Amory Lovins' "Energy strategy: The road not taken?" New York: Charles YuIish Assoc. Inc. 138 pp. [Also published as Edison Electric Institute, Soft vs. Hard Energy Paths. In Electric Perspectives, 77(3): 60 pp.]

Zárate, D., & Ramírez, R. (2016). Matriz Energética de Costa Rica Renovabilidad de las fuentes y reversibilidad de los usos de energía. *Friedrich Ebert Stiftun*, *4*, 28.

Zheng, W., Shen, G. Q., Wang, H., Hong, J., & Li, Z. (2017). Decision support for sustainable urban renewal: A multi-scale model. *Land Use Policy*, *69*, pp. 361-371.

Zhou, X. Y., Lu, G., Xu, Z., Yan, X., Khu, S. T., Yang, J., & Zhao, J. (2023). Influence of Russia-Ukraine War on the Global Energy and Food Security. *Resources, Conservation and Recycling*, *188*, 106657.

Zimonjic, P. (2020). *Federal government invests in small nuclear reactors to help it meet net-zero 2050 target.* CBC News. Retrieved from: https://www.cbc.ca/news/politics/bains-small-modular-reactors-net-zero-1.5763762.

APPENDIX A – Recruitment letter for Ontario

UNIVERSITY OF WATERLOO | FACULTY OF ENVIRONMENT
SCHOOL OF ENVIRONMENT, RESOURCES AND SUSTAINABILITY

Date: ______

Dear ______,

My name is ***Ignacio Aguilar,*** and I am a PhD student working under the supervisions of ***Robert B. Gibson*** and ***Ian H. Rowlands*** in the ***School of Environment, Resources and Sustainability*** in the Faculty of Environment at the University of Waterloo, Canada. The reason that I am contacting you is that we are conducting a study on *designing electrical energy systems for a new generation of sustainability-based assessments.* This research will study the electrical energy systems of two jurisdictions: Ontario and Costa Rica. We are currently seeking for experts with deep knowledge and familiarity with the Ontarian electricity sector such as academics, government workers, as well as people in the social community. Participation in the study consists of one semi-structured interview, in which you will be asked to answer five open-ended questions related to electricity planning towards sustainability. For example, the two following questions are included:

What are the defining features of an electricity system that makes positive and overall contributions to sustainability?

What do you consider to be the main social and ecological issues that current electricity system planning face?

Other questions include topics related to necessary changes in the system, barriers and opportunities to enabling positive change, and the main actors involved in the process.

This interview consists of one session of 20 to 30 minutes, with the possibility of a couple of additional follow-up questions. I will meet you to conduct the interview in person, by telephone or video call, according to your preference. Then, you will be asked one question at a time and, with your consent, the answers will be recorded as audio files. The session will be scheduled at the time and by via of communication of your convenience. After all of the data have been analyzed, you will receive an electronic copy of the thesis at your request.

I would like to assure you that the study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee.

However, the final decision about participation is yours.

If you are interested in participating, please contact me by email at *fiaguila@uwaterloo.ca* and specify when you would like to participate in the study. I will then send a confirmation email indicating the agreed date, time and location, and provide you with any further information of your request concerning the study. If you have to cancel your appointment, please email me at *fiaguila@uwaterloo.ca*.

Yours sincerely,

F. Ignacio Aguilar
PhD Candidate
School of Environment, Resources and Sustainability
University of Waterloo
Waterloo, ON, Canada

Robert B. Gibson
Professor
School of Environment, Resources and Sustainability
University of Waterloo
Waterloo, ON, Canada

APPENDIX B – Recruitment letter for Costa Rica

Fecha:____

Estimado_____,

Mi nombre es Ignacio Aguilar y soy candidato a doctorado bajo la supervisión de ***Robert B. Gibson*** e ***Ian H. Rowlands*** en ***School of Environment, Resources and Sustainability*** (Escuela de Medio Ambiente, Recursos y Sustentabilidad) en la Facultad de Medio Ambiente en University of Waterloo, Canadá. La razón para contactarle es que estamos realizando un estudio sobre *diseñar sistemas de energía eléctrica para una nueva generación de evaluaciones basadas en la sustentabilidad.* Esta investigación estudiará los sistemas de energía eléctrica de dos jurisdicciones: Ontario, Canadá y Costa Rica. Actualmente buscamos expertos con un profundo conocimiento y familiaridad con el sistema eléctrico y/o sus implicaciones sociales y ecológicas, tal como académicos, actores gubernamentales, actores en el sector industrial, así como líderes y representantes de la comunidad social. La participación en este estudio consiste en una entrevista semi estructurada, en la cual se le pedirá responder cinco preguntas sobre la planeación de los sistemas eléctricos que contribuyan a la sustentabilidad de su entorno. Por ejemplo, las dos siguientes preguntas se incorporarán a la entrevista:

¿Cuáles son las características que definen a un sistema eléctrico que contribuye positiva, global, y equitativamente a la sustentabilidad?

¿Cuáles considera ser los principales problemas socio-ecológicos que actualmente enfrenta el manejo y planeación del sistema eléctrico nacional?

Otras preguntas incluyen temas relacionados a cambios necesarios en el sistema, barreras y oportunidades para permitir cambios positivos, y los principales actores involucrados en este proceso.

Esta entrevista consiste en una sesión de 20 a 30 minutos, con la posibilidad de algunas preguntas adicionales de seguimiento. Si usted decide participar, yo lo contactaré para entrevistarlo por teléfono o video llamada, de acuerdo con su preferencia. Ahí se le harán las preguntas, una por una, y con su consentimiento, las respuestas serán grabadas como archivos de audio. La sesión será programada en la fecha y vía de comunicación de su conveniencia. Ya que toda la información haya sido analizada, recibirá una copia electrónica del trabajo de investigación, si usted así lo desea.

Quiero asegurarle que este estudio ha recibido acreditación de ética de investigación a través del comité de ética (Research Ethics Committee) de University of Waterloo.

Sin embargo, la decisión final sobre su participación será de usted.

Si tiene interés en participar, por favor responda a este correo, o contácteme al correo electrónico fiaguila@uwaterloo.ca, y especifique cuándo le gustaría participar. Yo le enviaré después un correo electrónico de confirmación, indicando la fecha, hora y vía de comunicación acordadas. También puedo proporcionarle más información y responder dudas acerca del estudio, si usted así lo desea. Si necesita cancelar la fecha programada, por favor contácteme al correo electrónico fiaguila@uwaterloo.ca.

Atentamente,

F. Ignacio Aguilar
PhD Candidate
School of Environment, Resources and Sustainability
University of Waterloo
Waterloo, ON, Canada

Robert B. Gibson
Professor
School of Environment, Resources and Sustainability
University of Waterloo
Waterloo, ON, Canada

APPENDIX C – Standard questions for Ontario

1. Evidence suggests that suggests Ontario has struggled to find methods to attain public approval for energy-related projects. Decisions that have prioritized economic and technical over social and ecological considerations have often resulted in financial losses, social distrust, and undermining effects for promising low-carbon alternatives – e.g., the development and deployment of renewable energy technologies as well as efficiency, and conservation and demand management alternatives. **What do you think are the main emerging effects from this issue that will have an impact in the Ontario electricity systems of the future?**

> What can be done to change this and who are the main actors that need to be involved in such change?
>
> What do you think are promising alternatives (for policy making and technology development) for addressing this issue?

2. Evidence shows that Ontario's electricity-related activities face an absence of effective planning in project development, a lack of transparency, failure to respect legislated milestones, and questionable consultation processes with stakeholders, First Nations and the social community in general. According to some authors, this issue persists partly because of a lack of commitment from national and provincial authorities to clarify what are the policy implications of attaining climate commitments through social justice considerations and other social and environmental goals. **Does your experience suggest the same and how well aligned do you think are national, provincial and municipal policy- and decision-making efforts for electricity system planning?**

> How well aligned do you think are national, provincial and municipal policy- and decision-making for electricity system planning?

3. Evidence shows that unaffordable electricity is a significant concern in Ontario. For instance, the average electricity cost increased steadily since 2006 to 2015. Industries and major power consumers have been affected since these rates are among the highest in North America for the industry. Also, the 'jobs vs environment' concerns have led to revoking initiatives for environmental protection (for example, the Green Energy Act). And there are concerns that these events may have a disproportionate impact on First Nations and other disadvantaged groups. For example, the Green Energy Act provided incentives for local communities and First Nations to compete more fairly in the electricity market. **Does your recent experience confirm these concerns of affordability and justice, or other related issues?**

> According to your recent experience, what do you consider to be the main emerging opportunities for affordability and reliability in future electricity systems?

4. Evidence suggests that precaution and prudence in decision-making, system flexibility for the incorporation of promising technologies, modularity to isolate system failures (e.g., blackouts) *and resiliency capacity to recover after system failure due to natural disasters, accidents, malfunctions are essential for electricity systems to avoid vulnerability and provide higher benefits for their social and environmental context. However, in at least the five past years, provincial authorities have shown an inclination towards increasing the share of nuclear power. This raises concerns about the rigidity of nuclear infrastructure (since it entails commitment for up to 50 years), higher risks in the consequences of system malfunction (e.g., spills, explosions, attacks, etc.), as well as high intergenerational risks (e.g., waste disposal).* **According to your experience how relevant are these concerns in the recent provincial energy debates?**

> What does your experience suggest are the main recommendations from authorities and the private sector to address these concerns?

Is there anything you would like to add as a key aspect to be addressed for current and future electricity systems of the future?

APPENDIX D – Standard questions for Costa Rica

1. El gobierno nacional ha reconocido la necesidad de incrementar la precaución, modularidad, y resiliencia del sistema eléctrico. Entre las estrategias para el logro de estos objetivos se encuentran una mejor planeación entre sectores, alcanzar 100% de energía renovable en la matriz eléctrica, así como alternativas de eficiencia energética y red eléctrica inteligente. Asimismo, diferentes autores también han reconocido como estrategias importantes la integración de opciones de almacenamiento eléctrico, generación distribuida, y manejo de la demanda. Sin embargo, algunos expertos han destacado vulnerabilidades del sistema eléctrico a causa de la alta dependencia en recursos hídricos, y en consideración de los riesgos que presenta el cambio climático. **De acuerdo con su experiencia reciente, ¿cuáles son los retos y oportunidades principales para incrementar la capacidad de adopción de una matriz energética completamente renovable y más diversificada, así como la adopción de alternativas de eficiencia, conservación y manejo de la demanda (e.g., medidores y redes inteligentes, generación distribuida, almacenamiento de energía)?**

- ¿Cuáles considera ser las principales alternativas tecnológicas, de planeación y/o de diseño de políticas prometedoras para incrementar la precaución, modularidad, y resiliencia, y reducir la vulnerabilidad del sistema eléctrico costarricense?
- ¿Cuáles son los principales cambios necesarios y los actores principales que pueden ayudar a incrementar la implementación de dichas alternativas en el sistema eléctrico nacional? ¿Y cuáles son los principales retos?
- ¿Considera usted que existe una necesidad de más estudios científicos que contribuyan a la innovación y desarrollo tecnológico (e.g., energías renovables), así como a la planeación y diseño de políticas, para la implementación y aceptación social de las alternativas mencionadas anteriormente?

2. Algunos autores han resaltado que el manejo del sistema eléctrico en Costa Rica ha enfrentado retos en términos de preservación ambiental y abatimiento del cambio climático, así como de tensión social y aprobación ciudadana. En este sentido, diversos autores han resaltado la importancia de planear efectivamente a largo plazo para objetivos de bienestar social y preservación ambiental, así como para mantener los sectores esenciales para la humanidad – incluyendo el sector eléctrico. Particularmente, algunos autores han propuesto poner atención al largo plazo en la planeación gubernamental y de proyectos, y evitar la toma de decisiones basada en reacciones a corto plazo ante situaciones de crisis. **¿Está de acuerdo con estas aseveraciones? Y de acuerdo con su experiencia, ¿cuáles considera ser los principales retos emergentes que el manejo y planeación del sistema eléctrico tendrá que enfrentar en el futuro?**

- ¿Cuáles considera ser los principales cambios necesarios en el sistema eléctrico para enfrentar tales retos?
- ¿Cómo se puede mejorar la planeación a largo plazo en el sistema eléctrico costarricense?

3. Algunos expertos han enfatizado los riesgos para Costa Rica ante el cambio climático (por ejemplo, periodos intensificados de huracanes, tormentas, inundaciones y sequías). Esto al mismo tiempo presentaría riesgos y vulnerabilidades para el sistema de energía eléctrica. Por otro lado, existen autores que han documentado riesgos que la ineficaz planeación y manejo del sistema eléctrico pueden imponer hacia el deterioro socioambiental – por ejemplo, riesgos impuestos hacia áreas protegidas y territorios indígenas. Otro problema relevante encontrado en este sentido es el contexto más amplio del sector energía – por ejemplo, la dependencia del petróleo en la matriz energética, así como las emisiones a la atmosfera del sector de transporte. **¿Su experiencia en la planeación del sector eléctrico confirma estos aspectos como retos relevantes para el país? Y:**

- ¿Existen otros retos que usted considere como los principales problemas socio-ecológicos que actualmente enfrenta el manejo y planeación del sistema eléctrico nacional?
- ¿Cuáles considera ser los principales retos y oportunidades para una mejor alineación entre sector eléctrico y otros sectores de la energía (e.g., transporte) para el logro de objetivos de preservación ambiental y cambio climático?

4. El sistema eléctrico de Costa Rica provee acceso a electricidad a más del 99% de su población, alcanzando un requerimiento importante para la sustentabilidad global. Sin embargo, el gobierno nacional ha reconocido que uno de los retos para el futuro será garantizar precios asequibles, mientras se mantiene una matriz energética renovable, eficiente y confiable. El Plan Nacional de Energía, en 2015, mostró tendencias de precios al alza desde principios de los años 1990s. La Cámara de Industrias de Costa Rica, por ejemplo, ha mostrado su inconformidad con propuestas oficiales para el incremento de precios. Al mismo tiempo, la cancelación de proyectos eléctricos de gran inversión capital ha provocado grandes pérdidas financieras. **¿Su experiencia en el sector eléctrico confirma estos retos? ¿Existen otros retos relacionados que usted pueda identificar como relevantes?**

- De acuerdo con su experiencia, ¿cuáles son las principales oportunidades, alternativas prometedoras, así como los retos para mantener los precios asequibles de la electricidad, sin comprometer los logros que ha alcanzado el sistema eléctrico?

5. Diferentes autores han hablado de problemas históricos de gobernanza del sistema eléctrico nacional. Por ejemplo, algunos han documentado cómo algunas propuestas de proyectos hidroeléctricos en el pasado han tenido problemas de falta de transparencia, apresurar procesos para priorizar objetivos a corto plazo, consulta y participación ciudadana insuficientes, riesgo de violaciones a derechos indígenas, entre otros. Esto ha resultado en la coordinación entre múltiples comunidades para la protección de su territorio y su entorno social y cultural. Al respecto, líderes comunitarios también han enfatizado que algunos proyectos de generación eléctrica han brindado oportunidades de trabajo mayormente a corto plazo, y que pueden deteriorar áreas esenciales para sus actividades de sustento económico. En consideración a lo anterior y de acuerdo con su experiencia, **¿Cuáles son los principales retos que enfrentan las autoridades del sistema eléctrico para mejorar en la inclusión y participación democrática**

para las comunidades que se ven afectadas directamente por la construcción de proyectos eléctricos?

- ¿Cuáles son las principales oportunidades para mejorar los procesos equitativos y democráticos de participación, así como los procesos justos para la aceptación pública en la planeación y manejo de proyectos de electricidad?

¿Existe algún tema importante que le gustaría añadir en términos de un sistema eléctrico que contribuya positiva, global, y equitativamente a la sustentabilidad que no se haya discutido en esta entrevista?