

Local Material and Energy Flow Analysis for the Region of Waterloo,  
Ontario, Canada

by

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## AUTHORS 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.

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## ABSTRACT

To address global environmental challenges, resource use patterns at local and sub-national scales can provide relevant insights into drivers and how these link to local policy and decision-making. The Region of Waterloo is often referred to as “Canada’s Silicon Valley” consists of the townships of Wellesley, Woolwich, Wilmot, and North Dumfries and the tri-cities of Kitchener, Cambridge, and Waterloo. Close to Toronto, and reputation of being the tech hub, Waterloo’s population (mainly from immigration) is on the rise and region is under rapid transition from a rural to an increasingly urban system being connected by rapid transit systems. To better understand the region from a systems perspective and to provide input into sustainability policies of the region, the concept of social metabolism is applied.

Society’s metabolism measures pressures on the environment where increasing throughput can have negative impacts on ecosystem and human health in the short and long term. Material and Energy Flow Analysis (MEFA) is conducted to calculate derived indicators of biomass and energy use for the Region of Waterloo in accordance with established conventions. Using a number of MEFA indicators, the paper will outline some of the major sustainability challenges in resource use patterns in the region since 2006. This study is the first to conduct a material and energy flow analysis for the Region of Waterloo in three points in time. Data on extraction, consumption, imports, and exports of various biomass and energy flow indicators will be presented.

Results from MFA show that the Region of Waterloo has a high import dependency for food crops and high domestic extraction of feed crops mainly fodder corn. And results observed from Energy Flow Analysis indicates that the Region of Waterloo imports 100% of its technical energy and is highly dependent on outside markets. This study will encourage discussions on food and energy security in the region and help the policymakers in the region to make informed decisions.

This research adds to the growing data points of research on Material and Energy flow analysis and social metabolism and serves as a starting point for more related research in sub-national socio-metabolic studies.

Keywords: Region of Waterloo, Social Ecology, Sub-national study, Material Flow Analysis, Energy Flow Analysis, Social Metabolism, Food security, Energy security

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## LIST OF ACRONYMS

ROW- Region of Waterloo

MEFA- Material and Energy flow Analysis

MFA- Material Flow Analysis

EFA- Energy Flow Analysis

DE- Domestic Extraction

DMC- Domestic Material Consumption

PTB- Physical Trade Balance

DEC- Domestic Energy Consumption

GHG- Greenhouse gases

OMAFRA- Ontario Ministry of Agriculture, Food and Rural Affairs

GCV- Gross calorific value

NCV- Net calorific value

SDG- Sustainable Development Goals

# 1 INTRODUCTION

## 1.1 Introduction

In today's world, it is becoming increasingly apparent that humans as a society are living in a world that has built its foundation on environmental degradation and human suffering with fascination for more growth consuming more natural resources that is not sustainable and neglects the quality of life (OECD, 2012).

The current environmental crisis is largely due to the ways humans consume natural resources (material, energy, land) causing sustainability problems (Fischer-kowalski & Weisz, 2016). In the sustainability literature, unsustainable use of socioeconomic resources is linked with the current global anthropogenic change in the form of climate change, food insecurity, energy insecurity, land degradation, biodiversity loss and so on (Mayer, Schaffartzik, Haas, & Sepulveda, 2015; Steffen et al., 2011).

In addition to the environmental challenges of rising temperatures and increased natural disasters among others, consumption of biophysical resources (especially food production and consumption) is the most affected phenomena globally (IPCC, 2014). Furthermore, the rise in extraction of natural resources and the resulting emissions and wastes from their use have pushed the natural ecosystems directly or indirectly to a tipping point near the planetary boundaries (Krausmann et al., 2017; Rockström et al., 2009).

Under the business as usual scenario, it is expected that the global material use will increase three times by 2050 which is not feasible considering the availability of resources including biomass in the future (UNEP, 2016). *The United Nations Environment Programme* indicates that the countries of the global north consume materials on an average of 10 times as the countries in the global south (UNEP, 2016). This scenario implies that to meet the requirements of the global population compromises have to be made in the global north to cut down their metabolic rates to help the global south where material and energy use and population are expected to increase multifold (Marina Fischer-Kowalski & Haberl, 2015).

Globally, there is a rising interest in resource efficiency and sustainable management of natural resources in the recent years and it is one of the top priorities on the International political agenda(UNEP, 2016). The sustainable development goals (SDG's) which are at the heart of the United Nations Environment Programme (UNEP) agenda, were adopted by the international community in 2015, with the adoption of the 2030 agenda for Sustainable development. The primary purpose of the 17 SDGs is to transform the world into a better place for current and future generations. To achieve and sustain such a world in the coming years, it has been widely accepted that the need to conserve and use natural resources and the need to improve resource efficiency in both the production and consumption is very significant(UNEP, 2016).

Also, *the International Resource Panel* (UNEP, 2016) stresses on the need for resource decoupling by decoupling economic growth from environmental impacts and natural resource use(UNEP, 2016). All these points towards an urgency in decoupling resource use or increasing resource productivity while maintaining or increasing economic growth in the global north. However, this process cannot happen with just policy strategies at the national level but with trying to reduce material use even at the local and regional level to help the nation as a whole in the reduction of their metabolic rates.

The global demand for material and energy resources have increased in the last few decades with the rise in global population, consumerist lifestyle and the current industrial transitions of various region of the world (Schaffartzik, Mayer, et al., 2014). This increase in global demand for material and energy resources has increased the global socioeconomic metabolism significantly. It is estimated that currently 70 billion tons of materials are extracted every year to meet the rising demands of the population. In the last four decades, per capita extraction of materials annually has increased from 7 to 10 tonnes per capita globally while global material use has increased 3 times from 22 billion tonnes in 1970 to 70 billion tonnes in 2010 (UNEP, 2016). And this growth in global material resources is driven by the rise in per capita income and the affluent lifestyle which has an intricate relationship with the industrial and urban transformations of various regions of the World(UNEP, 2016).

Of all the materials extracted globally, biomass is of particular significance as it constitute one third of the global material consumption.(Krausmann, Erb, Gingrich, Lauk, & Haberl, 2008). Biomass is the most important one and its usage as food for human sustenance is highly irreplaceable (Weisz et al., 2006). Also, biomass is used for various purposes by humans for their survival, it is consumed as food directly and as food for livestock, as construction material, and for different purposes such as energy generation and its ecosystem services(Singh, Ringhofer, Haas, Krausmann, & Fischer-Kowalski, 2010). Even though fossil fuels dominate the global energy sector, biomass remains the most important energy carrier for a large part of world's population.

Therefore,the demand for biomass are likely to grow multifold in the coming years driven by the need to meet the rising food requirements of humans and to maintain the flows of raw materials for industries. The current trends of global biomass metabolism also poses an increasing socioeconomic threat along with the environmental issues in the name of food security(Giovannucci et al., 2012).

Also, urbanization coupled with current trends of population growth, bioenergy demand and changing human diet poses greater sustainability challenge increasing the competition for biomass end use(Weisz et al., 2006). And as a result of that, biomass extraction have changed from food production to commercial feed and non-food crops to meet the rising demand for meat and bioenergy (Nonhebel & Kastner, 2011).

This shift in the uses of biomass from food to commercial applications also poses a bigger ramification to the human society in the face of rising food security, water security, climate change and extreme weather events(Nonhebel & Kastner, 2011). And this poses the biggest threat to the resilience of the human future and the current way of living.

Firstly, talking about food security, it is imperative to define what food security means. Even though many definitions of food security exist, the most common definition is the one made at *World food summit* in 1996 by FAO "Food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life"(World Food Summit, 1996) Also, there are four pillars of food security according to FAO which are food access, food availability, food utilization and food stability(FAO, 1996).

Currently, there is a high degree of disconnection between humans and agri-food systems concerning both consumption and production (Fraňková, Eva, Haas, Willi, Singh, 2017) (Forthcoming). In western countries, most consumers don't have the experience of the first-hand contact with food production and are instead dependent on transnational food chains that are so distant and disconnected from our direct experience (Fraňková, Eva, Haas, Willi, Singh, 2017). Also, the global increase in population along with the food-climate nexus affects the current agri-food system. Hence, the need for (re)localization of food systems, "i.e., more embedded in local ecosystems and social relations, and shorter in both physical and psychological distance between producers and consumers" (E. Frankova et al. , 2017, p. 5).

Local food systems is termed as an "alternate food production and distribution models to the dominant globalised, industrialised and commodified agri-food system trying to create its more sustainable variants" (E. Frankova et al. , 2017, p. 6). While usually food systems are defined as local based on its physical distance, it is only one of the attribute to define a system as local. Local food systems are also characterized by the combination of social, environmental and social attributes (Martinez et al., 2010). Such as "commitment to a specific place, to concrete people who produce and consume the food, nurturing of traditional and/or sustainable practices of production and processing, knowledge about these processes and the possibility of direct participation in them" (E. Frankova et al. , 2017, p. 6).

Local food systems have social, environmental and economic benefits. Local food systems reduce the food miles of the food thereby reducing consumption of fossil fuels, reducing Co2 emissions and reducing packaging material. Also, LFS improves the local economy and thus reducing the dependency on outside markets. While LFS has there merits, critiques also question its sustainability impacts and its ability to spread beyond small niche markets. E. Frankova et al. (2017) argue that the level of localization desired in a system should be open, case-specific and explicitly questioned.

## 1.2 Overview of the Region of Waterloo

The Region of Waterloo is in Southern Ontario, west of Canada's financial capital Toronto, Ontario. The Region of Waterloo often referred to as "*Canada's Silicon Valley*" comprises the cities of Kitchener, Cambridge, and Waterloo known as the Tri cities and the townships

of Wellesley, Woolwich, Wilmot, and North Dumfries. The region is 1369 square kilometers regarding land area size and is the embodied home between new and old, urban and rural, technology and nature. The region is also touted as one of Canada's smartest cities.

The region is also the home of Blackberry and two of Canada's leading universities, Wilfrid Laurier University and the University of Waterloo which act as a backbone and accelerate the growth of high-tech companies and foster innovation.

The Region of Waterloo is one of the fastest growing regions in Canada concerning Population and GDP growth and is also experiencing a massive growth in infrastructure owing to the development of the technology sector and is under rapid transition from a rural to an increasingly urban system(Region Of Waterloo, 2014; Waterloo EDC, 2016). The population in the region is expected to grow to 729,000 by 2030 from 535154 in 2016 (Region Of Waterloo, 2014). And the diversity in population has also steadily increased over the years, because of the region's proximity to Toronto and its reputation as a technology hub attracting talents across the World to move to Waterloo to study and work.

Undoubtedly the Region of Waterloo is constantly evolving into a tech hub of the world to solve the problems of the future through innovation and change and is rapidly developing. But with development comes a myriad of issues, a society has to face including increasing population, land use changes, resource scarcities...etc.

There is a growing concern regarding the region's rise in material and energy use with the increase in population and affluence, and the future resource availability continues to be of paramount issue in the region. The significant challenge for the region of Waterloo is to meet the requirements of the growing population in a better and sustainable way while increasing the self-resiliency of the region to meet the Sustainable development goals(United nations, 2016). These challenges can lead the region to a tipping point by the impacts of climate change, extreme weather events and unsustainable resource use.

Correspondingly, the Region of Waterloo is at a precarious point with ecological challenges where the economy is growing with more people consuming more resources drawing down the finite resources and withdrawing the possibilities from future generations which aren't sustainable and can't work in the long run (Climate Action WR, 2013). Therefore, it is imperative

that the Region of Waterloo have to make radical changes in their material and energy consumption dynamics to decouple away from economic growth to be a sustainable society.

Even though the Region of Waterloo is an industrialized economy it is also in its early phases of rapid urbanization and development, which implies that the region is in a position to consider all these issues and learn from many similar mistakes other developing regions/societies has made in the past and possibly learn from it to become a sustainable innovator. Moreover, the Region of Waterloo is in a transition phase from a small region to be one of the most important technology hub in North America which makes it the right time for the region to make changes and improve the quality of life of its people rather than just maximizing economic growth and consumption.

In this research, the Region of Waterloo is investigated through the lens of social ecology to aid the Region of Waterloo's transition and address its sustainability problems by understanding the society nature relationship rather than studying the societal and natural systems alone (Singh et al., 2013). Material and Energy flow accounting which is an operational tool for Social metabolism is used to analyze the relationship between biophysical resources and the socioeconomic systems (Fischer-Kowalski & Haberl, 1998).

Standard derived Indicators of MEFA are used in this study to better understand the relationship between biophysical flows (biomass and energy flows) and the society of the Region of Waterloo and its associated environmental pressure.

Derived indicators are pressure indicators for material and energy flows related to environmental impacts. The main drivers of material and energy demand are population, consumption and economic growth. This derived pressure indicators of MEFA can also be used to guide policy intervention by allowing for an early identification of environmental issues and impacts associated with the study area of the Region of Waterloo related to development. The environmental impacts include resource depletion, climate change, toxicity, pollution and wastes, and human health. The identification of the environmental issues at its early stages facilitates in curbing those issues by setting a limit to it for example setting GHG emissions target to reduce global climate warming below the 2 degrees Celsius (Bringezu et al., 2016; Schandl et al., 2017).

Globally there is a rising increase in interest from policy makers in biophysical view of the economy i.e., for national material flow accounts as they are in need of an integrated approaches that looks at economic, societal and environmental together. These need for new integrated approaches that provide a broad perspective for decision making are currently met by national material flow accounts that are compatible with national economic accounts(Bringezu et al., 2016). The indicators and data sets determined using MEFA are useful to policy makers at various stages of the policy cycle. These indicators and data sets helps the policy makers in identifying the issues and establishing goals, targets , and policy objectives and then to finally monitor the progress of their policy initiatives(Schandl et al., 2017).

Traditionally, various authors have applied the concept of MFA to rebuild and understand the biophysical interrelation process between Nature and Society at national and global scales and some local rural systems. But, it also becomes imperative to focus the MEFA studies on subnational systems which are a combination of urban-industrial systems and agricultural systems.

MEFA studies on subnational scale will help to better understand the drivers of social metabolism in regions that are poised for rapid development and their significant environmental pressures. To shift to a more sustainable society, understanding the social metabolism of societies at rapid development is very crucial as these are the regions where the population are progressively rising and are highly dynamic concerning development and metabolic changes. And also to address global environmental challenges, resource use patterns at local and sub-national scales can provide relevant insights into its drivers and how these link to local policy and decision making (Singh et al., 2010). This thesis is a contribution to the growing body of knowledge of MEFA and hopes to be one of the first few studies to be on a subnational scale.

This study will also assist various stakeholders of the region to gain knowledge, understand and identify the areas (critical points) where resource use is inefficient and where changes must be made regarding material use. The quantification of biomass and energy flows will also help the people of the region to move to a better way of living facilitating sustainable socio-economic development. Furthermore, this study will also assist the community in the region to smoothly

transition to the ultra-modernization of the region as a large urban sprawl without causing further environmental damages.

In this research, some of the biophysical challenges that the Region of Waterloo has been explored to comprehend the future sustainability challenges the Region of Waterloo might face in the future.

It is hoped that the analysis of biomass and energy flows of the Region of Waterloo will serve as a chance for the stakeholders, policy makers and the government to take a system perspective of the region and rethink their current position regarding sustainable development to move towards a more sustainable region.

### 1.3 Research Objective

The primary purpose of this study would be to quantify the biomass and energy flows for the Region of Waterloo (Canada) at three points in time (2006, 2011, 2016) in the context of food and energy security using the standardized material and energy flow accounting methodology from Eurostat (2013) along with the “local studies” methodological guidelines laid down by Singh et al (2010). The secondary objective is to provide insights into local actions using the standard derived indicators of MEFA to observe and analyze the challenges in resource use patterns in the region since 2006 to facilitate sustainable development of the region.

### 1.4 Thesis Structure

In this current chapter, the overview of this research regarding the Material and Energy flow analysis of the region of Waterloo has been provided followed by the research objectives and questions.

In Chapter 2, an overview of the literature of the concept of social metabolism and how it evolved followed by literature overview of the frameworks of Material Flow Accounting and Energy flow accounting is provided. And then the current state of knowledge of local studies in MFA have been provided.

In Chapter 3, the context of the study, the Region of Waterloo was described briefly to gain an understanding of the region.

In Chapter 4, a detail description of the methodology used to quantify the data required for Material and Energy flow accounting and calculate the derived indicators meet have been provided.

In Chapter 5, the results of the study have been presented using the indicators derived from material and energy flow accounting focusing on key findings from the analysis of the metabolic profile of the region of Waterloo.

Finally, in chapter 6 results from the study have been explained in detail and what it means to the region of Waterloo's food and energy security while also recommending the needs for changes in the current system for policy decision makers and other stakeholders of the region. Also, the validity of the results and the opportunities for further studies have also been explained in this chapter.

## 2 LITERATURE REVIEW: A BROAD UNDERSTANDING OF THE CONCEPTS USED IN THIS STUDY

This chapter presents a literature overview of Social metabolism and its operational tool, Material Flow Analysis. The goal of the literature review is to illustrate the concepts and methodologies used in this research to demonstrate current knowledge gaps and identify current research practices.

### 2.1 Social metabolism and its operational tool- Material and Energy Flow Analysis (MEFA)

It has been argued that the existing environmental problems are a result of the way humans interact with the natural environment. The sustainability crisis (e.g. Natural resource depletion, extreme weather events, loss of habitat, deforestation, Climate change, Ocean acidification... etc.) humans are currently experiencing is due to the ways humans consume their natural resources (material, energy, land) causing sustainability problems. It is widely accepted that Sustainability is a problem of society- nature interactions. Therefore, it becomes vital to understand the interrelations between the society and the natural environment to gain knowledge of the environmental problems humans face and what is it humans require to be a sustainably developed economy or society (Fischer-Kowalski & Weisz, 1999). In order to understand the relationship between nature and society, several research fields exist namely: Social and human ecology, Ecological economics, Political ecology, Industrial ecology and social ecology. These research fields do not look at social and natural systems as themselves but together in more or less an interdisciplinary way to address sustainability issues (Fischer-kowalski & Weisz, 2016). As such a common unit of analysis in these research fields to investigate sustainability is coupled social ecological systems. (Fischer-kowalski & Weisz, 2016)

Nevertheless, understanding the interaction between societies and nature is one of the several debated complex issues in the realm of sustainability science and one way to conceptualize it is the concept of socioeconomic metabolism that comprises of the processes of extraction of material resources from the environment (input), the processing of the materials extracted (throughput) and finally releasing the materials processed back to the environment in terms of wastes and emissions (output) sooner or later (Fischer-Kowalski & Hüttler, 1999). The

assessment of material throughput is done using Material flow accounting (MFA) which is an operational framework to operationalize the socioeconomic metabolism and to derive environmental pressure indicators (explained in detail in the following paragraphs). In understanding the relationship between human societies and the environment in terms of resource and energy use, the concept of socioeconomic metabolism helps us to assess human societies and their relationship with the environment by providing a framework to analyze the flow of materials and energy in a society (Fridolin Krausmann, 2016).

There are different ways to conceptualize Society-nature interactions. Boyden's Human Ecological Model, Godelier's Society-Nature Interrelations as a driving force of Social change, Sierferle's Complex systems and Cultural evolution, Ostrom et al.'s Social-Ecological systems framework (SES), Resilience Alliance, the Frankfurt approach to "Societal nature relations", Dutch school of socioecological transitions and Fischer-Kowalski's Vienna school of social ecology's concept of society-nature interaction are all frameworks that have tried to explain the concept of society-nature interactions. Also, a new research area from socio ecological research to address complex society-nature relationships over long periods of time is developing and is called Long term socioecological research (LTSER) (Singh et al., 2013). All these research fields share a fundamental premise that "human social and natural systems interact, coevolve over time and have substantial impacts on one another" (Fischer-kowalski & Weisz, 2016, p. 4). But they also have distinct perspectives on how to account for society-nature interactions.

Societies organize similar to organisms through the flows of material and energy with their natural environment and is the most commonly used analogy by scholars to describe society's metabolism (Marina Fischer-Kowalski & Weisz, 1999). Metabolism was first referred by Karl Marx when he described labor as a process through which people appropriate nature to regulate, reproduce and maintain their metabolism (Fischer-kowalski & Weisz, 1999, 2016). Later, Ayres and Kneese in 1969, referred to the material and energy throughput of industrial societies and termed it as "industrial metabolism" and subsequently "social metabolism" to refer to the metabolism of any society at any scale (Fischer-kowalski & Weisz, 1999, 2016).

For the purpose of sustainability research, naturalistic view of ecology and culturalistic view of social sciences are both required, as neither one alone will not suffice to comprehend the

complex issues that are being faced by the society. Hence the concept of social-ecological systems is one of the clever concepts for sustainability research. , to analyze the evolution of a socioecological system and its course of development towards a sustainable future, the need to understand and account for biophysical flows is prominent, likewise the necessity to understand the societal flows that govern and support the biophysical flows is also of importance in the realm of social ecology (Fischer-kowalski & Weisz, 2016).

In this thesis, the socioecological model developed by Marina Fischer-Kowlaski and her colleagues at the Viennese school of Social ecology has been focused. A review of all this concepts is available in Fischer-kowalski & Weisz (2016) and Marina Fischer-Kowalski & Weisz (1999).

### 2.1.1 Conceptual model of Society-Nature Interactions by the Viennese School of Social Ecology

The conceptual model of Society-Nature interactions by the Viennese school of social ecology is different from other similar conceptual models as it highlights *“The intersection of the Cartesian distinction between the material and symbolic (cultural) realms as mutually exclusive domains, on the one hand, and of the material world and human society, on the other hand, as comprising all of culture and specific elements of the material world. Therefore, the natural and cultural spheres of causation partly overlap in society; human society is thus a hybrid of the two realms”* (Fischer-kowalski & Weisz, 2016, p. 22).

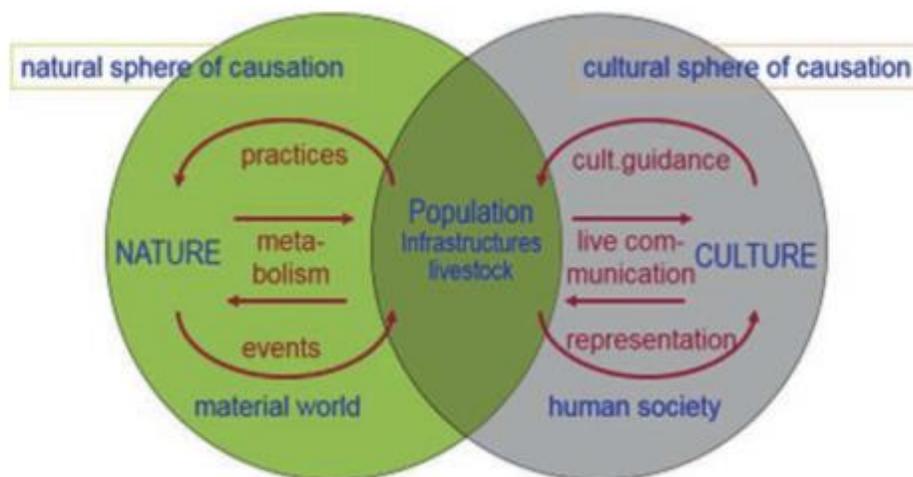


Figure 2-1 Conceptual model of Society-Nature Interaction Source: Fischer-Kowalski and Weisz (2016)

The society nature coevolution is described by this conceptual model (Figure 2-1) where the bent arrows are followed in a recursive way. Human Society is reproduced both culturally and biophysically which are both interdependent and indispensable. The biophysical structures of the society are Human population, Livestock and Human made infrastructure (Marina Fischer-Kowalski & Weisz, 1999). Human society is reproduced culturally through the flow of communication and biophysically through the flow of materials and energy from and to the natural environment.

As figure 2-1 illustrates, society intervenes with nature through *practices*- labor, capital and technology and modify nature for its required needs (e.g., agriculture). In the other direction, the biophysical structures of society are also vulnerable to the forces of nature like catastrophes (e.g., flood) and these physical forces from nature are *represented* culturally through communication and are represented as rewards for society's efforts.

Following the arrows from the cultural sphere to the nature sphere, collective decisions and actions are made based on the *guidance* supplied from culture, sometimes these culturally guided regulations lead to *events* (alterations in physical processes), in turn this might lead to new forces from nature upon society intended or unintended. Certain of these new forces that are created from nature might be represented culturally and sometimes may not be and again for future action upon nature these forces may sometimes modify the *cultural guidance* or may not modify at all (Fischer-kowalski & Weisz, 2016).

Over the past few decades, the interest in the biophysical dimensions of society/economy along with its interaction with the natural environment paved the way to the concept of society's metabolism or industrial metabolism. As put by Fischer-kowalski and Weisz (2016) "*Social metabolism is the key link between society and the natural environment. Therefore, to reproduce its biophysical structures, society requires a continuous flow of energy and materials that need to be extracted from and eventually released to the environment*" (Fischer-kowalski & Weisz, 2016, p. 22). In other words, the process of exchange of materials and energy between the natural sphere of causation and society is called social metabolism (Fischer-Kowalski & Weisz, 1999). Similarly, communication is the key between culture and individual human consciousness (considered under *population*). In other words, society is a hybrid because society not only

reproduces itself biophysically through exchange of materials and energy but also culturally through communication.

Currently, the concept of metabolism serves as the foundation for research into the human dimension of sustainability and environmental change (Fischer-Kowalski & Haberl, 1998). The quantity and quality of material and energy throughput of social metabolism is influenced by (Krausmann, Weisz, & Eisenmenger, 2016a).

1. The size of the population of humans and livestock and the human-made artifacts that need to be reproduced.
2. The productive/exploitive technology
3. Affluence, lifestyle and consumption patterns.

The amount of flow or quantity of the flow of energy and materials with the natural environment and also with other developed social systems decides the type of *socio- metabolic regime* and its profile (Singh et al., 2010).

The other widely used concept in social ecology is *colonization*. Colonization is expressed as the voluntary involvement in natural environment or systems by the society to extract more resources from nature and make it useful (Fischer-Kowalski & Haberl, 1998).

MFA is defined as a physical accounting method that gives “*an aggregate overview, in tons, of annual material inputs and outputs of an economy including inputs from the national environment and outputs to the environment and the physical amounts of imports and exports*” (Eurostat, 2001, p.15).

MFA is based on the simple model that the economy is embedded into the environment, and the economy/society is an open system of matter and energy exchanges entering and leaving the system. The calculation of amount of materials that flows to the society from the environment and the material that flows back into the environment from the society in terms of emissions and pollutants can not only be used to quantify the resource usage on the input side and output side but also to calculate the amount of materials that stays in the system/society as stocks (Fischer-Kowalski et al., 2011). (See Figure 2-2)

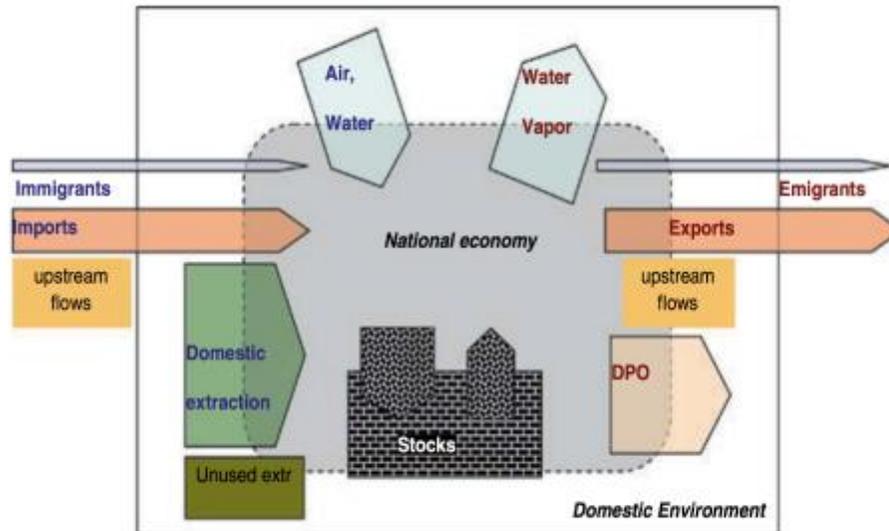


Figure 2-2 The Material metabolism of an economy (Source: Fischer-Kowalski et al. (2011))

The foundation of the methodology of MFA rests on the *law of conservation of mass*, (the first law of thermodynamics) that matter or energy can neither be created nor destroyed but can only be converted from one form into another in physical processes (Fischer-Kowalski et al., 2011). Hence, the material balance approach which states that the total inputs must equal the total outputs plus the net materials accumulated in the system (stocks) serves as the basis for material flow accounting.

*Stocks* are materials that stay in the system or society for more than a year whereas *flows* are materials that remain in the system or society less than a year. In other words, *Stocks* are materials that flows into the system and are used to build up and maintain the system whereas materials required to maintain the system or stock are contemplated as *flows* (Fischer-Kowalski et al., 2011). This material balance goes for any societal system (national or local) or subsystem (a company or household) (Fischer-Kowalski et al., 2011). There are three important stocks compartments in MFA that are maintained and reproduced by metabolic activity of a socioeconomic system. They are Human population, Built environment and (infrastructure and buildings and artefacts (machinery and durable consumer goods), and livestock and other domestic animals. Even though Human population is the most important stock, in highly industrialized economies built environment and artefacts determines the largest flows.

### 2.1.2 Why analyze material and energy flows?

Energy and materials are biophysical resources that are necessary for the survival and reproductions of humans and other species and are limited in terms of availability and productivity.

The new *sustainable development goals* (SDG's) stress the necessity for a balanced focus on people, planet and prosperity to attain sustainable development and acknowledges the significance of sustainable resource use and climate mitigation to achieve those sustainable development objectives. The SDG's made the global policy makers and development practitioners to realize the shortcomings of economic indicators that ignores environmental sustainability and equity issues but focusing on only economic growth and employment. The rise in global issues of social inequity and environmental degradation and the environmental impacts of urbanization and industrialization along with the introduction of SDG's have drawn the interests of the policy makers "to reset the international policy discourse and renewed the environmental agenda underpinning economic and social objectives"(Schandl et al., 2017, p. 2).

Material and energy flow analysis integrates economic, environment and social objectives in its accounting and fills the need of the policy makers around the world currently with the help of standard derived indicators of sustainability. Derived indicators are pressure indicators that show the human pressure on the environment (both on the input and output side). Some of the indicators that are usually derived from MFA are Direct material input(DMI), Domestic material consumption (DMC) and Physical trade balance (PTB)(Weisz et al., 2006). (Explained in detail in Chapter 4)

### 2.1.3 Historical development of MEFA

Fisher-Kowalski and her colleagues(2011) in their work, *Methodology and Indicators of Economy-wide Material Flow Accounting* briefly talked about the development of MFA historically, and that served as the basis of the following section. MFA of national economies was first presented by Robert Ayres, an American physicist, and Allen Kneese, an economist in 1969 as an economic case which happened to transpire later in the 1990's(Ayres & Kneese, 1969). They argued that environmental pollution and its control can be solved only when accounting for

priceless environmental commodities like water and air i.e. to view environmental problems as material balance problem of the national economy (Ayres, Ayres, & Warr, 2002; Ayres & Kneese, 1969). At the same time in 1974 Gofman et al. made a complete material flow analysis including air, water and raw materials for the economy of Soviet Union without knowing what was transpiring in the USA by Robert Ayres and Allen Kneese. This economical solution of accounting for free environmental goods like air and water in the economy accounting transpired to be known as "internalizing externalities" was applied to state planning by Gofman during that time which remains as common practice to address externalities for the sake of solving environmental problems. Then in the 1990s nearly after 20 years, the *Wuppertal Institute* in Germany, *Institute of social ecology* in Austria and *National institute of environmental studies* in Japan, all accounted for the full material flow accounts for their countries while initializing the concept of MFA to mainstream national accounting. Later in 1997, the *World Resources Institute (WRI)*, a non-profit organization based in the USA published the first MFA comparison study of four industrial economies with the help of the three institutions mentioned above and again in 2000 published the MFA of national economies of few more countries while explaining the methodology in detail. Subsequently, the statistical office of the European Union, Eurostat played a major role in creating the path for MFA by incorporating it into its standard environmental program and with the help of WI and Vienna SEC published the material flow indicators for EU- 15 in its methodological guide in 2001, which was expanded, revised and updated by SEC, Vienna in 2002. Much later, in 2007 by including better data sets from national statistics offices, the methodological guide was updated with more indicators by Eurostat with the help of WI and Vienna SEC. Also, the Eurostat made it compulsory for its member countries to include MFA in its System of environmental, economic accounting (SEEA). Following the footpath of Eurostat, OECD (Organization for Economic co-operation and development) also joined in the advancement and international standardization of the methodology of MFA in the second half of the 2000s (Fischer-Kowalski et al., 2011).

#### 2.1.4 Uses of Material Flow Analysis

Again, the usability of MEFA as a tool is to analyze the flows of the materials and energy takes place in the society and allows us to interpret the impacts of these flows with reference to sustainability. Also, analyzing the flows of the materials and energy through MEFA allows us to address the development concerns of society such as environmental justice, distributional conflicts, ecological unequal exchange, and such. Moreover, analyzing the flows of biophysical resources with the help of MEFA helps us to monitor the progress of decoupling from the use of biophysical resources of a society (Fischer-Kowalski & Haberl, 2015).

##### 2.1.4.1 *Resource Decoupling*

Environmental degradation and economic growth was seen to be closely linked in the 1970's. While some argued that economic growth needs to be stopped to prevent the exhaustion of finite natural resources. Currently, the global environmental debate has changed to dematerialize or decouple the economy from material inputs. Absolute decoupling is the reduction in material throughput while GDP increases and relative decoupling shows slow increase in material throughput compared to increase in GDP. However, decoupling truly happens when absolute decoupling happens i.e., absolute reduction in material or energy consumption. It is being estimated by UNEP(2016) that business as usual scenario continues global material resource use will increase by a factor of 3 by 2050, which is impossible to extract without affecting the global ecosystems tremendously(UNEP, 2016).While few argue that technological solutions will pave the way to solve this crisis, but it still remains questionable.

A recent report "Global Material flows and Resource Productivity" by UNEP stresses the urgent need to decouple material resource use from economic growth and human wellbeing(UNEP, 2016). Thus, it becomes necessary to decouple our way of life from more consumption of materials and energy. The decoupling of the quality of life from high usage of biophysical resources is not possible through technological solutions alone but by making radical changes in the society as early as possible to move towards development of a more fair and sustainable society.

#### 2.1.4.2 Environmental Justice

While many industrialized countries in the past have experienced absolute decoupling, it is believed that was partly because those industrialized countries externalized the environmental impacts of their material intensive processes to the countries of the Global south where cheap labor and resources are common. This leads to the sustainability issues of global north and south and environmental justice. There are very fundamental research questions that are addressed by MFA on a global scale “including identifying the quantity of materials extracted and traded globally to support economic processes, assessments of how the level and composition of material extraction have changed over time, and analysis of who has profited most from natural resources”(Schandl et al., 2017, p. 2).

The EJOLT report also emphasizes the rise in socio-environmental conflicts between the Global North and Global South through Global trade of biomass. Materials and resources flow from one place to another i.e,they are traded to improve their value. It is established by various researchers that there exists a unequal distribution of environmental burdens between global north and global south and the conventional national economic accounting does not account for the environmental burdens but only the GDP. Recently, Raw material equivalent(RME) has been used as an indicator to denote unequal trade where imported and exported products are converted to their used raw materials to create the product(Muñoz, Giljum, & Roca, 2009; Schaffartzik, Eisenmenger, Krausmann, & Weisz, 2014).

#### 2.1.4.3 Socio-metabolic regimes

The mutual relationship between the society and the environment has a set of biophysical patterns over an extended period in dynamic equilibrium. This particular pattern of interaction between the natural and social system is called *socio- metabolic regimes*(Krausmann, Weisz, & Eisenmenger, 2016b; Singh et al., 2010). Understanding the socio-metabolic regimes is of significance as it covers the long-term dynamic trends of societal and natural interactions over the history of human progress and thus understanding the history will help us learn and move forward to the future knowing what and what not to do. Historical changes from one regime to another regime is referred to as *Transitions* (Singh et al., 2010). The concept of transition does not imply incremental adjustments or improvements but a major change i.e. to a relatively new

state of the system (Fischer-Kowalski & Haberl, 2007). Each regime has certain pattern of flows of material and energy which is called its *socio-metabolic profile* (Krausmann, Fischer-Kowalski, Schandl, & Eisenmenger, 2008).

Over the history of humans, three different modes of production have occurred, known as socio-metabolic regimes. The three socio-metabolic regimes are namely Hunter and gatherer, agrarian and Industrial. These socio-metabolic regimes are characterized by unique features with each regime having certain metabolic profile with material and energy use obtained by the use of different technologies and infrastructure and also a certain pattern of demographic reproduction, labor structure, population density, environmental impact (Krausmann, Weisz, et al., 2016b). Moreover, in order to change and constrain the reproduction of the socioecological regime, there exists regulatory positive and negative feedbacks between society's natural environment and its socio-economic system.

The typical features of the hunter and gatherer regime is that they have comparatively low rates of population growth and population density and have low material and energy metabolic rates with few biophysical structures. Also, they have relatively low working times and spent much of their time on shared cultural activities. Moreover, in the hunter and gatherer regime fossil fuels have not been used as an energy source and they did not colonize terrestrial ecosystems for their food production.

Likewise, the agrarian socio metabolic regime is characterized by its typical features such as active solar energy use for its biomass flows, distinct limits for physical growth (low energy density), tendency for population growth and increasing workload. Also in the agrarian regime, the key technology was the use of land through agriculture and has decentralized infrastructures. Moreover, they have both subsistence economies and market economies.

The Industrial sociometabolic regime has its own features characterized by a metabolic profile that is based mainly on the use of fossil fuels and exploitation of large stocks of natural resources eradicating the limits to physical growth. The industrial regime is secured by centralized infrastructures with key industrial technologies. The governance and economic structure of this regime is capitalism and functional differentiation. This regime is also characterized by thrifty demographical reproduction with the labors having less workload. The

material use and energy use of this regime is around 150-400 t/cap/yr. Figure 2-3 shows the sociometabolic profiles of various socio-metabolic regimes.

The key constraint and driver for the transition in sociometabolic regimes is the sources of energy and technologies used for energy conversion i.e. the energy system, starting from the hunter and gatherer regime to the agrarian regime and now to the industrial regime (Krausmann, Weisz, et al., 2016a). The industrial regime was solely based upon the exploitation and utilization of fossil fuels. Although the success of the industrial regime is pictured to be huge, this regime faces much criticism as the actions have adverse effects. The over-exploitation of fossil fuels has led to their depletion and have contributed to adverse effects of global warming, climate change, rising sea level, etc.

## 2.2 Social Metabolism at Various scales

MEFA has been adopted by various studies at different scales, for National scale refer , India (Singh et al., 2012), USA (Gierlinger & Krausmann, 2012), China (XU & ZHANG, 2007), Japan (Krausmann, Gingrich, & Nourbakhch-Sabet, 2011), USSR (Krausmann, Gaugl, West, & Schandl, 2016), Spain(Soto et al., 2016), Czechoslovakia (Kovanda & Hak, 2011), Argentina (Manrique, Brun, González-Martínez, Walter, & Martínez-Alier, 2013), Latin America (Russi et al., 2008) and also for local studies refer Trinket Island(Singh, Grünbühel, Schandl, & Schulz, 2001), Bolivia (Ringhofer, 2010), Sang Saeng (Grünbühel, Haberl, Schandl, & Winiwarter, 2003), Samothraki(Petridis, Fischer-Kowalski, Singh, & Noll, 2017) (see section 2.2.2 for detailed explanations). MEFA have also been used by studies at Global scale, refer (Eurostat, 2001; Matthews, Amann, & Bringezu, 2000; UNEP, 2016). While the advancement of the methodology of MFA was happening at a much quicker pace for national economies, there was also research being conducted at local levels.

### 2.2.1 Social Metabolism at Regional and Local scales

The existing literature on MFA is majorly concentrated at national levels and not at the local level in order to avoid excessive and time-consuming data abstraction at the local levels. At the local levels, researchers adopt a bottom-up approach, i.e., to rely on methods of measuring and counting, estimating, sampling and interviewing in the field to collect the data manually. However, when collecting data on material stocks for national economies, researchers mainly

rely on the data provided by the Statistics Office of the Government along with other sources since they are readily available.

One of the certain usages of local studies is in its ability to help understand the biophysical aspects of an economy or society. This, in turn, helps the policymakers to evaluate policy options in a more sustainable and environmentally friendly manner (Singh & Haas, 2016).

After the pivotal work of Wolfman (1965) more than 75 papers have been done on Urban metabolism and published. And these papers look at the metabolism of a particular city comprehensively and also to address specific components of water, materials, wastes, energy, transportation, etc(C. A. Kennedy et al., 2015; C. Kennedy & Hoornweg, 2012). These studies are done mostly to understand the ecological performance of the megacities and in relevance to current mainstream issues like urban sustainability, environmental degradation, population growth, and quality of life. There is a general acknowledgment among urban metabolism studies that availability of sufficient and reliable data at appropriate scale is a barrier to conduct these studies(C. Kennedy & Hoornweg, 2012).

In urban metabolism studies, a common theme that is found in all studies is ““growth and change”—each study is set in a similar context of growing populations and/or economies, and changing flows and stocks of resources and wastes”(Stewart, Kennedy, & Facchini, 2014, p. 29). And three aspects are found to be universal and specific in urban metabolism literature such as historical/temporal trends, Spatial/geographical patterns, and Social/economic influences.(Stewart et al., 2014)

Most of the metabolism studies(National, urban and local) are done at places where there are rapid population and economic growth, i.e., places that are undergoing/expected to undergo a transition in its metabolism. Therefore, most of the metabolic studies are concentrated in the global south and the industrialized megacities. Previously, in North America, urban metabolism studies are done only for New York City(Swaney, Santoro, Howarth, Hong, & Donaghy, 2012), Los Angeles(Ngo & Pataki, 2008) and the Greater Toronto Area(Sahely, Dudding, & Kennedy, 2003). Even though sustainable development is a global challenge that needs to be discussed and solved in the global context, it also has an inevitable local/sub-national dimension to it. It is only at local or sub-national scale, social, cultural, environmental and economic issues are interlocked and

experienced. Hence the need for studies at the sub-national level in the global north that are undergoing rapid change in population and economic growth to understand its ecological performance and the early identification of environmental implications and issues (Zhang, Yang, & Yu, 2015). The early identification of environmental impact and issues will help policymakers to intervene and make informed policy decisions.

### 2.2.2 Social metabolism research at Local level

In recent years, there has been an increasing amount of literature on socio-economic metabolism and material flow analysis at global, national and regional level. Usually, to shed light on the patterns and trends in resource extraction, use, and productivity, characterization of the biophysical aspects of the economy is done. This characterization is also done to analyze the composition of the resources for better understanding of the metabolic transition. 'Local' refers to sub-national scale, be it a province or a region or a municipality where direct empirical observation and primary data collection takes place (Singh & Haas, 2016). Also, local studies help us understand how the local society is altered through interventions such as markets, legal frameworks, and subsidies by global processes. Moreover, local studies are gaining significance as it provides insight into local actions and decisions which lead to having a cumulative effect on the global environment and society.

The study of local or rural society has a long tradition in social sciences- anthropology and human ecology since the 1960s. Whereas the study of local socioecological systems has gained prominence only in the recent times with sustainability perspective due to the context of global environmental change. Also, local systems serve as the core for national and global economies and provide various ecosystem services of culture, provisioning, and regulation. In the context of environmental change, local systems are also susceptible to various socio-ecological changes due to extraction, production, overconsumption, waste emissions, and also from preservation efforts (Singh & Haas, 2016). Hence, the need for understanding the biophysical patterns or metabolic profile of local regions have gained the attraction of researchers in the recent years to understand their society-nature interactions.

Some studies have tried to adopt MFA into local systems in recent years, and the first research was done in 1997 by Lyla Mehta in a small rural village called Mekar near Narmada dam

in India. Later, in 1998 the social metabolism of a village in Northeastern Thailand called Sang Saeng was investigated by Grunbuhel et al (2003). The need for this study during that time is because the economy of South-East Asia was growing at a rapid pace in the 1990's due to rapid population growth which had created massive pressure on the environmental system. Hence, the study of Sang Seng village was carried out to understand the production and consumption patterns and its relation to the environment. The study was also done to solve the associated impact on the environment. The primary objective of this study was to provide a holistic view of the interaction between the societies and its local environment and to also shift the perspective of the society and its associated material – energy exchanges with the environment(Grünbühel et al., 2003). Furthermore, the author has tried to establish the influence of higher scale interactions in the local society and sought to differentiate between traditional activities and the modern influences over the local system. Besides, Grunbuhel et al. also pointed out that there is a physical dimension to all social activities and there lies the need to recognize the social component to address the environmental issues. The study followed the conceptual model of socio-economic metabolism developed at the Institute for Interdisciplinary Studies at Vienna for national context (Adriaanse et al., 1997; Matthews et al., 2000). The MEFA toolbox prescribed by the statistics office of the European Union and then adopted it into a local context. The metabolic profile analysis from the study indicates that the primary energy input of Sang Saeng Village was 76GJ/Cap/year and that 91% of primary energy input comes from Biomass (Grünbühel et al., 2003). Grunbuhel and coworkers also determined that 55% of the final energy use was attributed to the nutrition of animals and only 16% belonged to human nutritional energy purpose, typical of a subsistence based village.

Subsequently, between the years of 1999 to 2010, Singh et al. assessed the dynamics of a local society on the Trinket Island part of the Nicobar Islands in the Indian Ocean to understand its socio-metabolic transitions (Singh & Haas, 2016). The primary objective of the study was to provide a clear perspective of the relation between the society of the island and its environment and to understand the characteristic metabolic profiles of the local society that was in transition. The main methodology used in the field study of the Nicobar Islands by Singh and his colleagues was participant observation and semi-structured interviews with the locals. Similar to the study

of Sang Saeng Village by Grunbuhel et al., this study also adopted the guidelines of material and energy flow accounting for the local context to find the material and energy throughput.

However, unlike the previous studies, Singh et al. used three socio-ecological concepts in this study: Socio-economic metabolism, Colonizing natural process, and Energy, labor and time. Additionally, the following socio-ecological concepts were operationalized by Singh et al. using material and energy flow accounting for socioeconomic metabolism; Human appropriation of net primary production for the Colonizing natural process; Energetic return on investment, bioeconomic pressure and time invested in labor to meet daily necessities for Energy, labor and time (Fischer-Kowalski et al., 2011; Singh & Haas, 2016) which haven't been done on local studies earlier.

Followed by the previous study, a research study was carried out on Tat Hamlet, a rural mountain region in Vietnam by Heinz Schandl and his colleagues from 2001 to 2003. This study was conducted since environmental aspects of the region was poorly understood, thereby making it troublesome for policymakers to make sustainable and environmentally benign policies. Hence, Schandl et al. applied the concept of MFA to understand the environmental aspects of the society-nature interactions similar to previous local studies in the field of social ecology. The main purpose of this study was to understand the material metabolism of the region of Tat Hamlet that was in transition using a holistic approach. Additionally, unlike the previous studies, Schandl and his colleagues used Action in Context research (AiC) to account for the social perspective of the people of the region causing the flow, and how policies influence their actions (Schandl, Hobbes, & Editors, 2006).

Hobbes et al. (2007) studied the Sierra Madre forest region in the Philippines during 2001 to 2002 using the MFA/EFA methodology and Schandl's Action in Context (Aic) methodology to understand the environmental and social context of the society-nature interactions (Hobbes & Kleijn, 2007). Since most local studies do not have readily available data for the MFA calculations, household and group interviews, and the respective observations were carried out to obtain sufficient data for MFA calculation.

During this same period, Nalang, a subsistence-based community in Laos was studied using the same MEFA methodology to gain perspective of the material and energy metabolism of the region of Nalang (Fischer-Kowalski et al., 2011).

In 2004, Ringhofer did a two-year study on Campo Bello, Bolivia at the Amazonia. The community there is indigenous and relies on foraging, farming, and trade with inhabitants of then 231 people. Ringhofer adopted the concept of MFA framework that is analogous to aforementioned studies(Ringhofer, 2010). Moreover, the reason for her to choose Campo Bello for her research was that the region was undergoing a transition as only during that time their modes of subsistence have begun to change. Although she adopted the MFA framework, she also accounted for functional time use along with social metabolism and colonization of ecosystems. Since the metabolic exchange process of the people of a social system and the natural environment are characterized by certain time norms in traditional social systems for its functioning (Ringhofer, 2010). From a system's perspective, human time is considered to be a critical resource in the operation of the society. Hence, Ringhofer(2010) accounted for functional time use to get a holistic picture of the social and the environmental pressures associated with it.

Recently, a watershed in Ethiopia was studied by Andarage in 2014 using the MEFA framework to account for the material and energy metabolism. Fischer-Kowalski and coworkers studied Samothraki a small island in the Greek archipelago from 2007 as part of a long-term research adopting the socio-ecological and transdisciplinary research methodologies (Petridis et al., 2017). Samothraki is in a socio-ecological transition from a traditional agrarian to a more modern society. The research was done there to help the local population while also understanding the complex issues faced by the island thereby making the transition to a more sustainable future.

### 2.3 ENERGY FLOW ANALYSIS

From a sustainability perspective, it is imperative to perform material and energy flow analysis to fully understand and have a holistic view of society's metabolism. The material and energy flow go like cogwheels, hence understanding both is of absolute importance from a

conceptual perspective to comprehend the metabolism of society (Haberl, 2001a). Haberl (2001) argues that energy flow analysis has to be a fundamental part of societal metabolism since the continuous material throughput is possible only when there is a constant throughput of energy to transform and transport the flows of materials in society (Haberl, 2001). The energetic metabolism of a society i.e. the energy throughput required for a society to reproduce and maintain itself can be quantified with the help of the operationalizing tool of *Energy Flow Analysis* (Haberl et al., 2008).

**Energy Flow Accounting** can be described as the process that seeks to establish the balance in the energy flows which comprises of the input and output energies, and the energy transformation that happens internally in a society or within a defined socio-economic system boundary (Haberl, 2001; Julesz, 2010). The system boundaries are compatible with Material Flow Accounting (MFA). This means that the energy input and output are taken for the society and socio-economic stocks as a whole, which includes the energy used and dissipated by humans, livestock, and artifacts. Fundamentally, energy flow accounting employs the same foundational concepts and boundaries of MFA to account for societies' socio-economic energy flows but with energy as its unit of analysis instead of materials. The total energy throughput of the region under investigation is obtained to derive biophysical indicators that remain and assist that derived from MFA. This is done to understand the dynamics of society-nature interaction of the system under study.(Krausmann & Haberl, 2002)

**Energy Balance Approach** is one of the key, where the MFA boundaries are considered for the study. It is necessary for the energy balance of the society to be compatible with these boundaries.(Julesz, 2010)

$$\text{System Inputs} = \text{System Outputs} + \text{Changes in Stock}$$

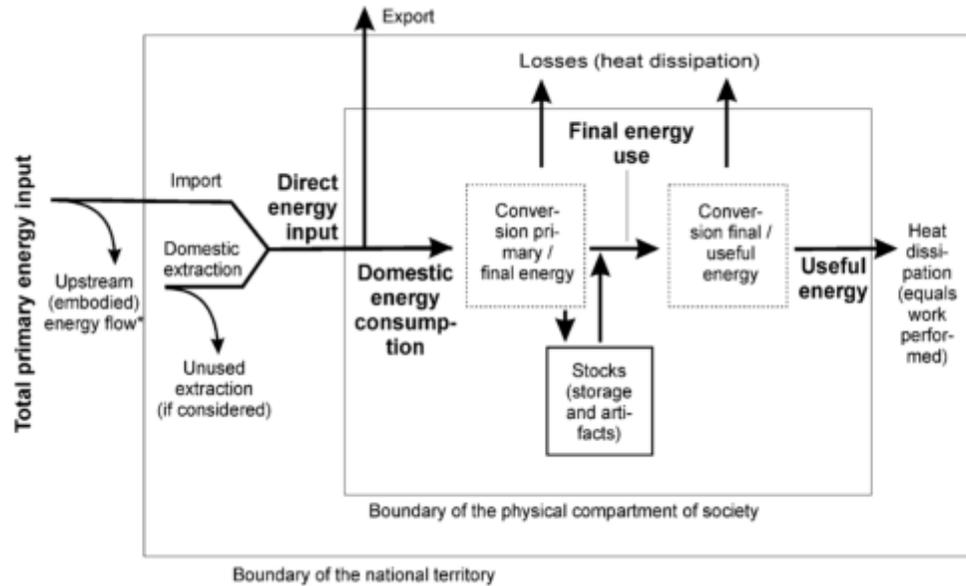


Figure 2-3 Energy flow analysis (EFA), Source: Krausmann and Haberl (2002).

To gain a better understanding of energy flow analysis, it was important to differentiate between energy statistics and energy balances. Energy statistics provide information about the energy flow data of a socio-economic energy sector or their process of conversion (Haberl, 2001). The entire energy that flows through an economy is not portrayed in this approach. However, the energy flow accounting approach provides a more consistent image of the energy flowing in an economy.

Conventional energy statistics account for only the energy used in technical devices which is in turn used to provide heat, light and mechanical work. Hence, it is imperative to have a robust accounting system. Such a system should also account for all energy-rich materials, electricity and light. Therefore, unlike conventional energy balances, an energetic metabolism accounting or energy flow accounting includes not just the biomass used for technical energy generation. It is important to include the total amount of biomass being employed as energy input since biomass also serves as food energy for humans and livestock (Haberl, 2001; Julesz, 2010).

However, unlike Conventional energy balances, EFA accounts biomass energy carriers-human nutritional energy(food energy) and animal nutritional energy (feed energy)as both are inputs of energy into the socio-economic system(Haberl, 2006).

Changes in a socio-economic system are quintessential to sustainability. Such changes include resource usage patterns, greenhouse gas emissions, land use patterns and their respective changes. Additionally, the transition that takes place from the agrarian to the industrial mode of sustenance can be covered only by a comprehensive energy flow accounting method since it is a subsistent change in the socioeconomic energy system. Much emphasis is laid on this elaborate method since significant biophysical flows like the human and animal nutrition which are needed to observe the changes in various social metabolic regimes are excluded in conventional energy statistics. However, the EFA accounts for these biophysical flows since the energy conversion process takes place within the systemic boundary of the society under study.

### 2.3.1 Indicators of EFA

#### *Domestic extraction (DE)*

*Domestic Extraction (DE)* is the sum total of the energy from biomass and technical energy input. Domestic extraction can be defined as the sum of all the biomass energies that enter the socioeconomic system and domestically harvested and the technical energy input taken from the energy statistics. Contrary to conventional energy balances, Gross Calorific Value (GCV) is used in EFA to calculate the energy equivalent of energy-rich materials (from tons to Joules in energy values) instead of Net Calorific Values (NCV).

#### *Imports and Exports*

Energy carriers are not the only parameters when it comes to imports and exports. Hence, consideration had to be provided to energy-containing materials as well. To get a complete picture of the entire energy contained in the final products, it is necessary to know the GCV of the imported items.

#### *Domestic Energy Input (DEI) or Total Energy Supply*

The energy flow analyses must be compatible with the material flow accounting. To make this happen, an entity that is equivalent to the direct material input of the material flow accounting is calculated. Energy input includes domestically extracted, imported primary energy

flows like electricity and light, and raw and derived energy-rich materials that cross the system boundary. All biomass inputs regardless of their purposefulness must be included in the system.

Direct Energy Input (DEI) = Domestic Extraction + Import

The sum of the total energy that enters the socioeconomic system boundary under scrutiny, through domestic extraction and or import is known as the direct energy input.

*Domestic Energy Consumption (DEC)*

Domestic Energy Consumption = Direct Energy Input – Exports

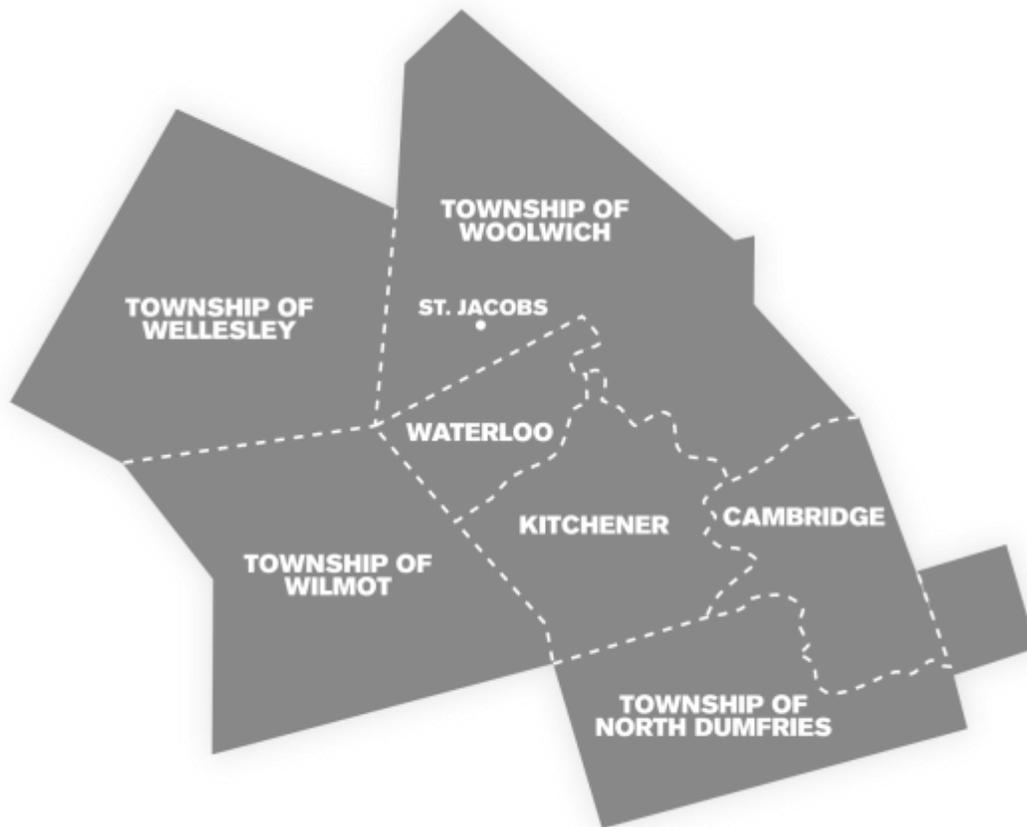
The difference between the exports and the direct energy input is known as Domestic Energy Consumption.

### 3 OVERVIEW OF THE REGION OF WATERLOO

#### 3.1 The Context: Region of Waterloo

The Region of Waterloo is in Southern Ontario, located approximately 100 km West of Canada's financial capital, Toronto. The Region of Waterloo often referred to as "*Canada's Silicon Valley*" comprises of three cities of Kitchener, Cambridge, and Waterloo and four rural townships of Wellesley, Woolwich, Wilmot, and North Dumfries (Figure4-1). The region is 1369 square kilometers in land area size and is the embodied home between new and old, urban and rural, technology and nature. The region is also a part of the "*Greater Golden Horseshoe*," a larger economic region in Ontario. Currently, the region has a population of 535,154 (2016 census) and is the fourth largest urban area in Ontario (Region Of Waterloo, 2014).

The Region of Waterloo is one of the fastest growing regions in Canada concerning population and GDP growth. It is also experiencing massive infrastructural growth due to the development of the technology sector and is under rapid transition from a rural to an increasingly urban system(Region Of Waterloo, 2014). The region is characterized by a mix of both urban facilities and small-town qualities and is a home for two leading universities in Canada- University of Waterloo and Wilfrid Laurier University. It is also home to many high-tech companies such as Google and Blackberry, and a large concentration of technology- startups.



*Figure 3-1 Map of the Region of Waterloo, Source: Region of Waterloo*

The region is placed between the Great Lakes and has a productive agricultural sector that contributes to the growth of the strong regional economy. Being post-industrial cities, Waterloo, Kitchener and Cambridge have a traditional city center which is surrounded by suburbs, neighboring villages, farms and open space areas which retains a rural presence in the region (Historica Canada, 2017). The region has the best of both worlds as it has both the vibrancy of a city and is surrounded by farmlands. Even though the region experienced unprecedented growth after the World War II which made the cities flourish, the region always has a rural presence evident even to the present day.

### 3.2 Historical development of the region

In the early 1800s, Mennonites from Pennsylvania arrived at the land area around the Grand Riverbank and were the early settlers in the region of Waterloo after the tribes of Six Nations. Moreover, after the Mennonites, roughly 50000 Germans came from Europe to settle in Waterloo hence the region has a rich German heritage associated with it (Region of Waterloo,2017).

In the early 20<sup>th</sup> century, economic development in the region was due to the skills and businesses of the regional German population along with the location of Kitchener along the Grand Trunk Railway. The primary industries of the region were manufacturing, milling and agricultural. Also, Waterloo was concentrated by insurance companies which reinforced its growth. Later, the region became a hub for the automotive parts industry along with the furniture and leather industry. All the major automobile manufacturing companies got their supplies from the Region of Waterloo which boosted its economy thereby employing its residents. In the 1960s, many industrial parks were created in the region along the highway because of its direct access to Highway 401 (Historica Canada, 2017).

The general recession in the later part of the 20<sup>th</sup> century made many traditional industries to cease operations, but the presence of the two major universities in the region invited many high-tech companies, predominantly software, to make investments in the region. Over the course of the century, the regional economy that once hinged on the manufacturing sector is now predominantly service-based mirroring the development of the region(Historica Canada, 2017).

The university of Waterloo and Wilfrid Laurier University, the then Waterloo Lutheran University, saw rapid expansion and growth in the later part of the century and changed the face of the region from an industrial to an educational region. The region later attained international recognition primarily because of the two world-class universities.

### 3.3 Regional governance

Post world war, the region experienced dramatic industrial growth, which caused significant local problems due to rapid immigration crisis and population explosion. Furthermore,

the massive growth in the cities has significantly challenged local governance. (McLaughlin & Jaeger, 2007)

The local government reform that took place in the late 1960s in Ontario paved the way for the creation of Regional Municipality of Waterloo in 1973. The regional municipality consisted of the union of two cities, Kitchener (then Berlin) and Waterloo, along with the creation of a new city of Cambridge which was the consolidation of Preston, Galt, Hespeler, and the surrounding townships.

The Regional municipality of Waterloo has a 16-member governing council that comprises of a Mayor in each of the seven cities and townships along with eight additional councilors and has a Regional Chair. The Regional Chair is directly elected by Waterloo residents, unlike most regional municipalities in Ontario.

#### 3.4 With growth comes issues

The Region of Waterloo has Ontario's fourth largest and Canada's tenth largest urban population. The population in the region is expected to grow to 729,000 by 2030 from 535,154 in 2016 which is a 36% increase from the current population level (Region Of Waterloo, 2014). (Figure 3-2) The diversity in population has also steadily increased over the years due to the region's proximity to Toronto, and its reputation as a technology hub is thereby attracting talents across the world to study and work in Waterloo. Even though population growth has its own benefits concerning the region's development, it also presents many challenges.

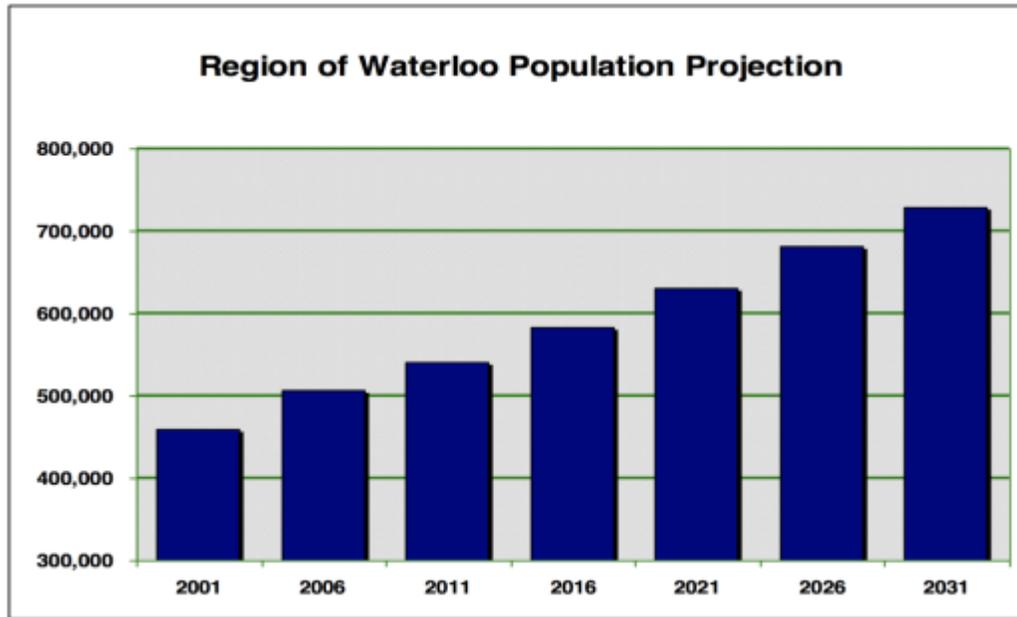


Figure 3-2 Projection of Region of Waterloo Population, Source: Statistics Canada

The region is witnessing significant commercial growth as well and is touted as one of Canada's smartest cities. The city has a dynamic and vibrant urban center in the middle of the Canadian Technology Triangle. All these factors have made steep infrastructural growth in the region along with fears of urban sprawl. Like many North American cities, the Region of Waterloo also has much of its growth happening in the suburban areas converting valuable farm lands for residential use. Furthermore, suburban development causes increased usage of personal vehicles, thereby increasing air pollution and GHG emissions (Climate Action WR, 2017). The regional municipality attended to concerns of a possible urban sprawl with the introduction of Light Rail Transit (LRT) in the region in 2011. The operation of Stage 1 of the system is expected by 2018 connecting Waterloo and Kitchener along the lines of Downtown Kitchener and Uptown Waterloo. Even though this project was initiated as a solution to the public transport issues, it was also intended to spur growth along the lines of LRT thereby increasing the growth density within the prime city areas.

Also, the GDP of the Region of Waterloo is one of the fastest growing regional economies in Canada. (Figure 3-3) The region's GDP is increasing at an exponential phase and is estimated to increase from 26 billion dollars in 2016 to 31 billion dollars by 2021 (WRCERG, 2016).

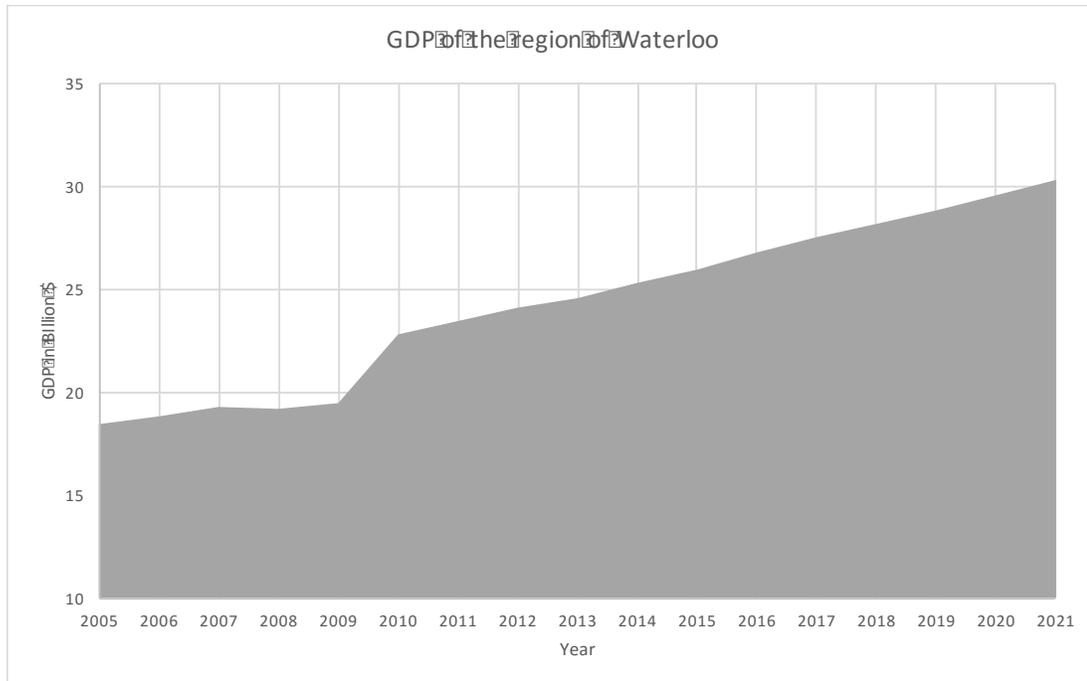


Figure 3-3 Projected GDP of the Region of Waterloo, Source: WRCERG, Region economy at a glance

To reach a balanced development of the region preserving the environment, a regional growth management strategy was designed by the municipality to protect and enhance the natural environment of the country side while building vibrant places in the cities to foster the regional economy.

While the region is facing growth in the technology sector, there is also a growing concern about the reduction of farms and farm area and the number of people willing to take up farming in the region. The 2011 census of agriculture for Waterloo region indicates that there was a 4% decline in the number of farms between 2006 and 2011, and a reduction of about 5000 acres during the same period (Statistics Canada, 2011).

The Region of Waterloo experiences a significant growth in the socio-economic development in recent times which is due to the growth of the technology sector. The region is trying its best to preserve and continue its identity as a unified region between rural and urban. All these factors along with few others have caused the region's resource use to soar, and concerns regarding future resource availability continue to be of paramount issue in the region.

For any growing region in the world, management of natural resources and land area is vital. Hence the need for this study to account for the flows of materials and energy in the region to account for its material and energy throughput in order to find and analyze the spatial dimension of these flows, and interpret their corresponding impact on developmental concerns.

## 4 METHODOLOGY AND DATA COLLECTION

### 4.1 Introduction

To investigate material flows in the region of Waterloo, the methodological guidelines and the framework of *Local study manual* by Singh et al. (2010) and the *Economy-wide material flow accounting* by Krausmann et al. (2015) have been consistently adopted for this research study.

In this study, to understand the analysis of the biomass flows in the region of Waterloo, derived indicators such as Domestic Extraction (DE), Domestic Material Consumption (DMC), imports and exports were used.

For the study of biomass, production, consumption, export, and import data were required for primary crops, crop residues, fodder crops and grasslands, wood, and hunting and gathering. Most of the production data (specifically for primary crops, fodder corn, and hay) used were from *Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA)*. The Balance of the data including consumption, disappearance, and import and export for all products were derived from different sources.

In MFA, the key yardstick for data validity is consistency. Hence, to have good quality data, it was made certain on the methods in this thesis that all data conform to the following conditions as per Krausmann et al. (2014):

- It was ensured that all data conform with the defined system boundary.
- The same unit of measurement was used for all data, and if the data sources report data in other units, they are converted accordingly using conversions to the same unit of measurement.
- The data collected for each pertinent flow was made free of double counts.
- All the data gathered is made comprehensive by using various estimation methods when there is no appropriate data available for the requirement to fill in data gaps.
- Data collected in this thesis adheres to the standard guidelines of *economy-wide material accounting* to maintain internal consistency and avoid extreme data quality issues.

## 4.2 System Boundary

When doing MFA, it is necessary to define the associated system boundaries at the beginning of the study to be consistent with MFA principles that follow the residence principle. The purpose of defining the system boundary between other socio-economic systems and the natural environment is to differentiate what stocks and flows belong to the system under study and what does not. (Refer to Figure 2-2 in Chapter 2).

The Political boundary of the region of Waterloo is defined and comprises of the three cities of Waterloo, Kitchener and Cambridge, and the townships of Woolwich, Willmot, Wesley and North Dumfries and was used as the system boundary for this study. The pragmatic consideration of choosing this scale is that the region of Waterloo is a CMA which has a tier structure for regional management and has legitimate political and economic control over the region. Data availability was another consideration for choosing this as the system boundary. The data was sourced from regional, provincial and other government institutions such as ClimateAction WR, *Statistics Canada* and *OMAFRA*. A well-defined systemic boundary allows us to distinguish between internal flows, i.e., material and energy flows extracted domestically within the system boundary viz a viz flows that comes outside the territory as trade. The two functional system boundaries of material flows used for this study were as follows:

1. The flow of biomass between the natural environment of the Region of Waterloo and the economy of the Region of Waterloo on both the input and output side concerning the society/nature boundary.
2. The flow of biomass between the societal system of the Region of Waterloo and other societal systems as to the society/society boundary, and it includes both imports and exports (Trade flows) to and from the Region of Waterloo.

## 4.3 Indicators

Having defined the system boundary, derived headline MFA indicators used and calculated in this study are defined in the following section from Eurostat (2001).

#### Domestic Extraction (DE)

Domestic Extraction refers to the quantity of materials that are extracted from the local environment which is used further as input for economic production. This indicator was used to measure the biomass (as fresh weight) that was extracted from the Region of Waterloo within its boundary.

#### Physical imports

Imports refer to the quantity of biomass commodities at various levels of processing from basic raw goods to processed ones that enter the system boundary of the Region of Waterloo and is measured as is weight.

#### Domestic Material Input (DMI)

Domestic Material Input refers to the amount of biomass throughput into the region of Waterloo required to maintain its metabolism. It is calculated by adding domestic extraction and imports of biomass together.

$$DMI = DE + Imports$$

#### Physical exports

Exports refer to the quantity of biomass commodities at various levels of processing from basic raw goods to processed ones that leave the system boundary of the Region of Waterloo and is measured as is weight.

#### Physical trade balance (PTB)

Physical trade balance refers to the physical dimension of biomass trade of the Region of Waterloo. This indicator is calculated by subtracting exports from imports. A positive PTB or a physical trade surplus signifies that the Region of Waterloo is a net importer of biomass, while a physical trade deficit or a negative PTB signifies that the region is a net exporter of biomass.

$$Physical\ trade\ balance\ (PTB) = Imports - Exports$$

#### Domestic Material Consumption (DMC)

Domestic Material Consumption refers to the absolute consumption of materials or biomass within the defined system boundary, i.e., the Region of Waterloo in this research. It also gives us an image of the metabolic rate of the definite consumption of materials in the society. It

is calculated by adding domestic extraction and imports and by subtracting exports. In other words, it is computed by subtracting exports from domestic material input.

$$DMC = DE + Imports - Exports$$

$$DMC = DMI - Exports$$

#### 4.4 Domestic Extraction of Biomass of the Region of Waterloo

Generally, MFA has data collected from various official statistics offices and national, international, provincial and regional databases and scientific papers and case studies. If the data is not available in official statistics, sometimes innovative methods are employed by researchers to calculate and make educated guesses to complete the study. The main data sources for MFA's are agricultural, forestry and fishery statistics, and databases such as FAO, IEA and Eurostat (Krausmann et al., 2015). In MFA, domestic extraction of biomass comprises all vegetable matter that is extracted by humans for their food and energetic purposes, and feeding their livestock, wood, fish capture and biomass of animals that are hunted and gathered. It is important to differentiate the primary and secondary production methods of biomass extraction.

Primary production consists of primary crops harvested, used crop residues, fodder crops including grazed biomass, wood, and biomass from hunting and gathering and fishing (explained more in detail in the next subsection). In other words, Primary production is equal to its domestic extraction (Krausmann et al., 2015; Singh et al., 2010). Therefore, in MFA, secondary production is not counted. That is, the biomass of livestock and its products such as milk, meat and eggs are not counted owing to the fact they are accounted in the analysis of stocks but not flows. Furthermore, another reason to not account for livestock and its products is to avoid double counting as the livestock takes primary production as their food (Krausmann et al., 2015).

##### 4.4.1 Primary Production

In lieu with the standard MFA conventions, biomass that was extracted from the domestic environment directly were accounted as primary production. Primary production is usually used as an indicator in MFA to account for domestic extraction of resources or biomass.

#### 4.4.1.1 Primary Crops

Primary crops are those crops cultivated from arable lands such as cereals, vegetables, pulses, nuts, roots and tubers, and fruits and the commercial feed crops and industrial crops that are used for personal, commercial and industrial purposes. Most of the extraction data of primary crops for the Region of Waterloo were obtained from *Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA)*. Although there are approximately more than 160 kinds of primary crops globally, the Region of Waterloo has only 24 primary crops that are produced in the region. These 24 crops were further grouped into subcategories according to their type (Table 4-1) following the *Local study manual* by Singh et al. (2010), and *Economy-wide material accounting* by Krausmann et al. (2015).

Cereal Crops	Pulses	Oil-bearing crops	Vegetables	Fruits	Other Crops
Winter Wheat, Spring Wheat, Mixed Grain, Grain Corn, Fodder Corn, Oats and Barley	White Bean and Coloured Bean	Soybean and Canola	Cabbage, Carrots, Dry Onions, Green and wax bean, Peppers, Potatoes, Sweetcorn, and Tomatoes	Apples and Strawberries	Coffee and tea

Table 4-1 Categorization of primary crops domestically extracted in the Region of Waterloo

Furthermore, all the primary crops data used were “as is weight” at harvest, as per MFA convention. Domestic extraction data of cereal crops, pulses, oil-bearing crops, vegetables and fruits for the Region of Waterloo has been taken from OMAFRA for the years 2006, 2011 and 2016 (OMAFRA, 2016). For better data collection and comparability, all the data has been converted to tons, from pounds and kg.

#### 4.4.1.2 Crop Residues

Usually, the harvest of primary crops is only a small portion of the overall amount of biomass that is being cultivated, and this leaves behind enormous amounts of residues. The crop residues comprise straw, stems and leaves(Krausmann et al., 2015). Although a significant portion of the crop residues is used as bedding material for livestock, only a small part of the crop residues is often subjected to further economic use by the local population(Krausmann et al., 2015). The economic applications of crop residues include livestock feeding, roofing and insulating material in construction, raw materials for industries, and energy production(Singh et al., 2010). Of all the crop residues that are left from the primary harvest, only the used fraction is accounted for as Domestic Extraction, and the remaining residues are often left on the field to be burnt or to be plowed into the soil or just discarded and not accounted for as DE(Krausmann et al., 2015). Also, the byproducts from the primary crops processing were not included in this accounting to avoid double counting as the primary crop consumption is accounted as per its use in MFA and included in DMC of Primary crops(Krausmann et al., 2015).

Since the regional statistical database from OMAFRA does not report data on the used crop residues or crop residues harvested required for the compilation of MFA for the region of Waterloo, they were estimated. Thus, the available quantity of crop residues and the used fraction of crop residues were estimated using the procedure in *EW material accounting guide* by Krausmann et al. (2015). The amount of available crop residues was first estimated using harvest factors of the particular crop and particular region taken from *EW Material accounting* by Krausmann et al. (2015).

$$\text{Available crop residues [t (as is weight)]} = \text{primary crop harvest [t (as is weight)]} * \text{harvest factor} \quad \text{-----}(1)$$

Primary Crop	Harvest factor
Cereals	1.2
Pulses	1.0
Soybeans	1.2

Table 4-2 Harvest factor for crop residues from primary crops, Standard values for harvest factors for North America Oceania (Region of Waterloo) Source: ( Krausmann et al., 2015, p. 28)

Since MFA requires crops and crop residues to be reported in “as is weight”, i.e., with the moisture content at harvest, it was ensured that all the crop residues have a moisture content of roughly 15 % (as is weight).

Since only a portion of the available crop residues are subjected to further economic use, used crop residues were estimated using <sup>1</sup>recovery rates based on Krausmann et al. (2015). Recovery rates were applied to specific crops belonging to specific regions, which in our case is North America to estimate the crop residues used using equation 2:

$$\text{Used crop-residues [t (as is weight)]} = \text{available crop-residues [t (as is weight)]} * \text{recovery rate} \quad \text{-----}(2)$$

Primary crop	Recovery rate
Cereals	0.7
Pulses	0.7
Soybeans	0.7

Table 4-3 Recovery rate for crop residues from primary crops (Source: Krausmann et al., 2015, p. 28)

#### 4.4.1.3 Fodder Crops and grazed biomass

This category comprise biomass that was grown exclusively for livestock feed such as fodder crops, roughage biomass harvested from natural grassland or meadows and biomass grazed by domestic animals (livestock) directly. Fodder crops include leguminous fodder crops such as alfalfa and clover, fodder beat crops such as barley and maize and soybeans are used as roughage (Krausmann et al., 2015; Singh et al., 2010). Primary crops and commercial feed crops which are edible for food production for humans or raw materials for industry are not included in this category. The data for domestic extraction of fodder crops and hay were taken from the regional statistics database from OMAFRA (OMAFRA, 2016). All the biomass flows are to be accounted for in-air dry weight (moisture content of 15%) according to MFA conventions. For

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<sup>1</sup> In a Canadian context, Recovery rate varies from 20-30% and it varies from area to area, the recovery rate value used in this research is only a theoretical value from krausmann et al.,(2015)

some categories, standardization of moisture content became necessary and were adjusted accordingly using the following equations from Krausmann et al. (2015)

Fodder crops that were reported in fresh weight, i.e., at a moisture content of 80% were converted to dry weight by applying the following equations 3 and 4:

$$Factor_{mc} = (1-mc_{fresh}) / (1-mc_{air\ dry}) = 0.2 / 0.85 = 0.235 \quad \text{-----}(3)$$

$$Air\ dry\ weight\ (at\ 15\% \ mc) = fresh\ weight\ (at\ 80\% \ mc) * Factor_{mc} \quad \text{-----}(4)$$

Domestic extraction data for fodder crops harvested from grassland and grazed biomass were not reported in the regional statistics database for the Region of Waterloo and were therefore estimated using estimation procedures from *EW material wide accounting guide*. (2015) A demand-driven approach was used to assess biomass harvested from grassland and grazed biomass to identify the grazing gap. Since livestock numbers and roughage requirements for each animal were reported in agricultural statistics and national feed balances (Statistics Canada, 2003), these data were used to calculate the demand for grazed biomass and biomass harvested from grasslands. Subsequently, the biomass harvested from grasslands were calculated using the number of animals (OMAFRA, 2016) and the feed from pasture required by those animals per year using data from *Canadian National feed balance study* (Statistics Canada, 2003) using equation 5

$$Biomass\ harvested\ from\ grassland = livestock\ [number] * annual\ feed\ intake\ from\ pastures\ [t\ per\ head\ and\ year] \quad \text{-----}(5)$$

Grazed biomass harvest was first estimated by calculating the total roughage requirement for grazing animals using the following equation. Data from OMAFRA for the number of livestock animals and values for average roughage intake by animals in industrial livestock system were obtained from Krausmann et al. (2015) (Krausmann et al., 2015; OMAFRA, 2016) It is important to note that the values indicate roughages at air dry weight. The coefficient values which were used to calculate the roughage requirements have already been taken into account, the fraction

of market feed and crop residues for all species in average. Roughage requirement is calculated using equation 6

$$\text{Roughage requirement} = \text{livestock [number]} * \text{annual feed intake [t per head and year]} \text{---(6)}$$

Livestock	Annual intake of Industrial livestock system (t/head and year) at Air dry weight
Cattle (and Buffalo)	5.5
Sheep and Goats	0.64

Table 4-4 Typical roughage intake per year by grazing animals for Industrial livestock system, source: Krausmann et al., 2015, p. 31)

Forage uptake includes fodder crops, grazed biomass, hay or silage and biomass harvest from grassland. Hence, to estimate the amount of grazed biomass, the quantity of biomass from fodder crops, hay and grassland are reduced from total roughage requirements using equation 7 at air dry weight:

$$\text{Demand for grazed biomass} = \text{roughage requirement [t at 15\% mc]} - \text{fodder crops [t at 15\% mc]} \text{-----(7)}$$

#### 4.4.1.4 Wood

Wood is used for various purposes such as construction, manufacturing, heating and cooking. This category includes fuelwood and industrial wood, and wood harvested from forests, short rotation plants and agricultural lands. Normally, the extraction of wood is reported in forestry statistics, and national wood balances provide complete data on wood harvested from forest and non-forest lands (Krausmann et al., 2015; Singh et al., 2010). However, some approximations have been made since exact data for the Region of Waterloo was not available.

Firstly, the area of forests was found to be 20,040 hectares in total out of which only 435 hectares is publicly owned, and the remaining are privately owned from. These data are obtained from [Albert Hovingh], the principal planner of the Region of Waterloo through personal communication. Also, the area of forests was double checked using GIS with the help of the University of Waterloo's Geospatial Centre which was found to be 21,042 hectares using the data

from *Agri-foods Canada* (Agriculture and AgriFoods Canada, 2014). Since forestry data was not readily available, for the purpose of approximation, the province of Ontario's data was used to find extraction and consumption of wood. The *National forestry database* and *Natural resources Canada* served as the foundation to determine the overall harvested area and wood production in the province.

The total quantity of industrial round wood, pulpwood, logs and bolts, fuelwood and firewood harvested in Ontario from private, federal and crown land were calculated from the National Forestry Database (Natural Resources Canada, 2017). Since wood data was often reported in volume and not in weight, and as per MFA conventions, the quantity of wood biomass in volume was converted to tons at 15% moisture content to standardize using the average density factor of Canadian coniferous and non-coniferous wood. The average density factor for Canada was derived to be 0.57 from the percentage of coniferous and non-coniferous forests in Canada that was derived from *Natural Resources Canada* and *Economy wide material flow accounting* (Krausmann et al., 2015; Natural Resources Canada, 2016). And then using these factors and approximating the data from the province of Ontario to the Region of Waterloo it was calculated that the region has 3.3, 2.1 and 2 tons of wood harvested during the years 2006, 2011 and 2016 respectively.

The domestic extraction of wood was considered very negligible as it does not account to even 1% of other biomass categories. Therefore, the category of wood was found to be negligible and was not used further in this study.

#### 4.4.1.5 Fishing

According to MFA conventions, fish capture including fishing, and plants and animals extracted from both fresh and sea water are accounted under this category. Even though the Region of Waterloo has three major fishing areas, namely Conestoga Lake, Shade's Mill and Laurel Creek, the total area of water bodies in the region was only 1065 hectares (Grandriver, 2016). But the calculated extraction quantities were very small. Hence, it was considered to be of minor significance and was also removed from Material flow accounting of this study. Also, there was

extremely low amount of fish extraction in the region since fishing is done only for recreational purposes in the region and there is not much coverage of water bodies in the region.

#### 4.5 Biomass use in the Region of Waterloo

DMC is usually calculated by adding DE and imports, followed by the subtraction of exports from it. However, since reliable imports and exports data were not available from official statistics and other sources, Imports and Exports were back calculated by calculating DMC first. As per the Local Studies manual by Singh et al. (2010), Domestic Material Consumption (DMC) or the use of Biomass can be categorized into food, feed, energy and other uses. Since the biomass can be exclusively counted under one of the above-mentioned categories and can further be categorized accordingly. Summarizing all the biomass in the region that was categorized based on their use, also provided is the DMC of the region. The purpose of categorizing biomass was to help us understand where the biomass goes into the system. For example, crop residues and fodder crops are mostly included in the feed use category. However, crop residues can also be used for livestock bedding purposes while primary crops such as cereals can go into both food and feed uses. The feed use in the “others category” includes biomass that was used as industrial or commercial raw material, material for construction and losses and wastes.

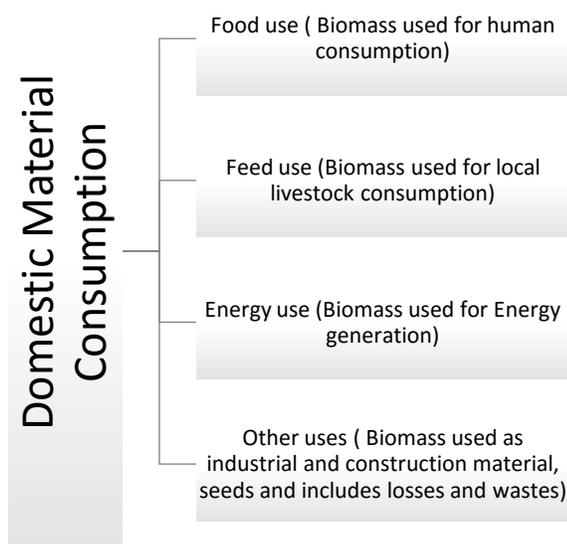


Figure 4-1 Domestic Material Consumption of Biomass based on its uses

4.5.1 Primary crops

The domestic consumption data for primary crops were not available directly from statistical publications of the regional or provincial governments. Therefore, DMC of primary crops was estimated by summarizing all the various categories of biomass use. Moreover, due to unavailability of data for energy biomass use and other biomass use as industrial raw materials, biomass used as food and feed that were consumed in the region were estimated using the official statistical data from the local regional and provincial governments. Since food and feed use were the larger flows in the region, biomass used for energy and other purposes that were negligible were neglected. Firstly, food consumption per capita (Table 4-5) was calculated using per capita domestic food consumption in the region obtained from *Canadian food trends to 2020 report* prepared by Agri-food Canada (Agriculture and Agri-Food Canada, 2005). And then the population of the region (Table 4-6) was obtained from *Statistics Canada* (Statistics Canada, 2016). Using this method, food consumption for all the primary crops were then calculated using the equation 8. Since the *Canadian food trends 2020 report* accounts for all the types of food consumed by the population, all food types were categorized based on their type. For example, fresh, frozen, dried and canned fruits, and fruit juices were categorized into fruits category. Similarly, barley, oats, breakfast cereal and rice<sup>2</sup> were included under Cereals category.

$$DMC_{food} \text{ (in tons)} = DMC_{food, i,c} * \text{population}$$

------(8)

	2006	2010	2016
<b>Meat</b>	47.48	48.41	49.24
<b>Fish</b>	7.41	8.04	8.73
<b>Diary</b>	83.29	80.85	80.18
<b>Eggs</b>	13.04	13.49	12.82
<b>Fruits</b>	68.32	69.15	69.82
<b>Vegetables</b>	100.79	102.35	103.23
<b>Cereals</b>	67.48	68.14	68.98
<b>Pulses</b>	9.02	8.97	8.84

<b>Sugar crops</b>	33.26	36.14	38.82
<b>Oil</b>	37.86	41.99	45.88
<b>Beverages</b>	186.11	192.65	197.19
<b>Coffee and tea</b>	163.22	173.93	186.10

Table 4-5 Per capita consumption in kg/cap Source: (Agriculture and Agri-Food Canada, 2010:47)

	2006	2010	2016
<b>Population of the Region of Waterloo</b>	478121	507096	535154

Table 4-6 Population of the Region of Waterloo Source: Statistics Canada

The feed uses of primary crops were further estimated using per capita animal feed requirement of Ontario (Table 4-7), which was in turn obtained from *the livestock feed requirements study* by Statistics Canada and the livestock number (Table 4-8) in the region were obtained from OMAFRA (OMAFRA, 2016; Statistics Canada, 2003). And then feed use is calculated using the equation 9. This method was similarly employed for all the primary crop categories except fruits and vegetables, which are exclusively used only for human consumption.

$$DMC_{feed} \text{ (in tons)} = DMC_{feed, i, c} * \text{Number of livestock}_m$$

------(9)

	2006	2011	2016
<b>Cereals</b>	97185.08	117250.32	147127.15
<b>Nuts and pulses</b>	281.06	214.08	437.88
<b>Oil bearing crops</b>	21233.63	25954.99	31165.66
<b>Dry hay (100% dry)</b>	55358.58	60210.03	71307.83
<b>Silage</b>	104469.84	103882.89	124352.29

<b>Pasture (Grazed biomass)</b>	53206.40	49948.28	80697.60
<b>Other roughages</b>	1144.75	1100.77	1419.80

Table 4-7 Feed Consumption per head Source:(Statistics Canada, 2002)

	2006	2011	2016
<b>Dairy Cattle</b>	42523	46867	45647
<b>Beef cattle</b>	47452	41966	77513
<b>Sheeps and lambs</b>	4151	9659	21359
<b>Hogs</b>	142531	87659	91255

Table 4-8 Number of animals in the Region of Waterloo Source:OMAFRA

4.5.2 Crop Residues

The regional agricultural statistics database does not cover data on domestic consumption of crop residues and therefore were estimated using Ontario level data. According to the report, *biomass crop residues availability for bioprocessing in Ontario* prepared for the Ontario Federation of Agriculture (Oo & Lalonde, 2012) only 3.28% of crop residues demand is for animal feeding, and 96.72% of crop residues were in demand for other purposes such as cattle and horse bedding, ginseng, mushroom and strawberry production (Oo & Lalonde, 2012). Because of the absence of availability of data for the Region of Waterloo crop residue consumption, it was assumed that all the available crop residues are consumed in the region. Also, it was observed that in industrialized economies there is usually a low demand of crop residues for feed consumption, since the farmers produce more fodder crops for animal feed (Krausmann et al., 2015).

4.5.3 Fodder crops and grazed biomass

The DMC of this category of biomass was calculated by determining the *feed use* of fodder crops and grazed biomass. The per animal feed requirement was determined *using the livestock feed requirement study by Statistics Canada* (Statistics Canada, 2003). The data pertaining to the

number of livestock such as beef cattle, dairy cows, calves, beef heifers, steers, sheep and lambs and hogs was obtained from OMAFRA (OMAFRA, 2016). DMC of fodder crops and grazed biomass were calculated using the data from the above mentioned resources using equation 10. The fodder crops were then adjusted for moisture content to 15% standardized MC.

$$\text{Feed use of fodder crops per year} = \text{livestock [number]} * \text{annual feed intake of fodder crops per head of livestock [t per head and year]} \text{-----}(10)$$

#### 4.5.4 Animal Products

Animal products refer to dairy, meat, eggs and fish that are consumed by the populace of the Region of Waterloo. DMC of animal products were calculated only to determine Imports and exports data for this study. The domestic consumption of these animal products was calculated using the per capita food disappearance data of animal products from *Canadian food trends to 2020 report*(Agriculture and Agri-Food Canada, 2005) and the population data from *Statistics Canada*(Statistics Canada, 2016) using the same methodology as food consumption of primary crops. This category was accounted for in both biomass and energy flow accounting as the animal products are used as food energy by humans for human nutrition.

#### 4.5.5 Others

The Others category refers to alcoholic beverages that are being consumed by the Region of Waterloo's populace. DMC of this category was also calculated only to determine Imports and exports data for this study. The domestic consumption of alcoholic beverages was also calculated from per capita food disappearance data from the *Canadian food trends to 2020 report* due to lack of availability of primary data sources (Agriculture and Agri-Food Canada, 2005). This category was also included in the EFA of the Region of Waterloo as alcoholic beverages, and is being considered as human nutritional energy.

#### 4.6 Physical Trade of Biomass in the Region of Waterloo

Physical trade of biomass includes both imports and exports of biomass in the Region of Waterloo. Imports and exports data were not available from the official sources of regional or provincial governments. Since both the DE and DMC of biomass were calculated previously,

Imports and Exports of biomass were back calculated from that data. If there was more production (DE) of biomass of a certain category, it was assumed that those quantity of biomass were exported from the region. If the DMC of biomass of a particular category was higher, it was logically assumed to be imported into the region. This method was used to achieve a certain degree of reliability to account for the biomass flows of the region due to the insufficient data from reliable sources. Calculating imports and exports data from DE and DMC was one of the huge assumptions made in this research to fill in the data gaps.

#### 4.7 QUANTIFICATION OF ENERGY FLOW IN THE REGION

The energetic metabolism of a society i.e. the energy throughput required for a society to reproduce and maintain itself can be quantified with the help of the operationalizing tool of Energy Flow Analysis (Haberl et al., 2008). In conventional energy balances and statistics, only energy carriers of technical energy are accounted for e.g. Steam engines, production and use of electricity or heat, combustion in furnaces, etc. and it neglects biomass(Haberl, 2006). Biomass is an important energy carrier as it is used for human nutrition and animal nutrition and also as raw material(Haberl, 2006). However, unlike Conventional energy balances, EFA accounts biomass energy carriers-human nutritional energy(food energy) and animal nutritional energy (feed energy)as both are inputs of energy into the socio-economic system(Haberl, 2006). The EFA follows the same logic as MFA conventions and acts within the same system boundary defined for MFA. The quantification of technical energy flows was carried through the compilation of data from the *Climate Action Waterloo region* report (Climate Action WR, 2013) which estimates GHG emissions and fossil fuel use in the region. Since there was no domestic production of technical energy in the region, almost all of the technical energy consumed in the region was imported from Ontario(IESO, 2010, 2016). *The climate action Waterloo region* report on GHG emissions provided the data on the consumption of electricity, Natural Gas, Fuel Oil, Diesel, Propane and Gasoline used for residential, commercial and industrial purposes for the Region of Waterloo (Climate Action WR, 2013). According to the conventions of MEFA, the energy data was standardized to Gigajoules from other units to ensure data consistency. The energy data of fossil fuels have been converted to Gigajoules from other units using the Gross Calorific energy density

factors (Table 4-5) from the IEA *Energy Statistics manual* (IEA, 2004; World Nuclear Association, 2016).

Fuel Energy Type	Gross Calorific energy density factor
Natural gas	0.038 GJ/m <sup>3</sup>
Fuel Oil	0.0306 GJ/L
Diesel	0.038 GJ/L
Propane	0.0255 GJ/L
Gasoline	0.034 GJ/L

Table 4-9 Gross calorific energy density factor for all fuel energy type (Source: IEA Statistics manual, 2004)

It was learnt that there is no domestic production of electricity within the system boundary, and the electricity consumed in the region was 100% imported from Ontario (Climate Action WR, 2013). The energy split-up or mix of electricity for the Region of Waterloo was shown in **Error! Reference source not found.**, Ontario electricity mix was used for this purpose since all the electricity in the region of Waterloo was imported from the province of Ontario (IESO, 2010, 2016).

Energy consumed from solar residentially and commercially in the Region of Waterloo was not available in official statistics and could not be determined unless a door-to-door survey was carried out. Hence, solar energy consumption was considered negligible and not included. As mentioned earlier, wood fuel in the region was also deemed insignificant and omitted from calculations due to the low amount of wood consumption in the region. Both solar and wood consumption in the region was omitted from calculations as they represented a non-significant percentage of the overall energy consumption.

Energy type	2010	2016
Nuclear	55%	61%
Hydro	20.4%	24%
Coal	8.3%	0%
Gas	13.6%	9%
Wind	1.9%	6%

Other (Solar)	0.8%	<1%
---------------	------	-----

Table 4-10 Ontario electricity mix (Source: IESO, 2010,2016)

Since there was no production of technical energy in the region, it is assumed logically that there were no exports of technical energy from the region. The human nutritional energy (food energy) and animal nutritional energy (feed energy) are estimated using the data previously calculated from MFA. The domestic consumption, imports and exports of biomass already calculated in the MFA were divided based on its use as food and feed and were standardized to 15% moisture content as per MEFA methodology to find the food and feed energy flows of the Region of Waterloo(Krausmann et al., 2015). The standardized biomass data was converted to Gigajoules to convert the biomass quantity in weight to determine its energy content. The Gross calorific value-GCV (energy content) and moisture content of all the biomass categories were taken from USDA(2016) and Gierlinger et al.,(2012) and are shown in Table 4-11

GCVs were used to calculate the energy content instead of Net calorific values (NCV) because NCV is a lower heating value and does not include the latent heat of water vapor of a fuel while the GCV is a higher heating value that includes the latent heat of water vapor during combustion of a fuel(Haberl, 2001; IEA, 2004).

<b>Biomass Category</b>	<b>Moisture Content</b>	<b>Energy content (GJ/ ton)</b>
Cereals	14%	18.3
Roots, tubers	78%	16.3
Sugar crops	80%	16.0
Pulses and nuts	10%	20.0
Nuts	4%	25.0
Oil bearing crops	10%	25.0
Vegetables	89%	18.5
Fruits	85%	20.0
Fibers	10%	19.5

Other crops (Coffee and Tea)	15%	1.2
Straw and other crop residues	15%	18.0
Fodder crops and hay	15%	18.5
Biomass harvested from grassland and grazed biomass	15%	17.5
Dairy	87%	25.0
Meat	50%	22.0
Eggs	66%	30.0
Fish	50%	22.0
Beverages	85%	9.0

*Table 4-11 Moisture and Energy Content of Biomass, Source: (Gierlinger & Krausmann, 2012; USDA, 2016))*

To calculate the human nutritional energy domestically consumed(DEC), DMC of primary crops, animal products and other products in Gigajoules were summarized. And to find the Feed nutritional energy domestically consumed, DMC of fodder crops and crop residues in Gigajoules were summarized. Similarly, DE, import and export values of human and feed nutritional energies were calculated. Using the data calculated using the methods described above, energy use per-capita and share of renewables and non-renewables were also determined.

## 5 RESULTS

In this chapter, primary results of the MEFA of the Region of Waterloo derived from the methods and indicators mentioned in the previous chapter is presented. Since biomass flows have been calculated for three points in time 2006, 2011 and 2016 and energy flows for two points in time 2011 and 2016, in each section of this chapter the results of these years will be compared, examined and presented using the standard MEFA Indicators to understand the region's resource use and usage patterns.

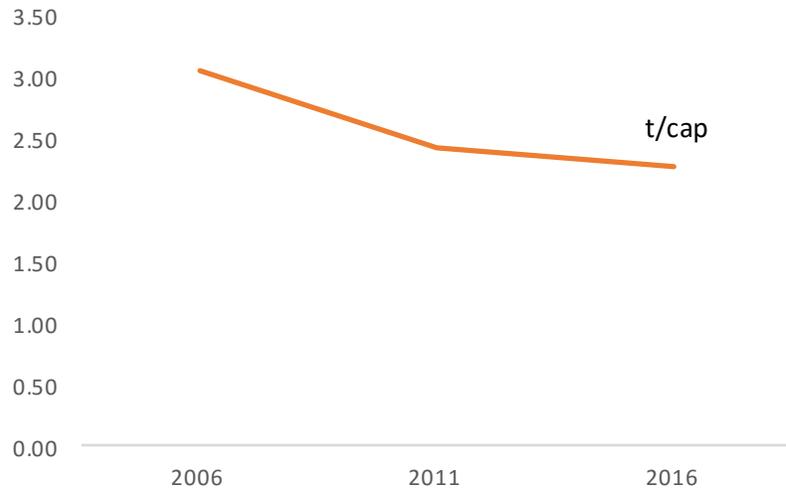
### 5.1 Domestic Extraction of Biomass (DE)

Domestic extraction of biomass indicates the quantity of all biomass in “as fresh weight” extracted from the local environment in the Region of Waterloo. DE of biomass in the Region of Waterloo decreased from 1.45 Mt to 1.22 Mt from 2006 to 2011, a 15.8% reduction, but there was little change, 1.22 Mt to 1.21 Mt, a decrease by 0.8% from 2011 to 2016. (Figure 5-1)



*Figure 5-1 - Domestic Extraction of biomass in the Region of Waterloo in absolute weight*

The per capita DE shows a similar trend decreasing from 3.05 tons/cap in 2006 to 2.42 tons/cap in 2011, a 20.6% reduction then decreased further 4% from 2.42 t/cap to 2.28 t/cap during 2011 to 2016. The reduction was greater on a per capita basis, because the population grew by 6% between 2006 and 2011 and 5.5% between 2011 and 2016.



*Figure 5-2 - Domestic Extraction of biomass in the Region of Waterloo in per capita units*

Cereals dominate the DE of primary crops in both absolute weight and per capita units. And there was a likely correlation between the pattern of DE cereals and DE of primary crops. Also, it can be noted that the primary share of primary crops extraction was from cereals which amounted for 93%, 92% and 91.1% of DE of primary crops during 2006, 2011 and 2016 respectively. Looking further in the subcategory of cereals, fodder corn and winter wheat constituted the majority of cereals extraction within the region. Fodder corn which is used as animal feed has implications on the region's food system, as it affects the production of food crops within the region.

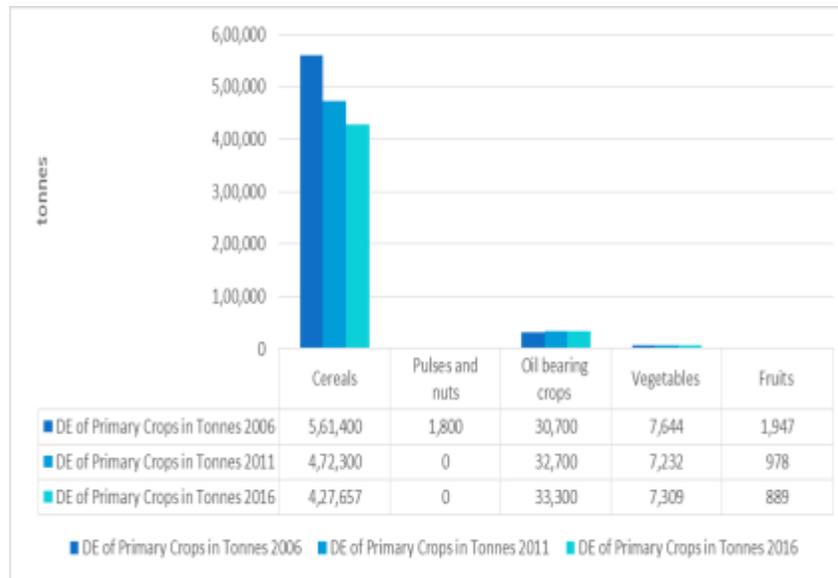


Figure 5-3 – Domestic Extraction of Primary Crops in absolute weight in Region of Waterloo

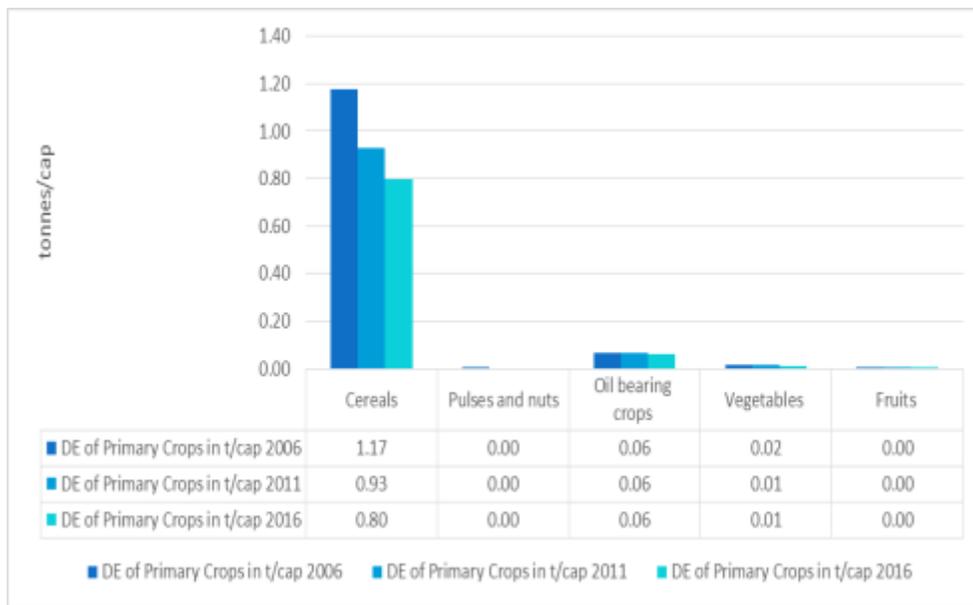


Figure 5-4 – Domestic Extraction of Primary Crops in per capita units in Region of Waterloo

Primary crops serve two main purposes - as food for humans and as feed to the livestock. So, based on its usage DE of primary crops had been further divided to gain a comprehensive understanding of the primary crops extraction and consumption in the Region of Waterloo. Figure 5-5 shows that 80- 82% of primary crops domestically extracted in the ROW was for the

purpose of feeding livestock and DE of feed primary crops was almost three to four times the DE of food primary crops. From Figure 5-5 it was also apparent that DE of both food and feed primary crops have reduced over the years.

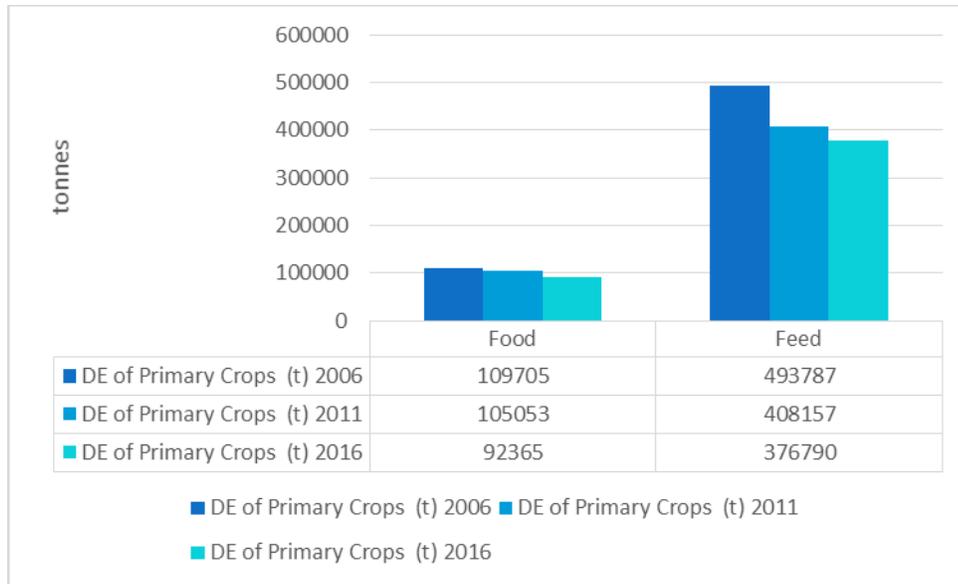


Figure 5-5 – Pattern of Domestic Extraction of food and feed primary crops in Region of Waterloo

## 5.2 Imports

Imports denotes the quantity of biomass imported into the Region of Waterloo from regions outside the system boundary and gives insights on the region’s trade dependency. Imports of biomass in the Region of Waterloo increased from 0.39Mt to 0.43Mt from 2006 to 2011 and increased further from 0.43Mt to 0.49Mt, from 2011 to 2016 (Figure 5-6).

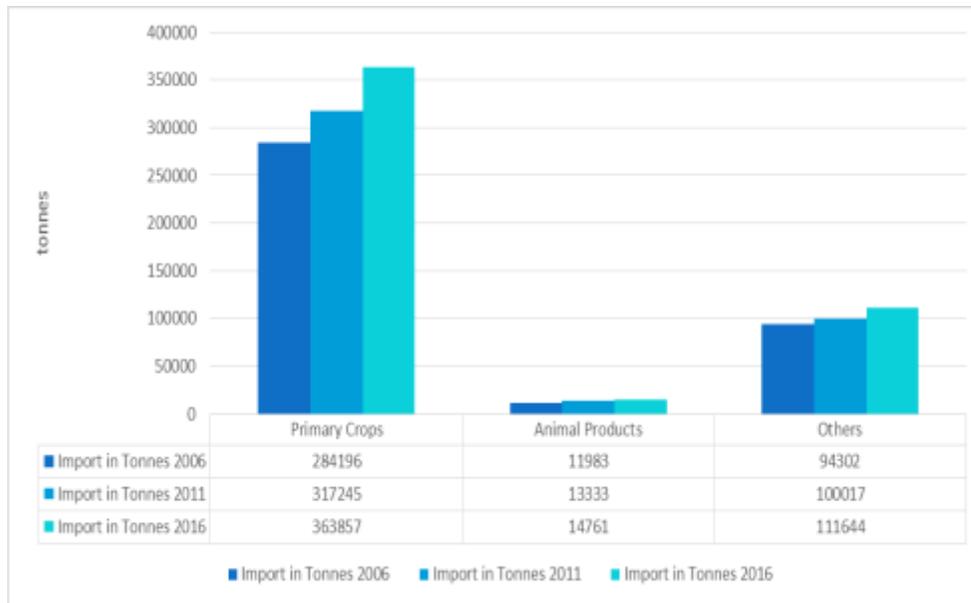


Figure 5-6 Import of Biomass into the Region of Waterloo in absolute weight

The per capita imports also show a similar trend, increasing from 0.82t/cap in 2006 to 0.85t/cap in 2011 and it increased further from 0.85t/cap in 2011 to 0.92 t/cap in 2016 (Figure 5-7). This points out the region’s high dependency on trade to meet its population’s requirements and there is not enough biomass production in the region.

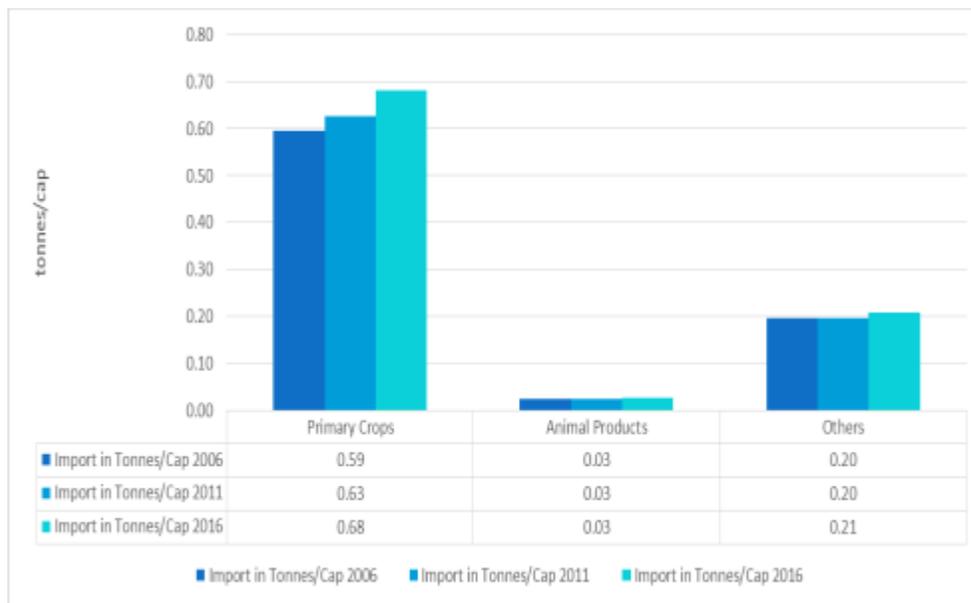


Figure 5-7 Imports of biomass into the Region of Waterloo in t/cap/year

Primary crops were the most imported crop category over the observed period and it increased from 0.28Mt in 2006 to 0.36Mt in 2016(Figure 5-6). Per capita Imports of primary crops also shows a similar trend increasing from 0.59t/cap in 2006 to 0.63t/cap in 2011 and then increased further from 0.63 t/cap to 0.68t/cap (Figure 5-7). Primary crops contribute to the largest composition of biomass imported into the region from 73% in 2006 to 74% in 2011 and to 74.2% in 2016 which is relatively more than the sum of imports of other two crops category. The reason for this observed trend is because of the increase in the population of the region of Waterloo along with their diversity during the similar observed period of 2006 to 2016.

Primary crops were imported highly into the region because there was only little amount of production of food primary crops in the region compared to feed crops and also because of the fact that ROW’s climate and soil conditions does not favor cultivation of many primary crops like rice, tropical fruits. Etc.(Desjardins, MacRae, & Schumilas, 2010).

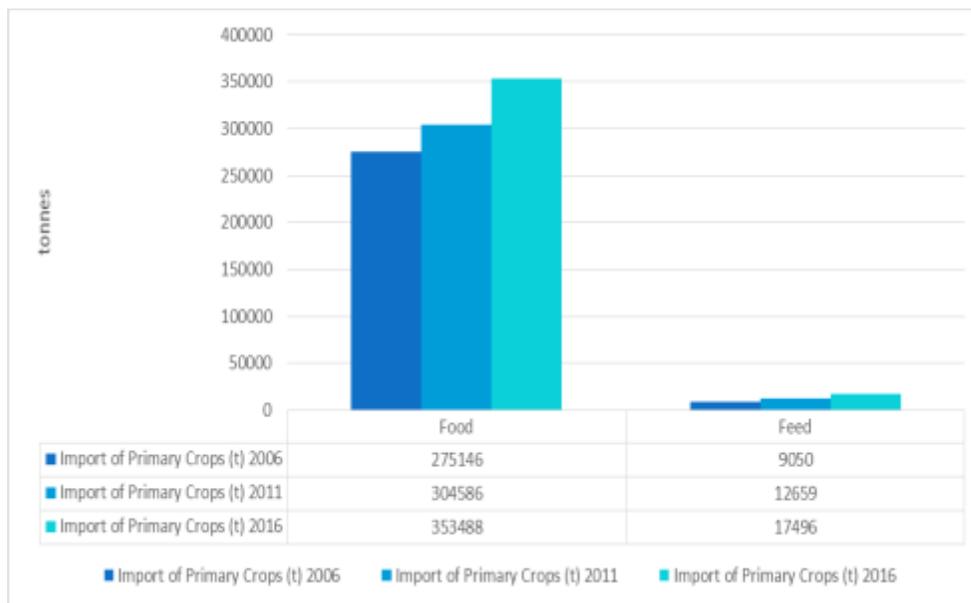


Figure 5-8 – Import of Food and Feed Primary Crops into the Region of Waterloo in absolute weight

Since, Primary crops were the highest imported biomass category they were further analyzed. Figure 5-8 shows the import of primary crops based on its use- food use and feed use. Imports of food primary crops increased over the years from 0.27Mt in 2006 to 0.35 Mt in 2016. Even

though, imports of feed primary crops are increasing over the years, imports of feed crops are 20 to 30 times smaller than the imports of food primary crops.

These observed import trends indirectly denote and signifies the over reliance of the Region of Waterloo s food system on outside markets to meet its need especially for food. Even though more imports mean less extraction from the local environment which in turn reduces the environmental pressure on the local system it also means transferring the externalities of environmental burden from the local system to another outside system for its survival. Since this is not a viable or sustainable option, the Region of Waterloo have to increase its local production of food crops to meet the requirements of the local population and survive independently while increasing its resilience in the face of extreme weather and climate events not depending too much on outside systems.

### 5.3 Domestic Material Input (DMI)

Domestic material input (DMI) indicates the sum of quantity of biomass extracted from the region of Waterloo and the quantity of biomass imported into the region of waterloo. Analysis of DMI shows that Primary crops had the maximum role in determining the pattern of DMI. DMI of biomass in absolute weight have decreased 10% from 1.8 Mt in 2006 to 1.65 Mt in 2011 while DMI of primary crops have also reduced 6.45% from 0.89 Mt in 2006 to 0.83 Mt in 2011(Figure 5-9). Also during 2011 to 2016 DMI of biomass has increased 3% from 1.65 Mt to 1.70 Mt while DMI of primary crops have increased 0.3% from 0.830Mt to 0.8330Mt in absolute weight (Figure 5-9).

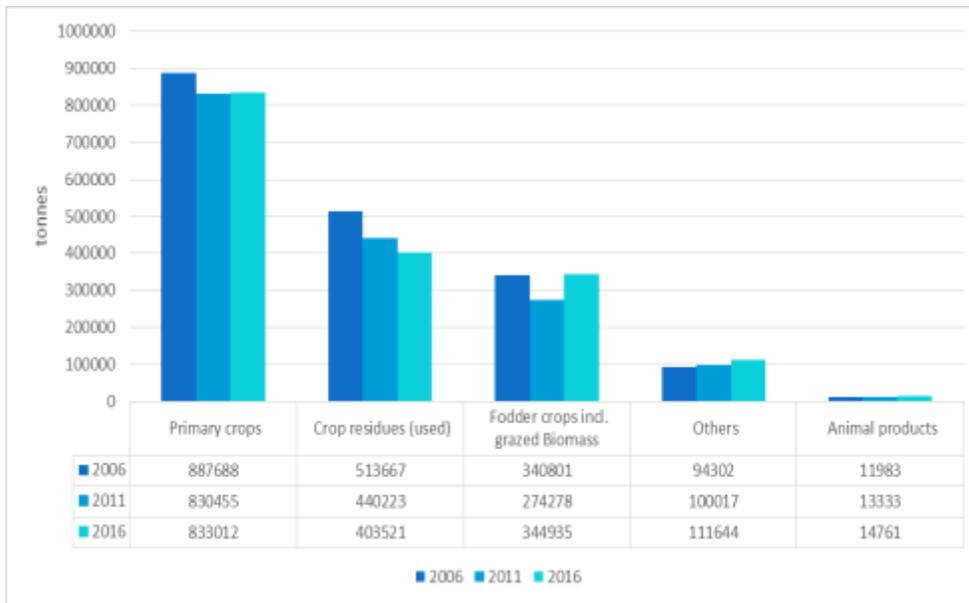


Figure 5-9 – Domestic Material Input of biomass in Region of Waterloo in absolute weight

Similar trends can be seen in per capita DMI as well, DMI decreases from 3.86 t/cap to 3.19 t/cap between 2006 and 2016 while DMI per capita of primary crops also decreases from 1.86 t/cap to 1.56t/cap (Figure 5-10).

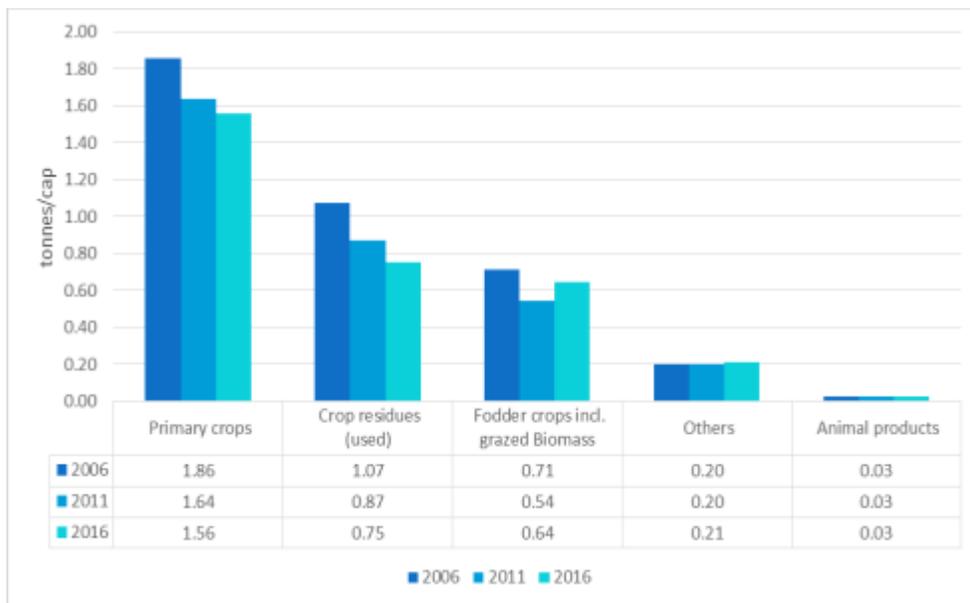


Figure 5-10 – Domestic Material Input of biomass in the Region of Waterloo in per capita units

Figure 5-11 shows the DMI of primary crops based on its use- food and feed use, food primary crops have high DMI while feed primary crops have low DMI. Food primary crops have the highest DMI because food primary crops are needed the most in the region for domestic consumption compared to feed primary crops.

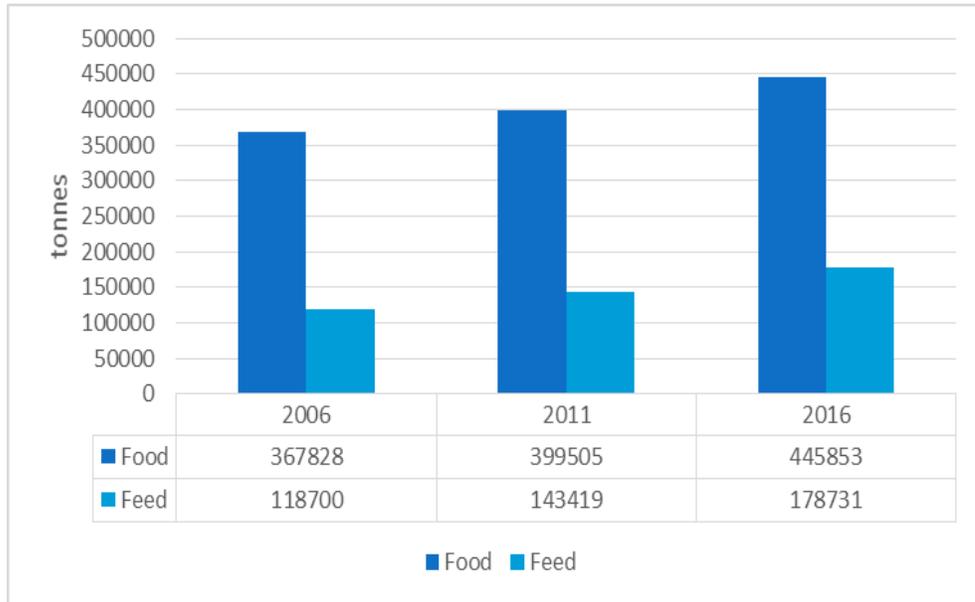


Figure 5-11 – Domestic Material Input of food and feed Primary crops in the Region of Waterloo in absolute weight

#### 5.4 Exports

Exports indicates the quantity of biomass exported from the region of Waterloo to other systems beyond the system boundary. Exports of biomass in the Region of Waterloo decreased from 0.4 Mt in 2006 to 0.3 Mt in 2011 and decreased further from 0.3Mt to 0.22Mt, from 2011 to 2016 and the per capita exports of biomass have also reduced from 1.03 t/cap in 2006 to 0.43 t/cap in 2016 (Figure 5-12).

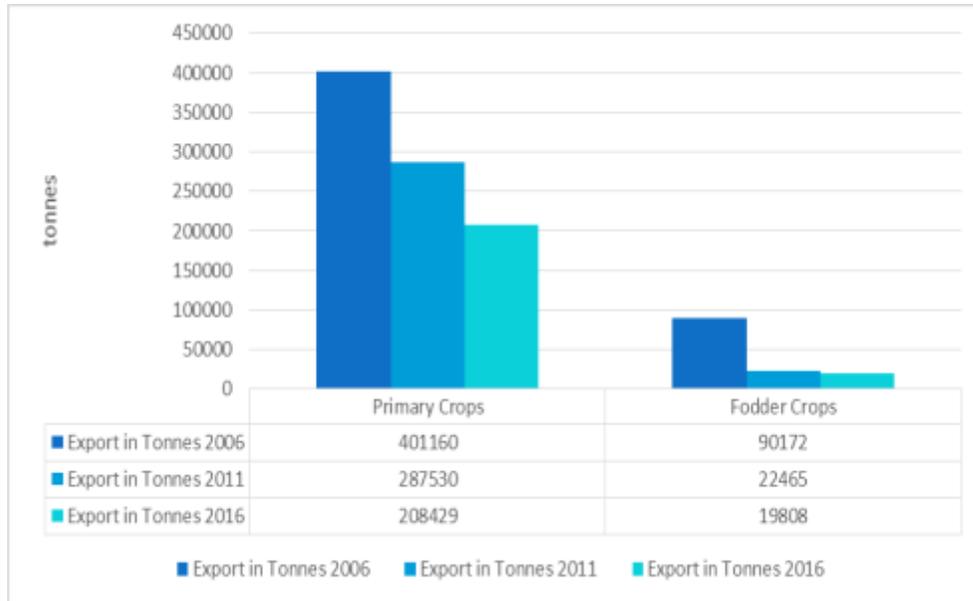


Figure 5-12 – Exports of biomass from the Region of Waterloo in absolute weight

In the export category, primary crops were the highly exported biomass category after fodder crops. Export of primary crops have also reduced from 0.84 t/cap to 0.39 t/cap, a 68% reduction between 2006 and 2016 (Figure 5-13).



Figure 5-13 Export of biomass from the Region of Waterloo in per capita units

Figure 5-14 indicates that approximately 95 to 100% of the primary crops exported from the region are feed primary crops. This indicates that the food produced in the region is just barely enough to meet its own purposes let alone export it outside economies/societies.

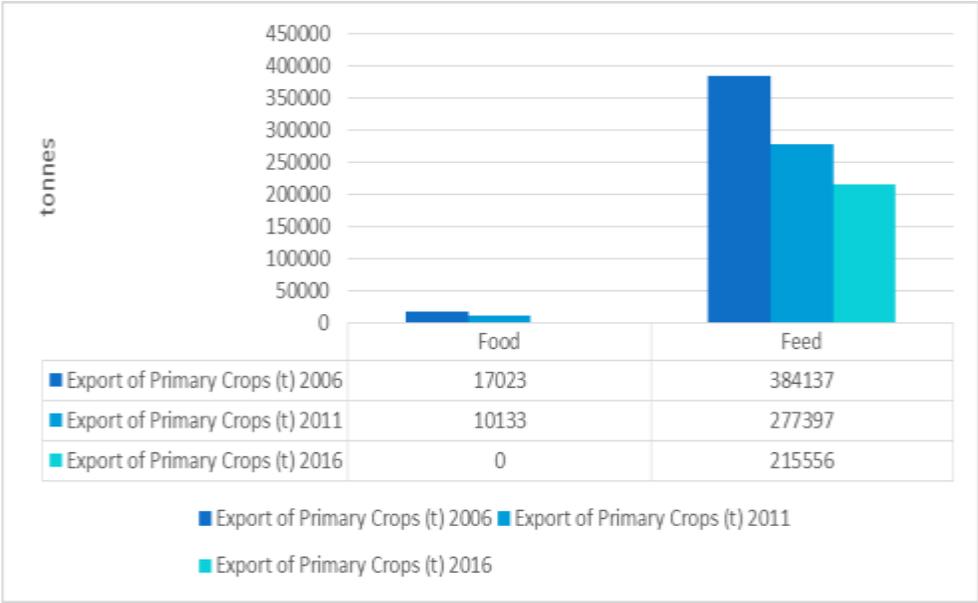


Figure 5-14 Exports of Food and Feed Primary crops from the Region of Waterloo in absolute weight

Delving further inside the exports of primary crops (Figure 5-15) it was found that cereals is the only primary crop that is exported from the Region of Waterloo for both feed and food. Under the cereals subcategory it was also found that the fodder corn dominated the cereals category and influenced its export flows.

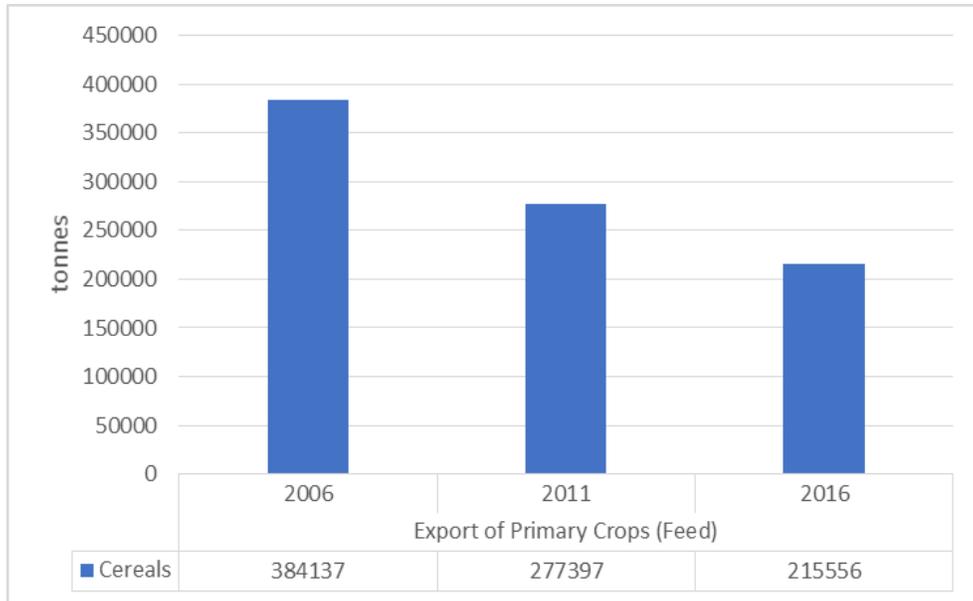


Figure 5-15 Exports of feed primary crops from the Region of Waterloo in absolute weight

## 5.5 Physical trade Balance (PTB)

The physical trade balance denotes the difference between imports and exports of biomass trade flows of the region of Waterloo. PTB shows that initially the Region of Waterloo was a net exporter of biomass in the year 2006 at 0.10 Mt in absolute weight and 0.21 t/cap but changed from net exporter of biomass to net importer of biomass from 2011 to 2016 both in absolute weight at 0.12 Mt in 2011 and 0.26 Mt in 2016 and per capita at 0.24 t/cap in 2011 and 0.49 t/cap in 2016 (Figure 5-16).

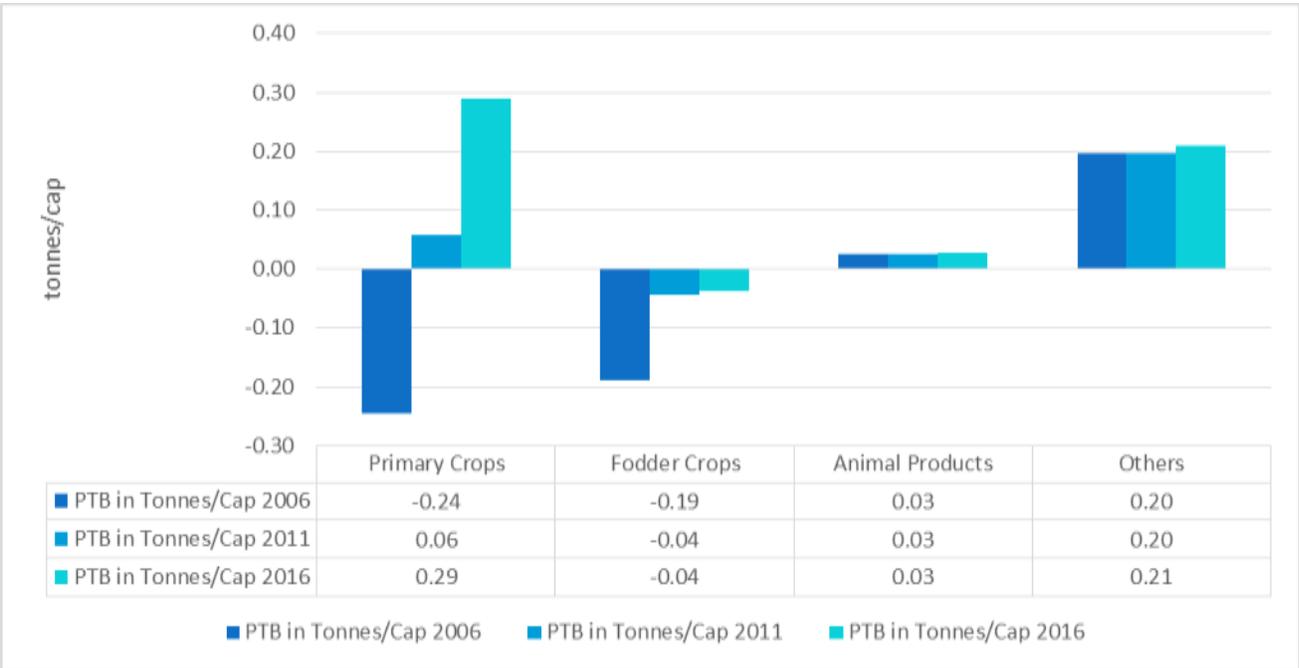
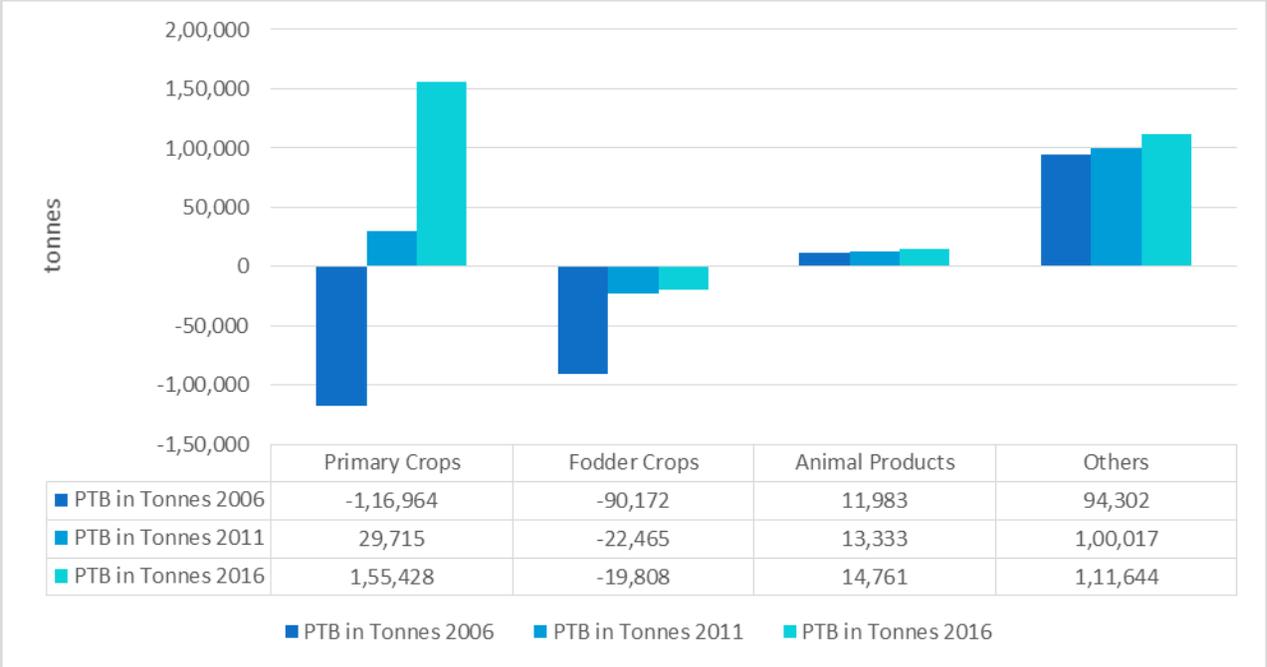


Figure 5-16 (a) PTB of biomass in the Region of Waterloo in absolute weight, (b) PTB of biomass in the Region of Waterloo in per capita units

Again, since the Region of Waterloo being a high producer of feed crops especially fodder corn the physical trade balance pattern of behavior was largely determined by the pattern of trade of feed primary crops which was exported at 0.24 t/cap during 2006 and have moved to imports at 0.06 t/cap in 2011 and 0.29 t/cap in 2016 (Figure 5-16). Since the extraction of food crops have been on the decline in the region, more food crops (food primary crops) have been imported into the region which influenced the change of PTB from net exporter to net importer.

Even though the regional government have taken steps to encourage local food production by making land use policies related to food in its regional official plan, the farmers seems to have more incentives with the production of cash crops like fodder corn used for feeding livestock.

### 5.6 DMC

Domestic material consumption indicates the consumption of materials domestically within the system boundary and consists of DMI minus exports. DMC of biomass in the Region of Waterloo decreased from 1.35 Mt to 1.34 Mt from 2006 to 2011 and then increased from 1.34 Mt to 1.47 Mt during 2011 to 2016 ( Figure 5-17). The rapid increase in DMC of biomass in between 2011 and 2016 was due to the rapid rise in livestock population from 88833 to 123160 numbers in between 2011 and 2016 and to a certain degree to the rise in human population as well.

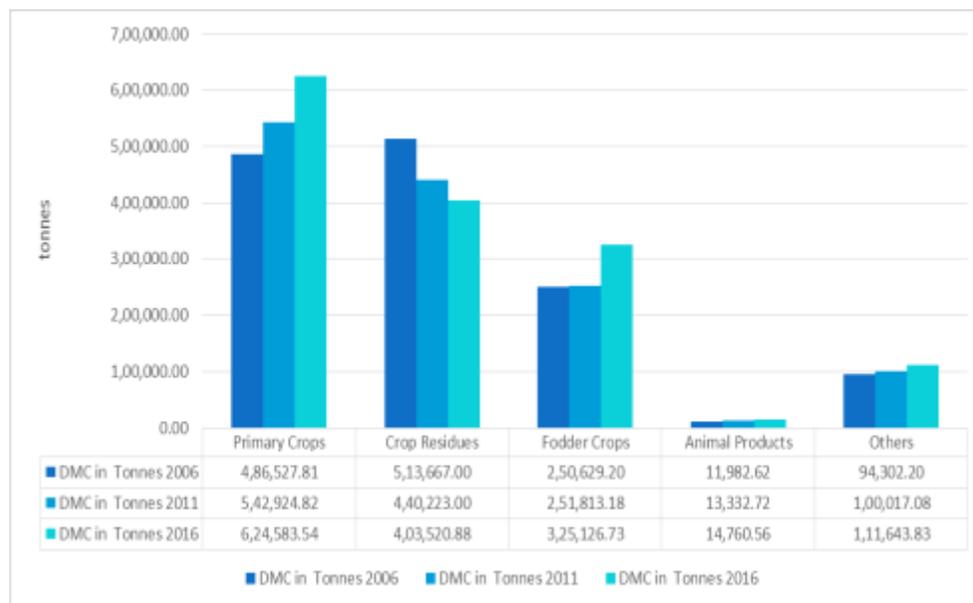


Figure 5-17 DMC of biomass in the Region of Waterloo in absolute weight

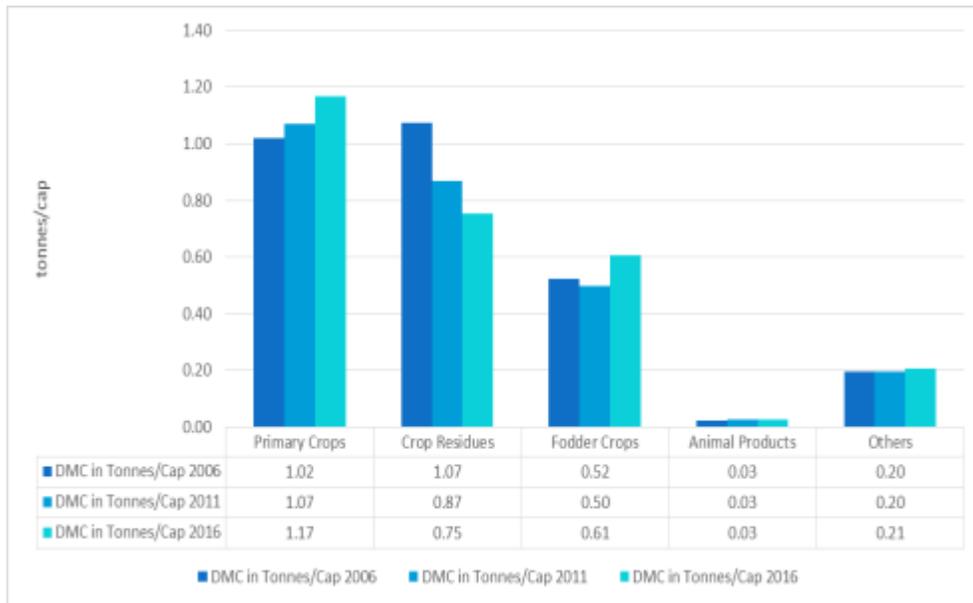


Figure 5-18 DMC of biomass in the Region of Waterloo in per capita units

The per capita DMC of biomass shows a similar trend decreasing from 2.84 tons/cap in 2006 to 2.66 tons/cap in 2011, and then increased from 2.66 t/cap to 2.76 t/cap during 2011 to 2016.

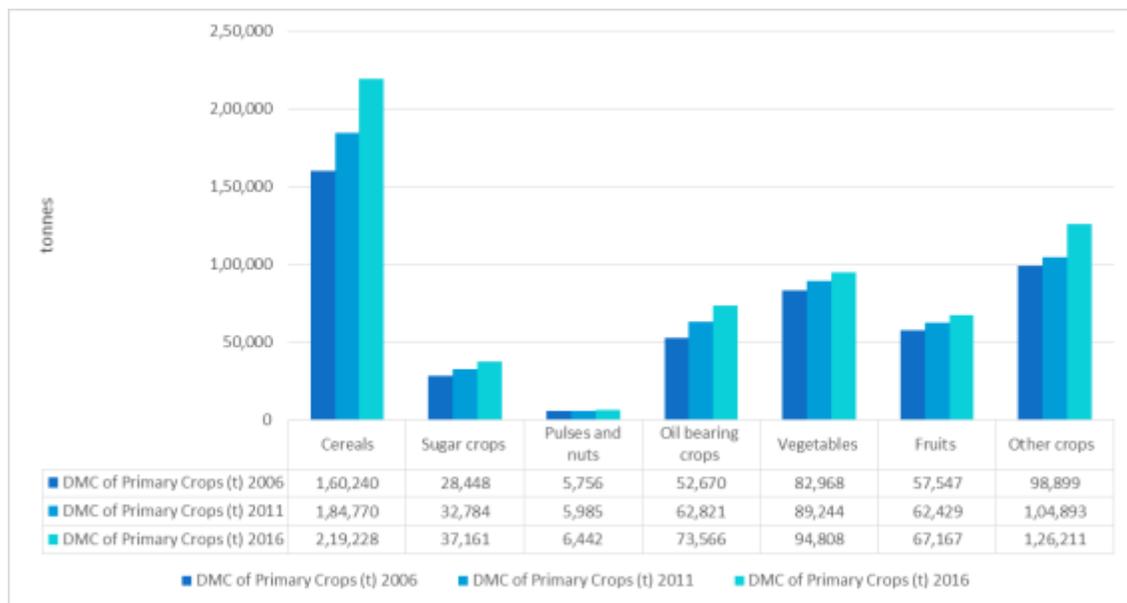


Figure 5-19 DMC of primary crops in the Region of Waterloo in Absolute Units

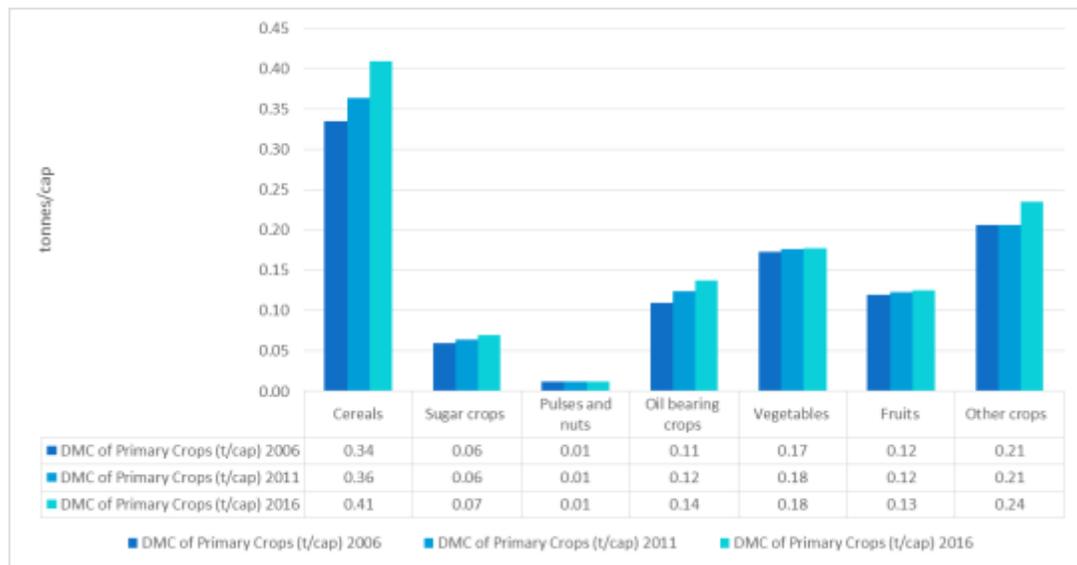


Figure 5-20 DMC of Primary crops in the Region of Waterloo in per capita units

Since primary crops were the highest domestically consumed category of biomass, it was analyzed further to understand the food scene of the Region of Waterloo better. DMC of primary crops in absolute weight and per capita indicates that the overall pattern of DMC of primary crops was influenced by the DMC of Cereals and the DMC of Cereals is increasing in both Absolute and per capita units over the years. (Figure 5-19 and Figure 5-20)

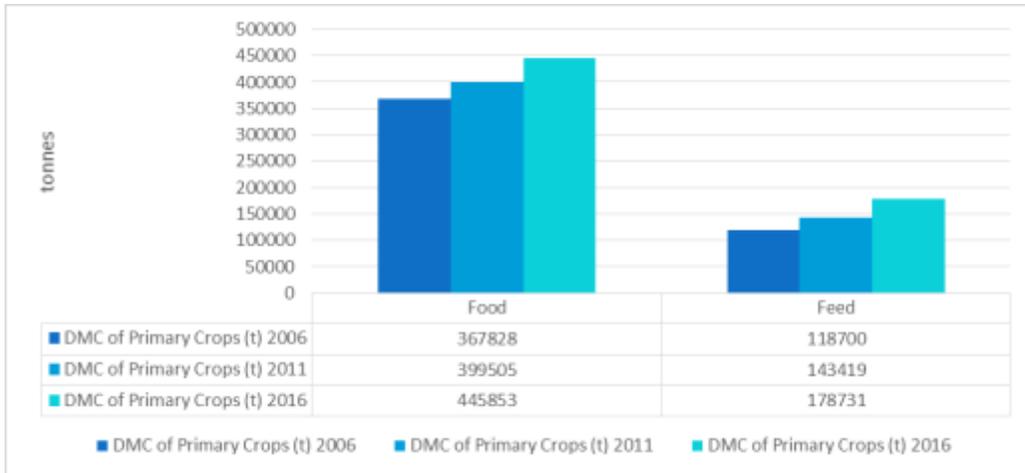


Figure 5-21 DMC of food and feed Primary crops in the Region of Waterloo in absolute units

Figure 5-21 shows the DMC of primary crops in the ROW based on its usage- food and feed in both absolute weight and in percentage. The figures clearly indicate that more than 70% of the Primary crops consumed in the region is for the purpose of food and only less than 30% of primary crops is for feeding the livestock.

## 5.7 Energy Flow Analysis (EFA)

Energy flow analysis of the region of Waterloo was done for the specific years of 2011 and 2016 due to the availability and quality of data that was accessible from reliable sources. To get a more broad and holistic idea, it was necessary that the difference between energy statistics and energy balances be established. Conventional energy statistics account for only energy used in technical devices used to provide, heat, light and mechanical work, while Energy flow analysis or energy flow accounting includes all energy-rich materials and electricity and light which are immaterial forms of energy which cross the societal system boundary as energy inputs irrespective of their use(Haberl, 2001; Haberl et al., 2008). Therefore, unlike conventional energy balances, EFA not only includes the biomass used for technical energy generation but also includes all the biomass used as energy input in the form of food energy for humans and feed energy for livestock(Haberl, 2001; Julesz, 2010).

EFA for the Region of Waterloo have been done for two points of time, 2011 and 2016 with the help of derived energy flow indicators. It can be noted that domestic extraction of technical energy in the region is null and imports almost 100% of its technical energy both renewable and non-renewable from outside its system boundary (mostly from its province of Ontario) (IESO, 2016).

Figure 5-22 and Figure 5-23 shows that Domestic extraction (DE) of energy had been down to 22.22 PJ in 2016 from 22.45 PJ in 2011. As evident from the analysis all or most of the DE energy was from human nutritional energy and feed nutritional energy as there was little or no production of technical energy in the region.

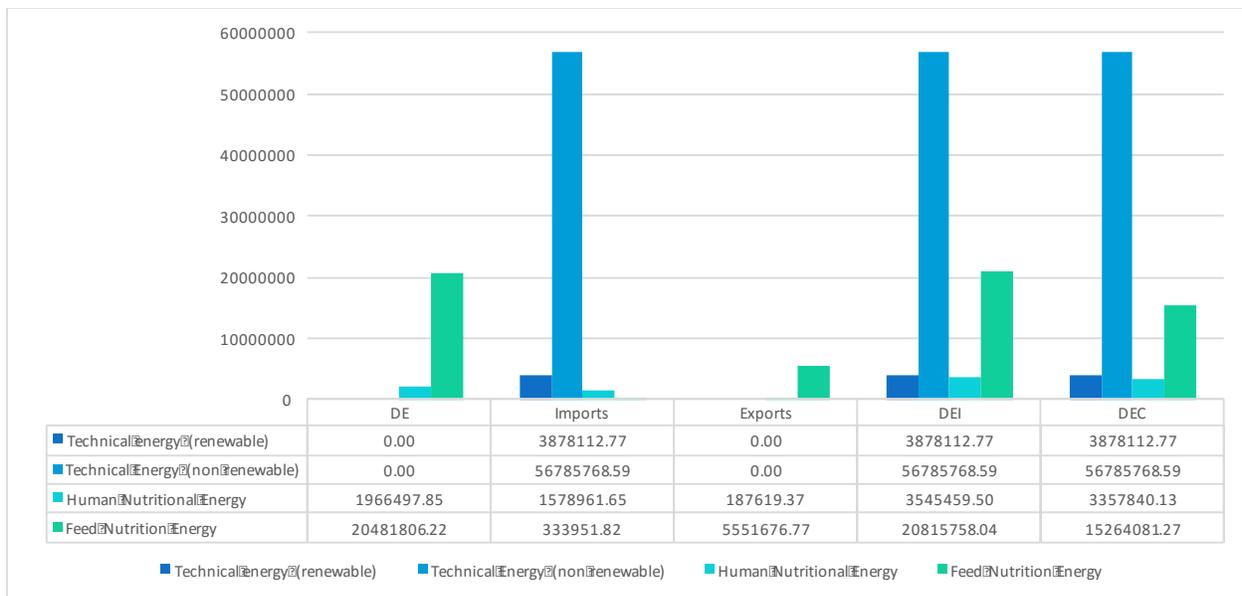


Figure 5-22 Energy Flow Analysis of the Region of Waterloo in 2011 in absolute terms(GJ)

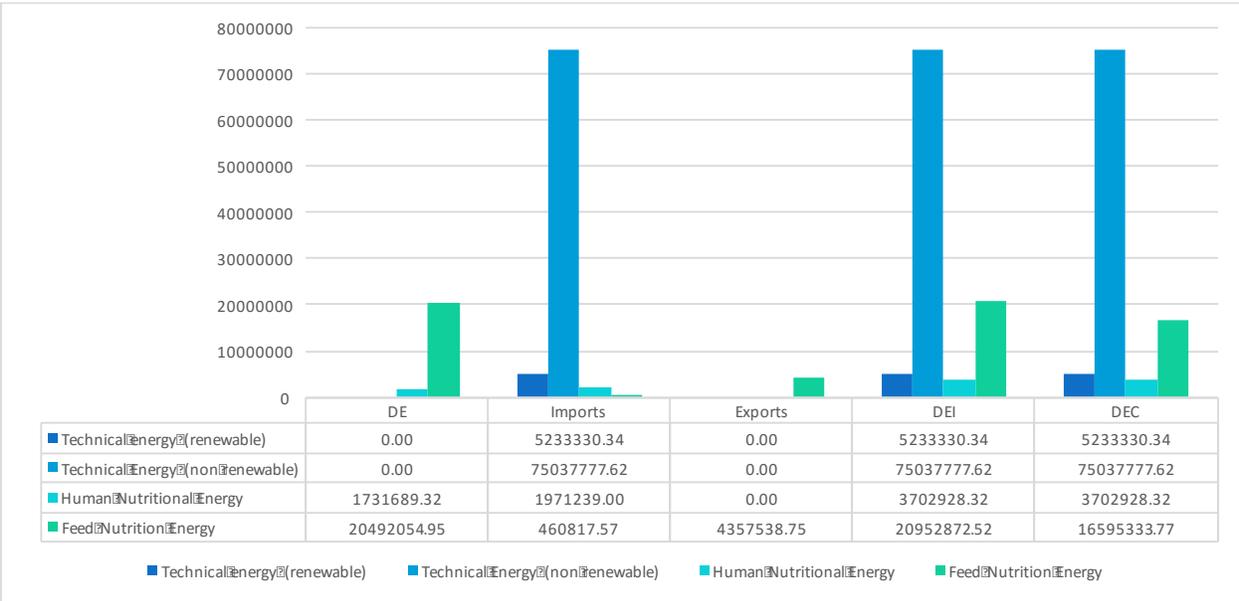


Figure 5-23 Energy Flow Analysis of the Region of Waterloo in 2016 in absolute terms(GJ)

On per capita basis, DE of energy in the region can also be seen to be reduced to 41.53 GJ/cap in 2016 from 44.27 GJ/cap in 2011 which was due to the decrease in local production of food and feed which again was due to the decrease in farming in the region. (Figure 5-24, Figure 5-25)

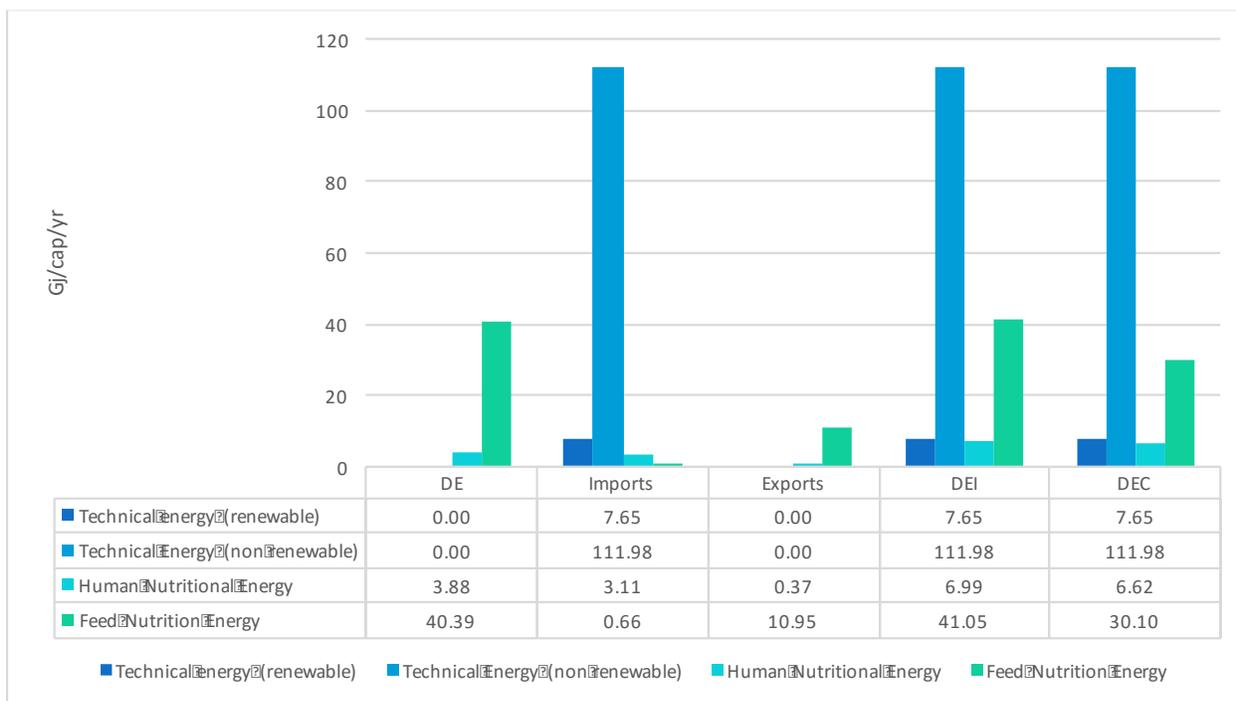


Figure 5-24 Energy metabolic profile of the Region of Waterloo in 2011

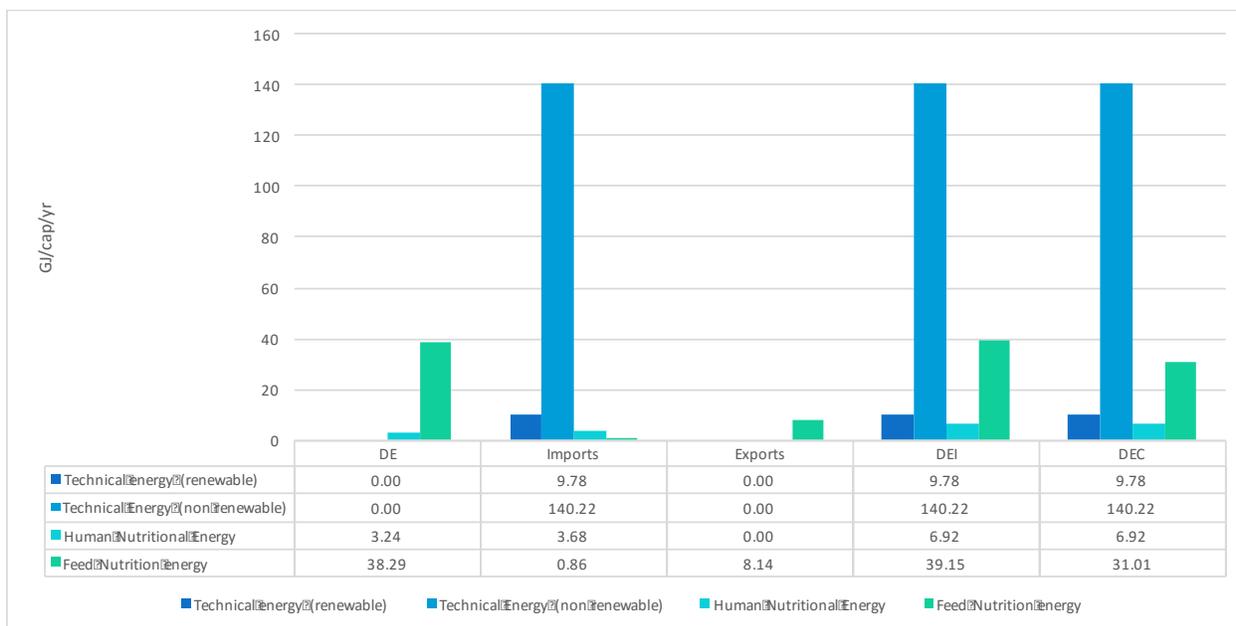


Figure 5-25 Energy metabolic profile of the Region of Waterloo in 2016

Import of energy have increased to 82.7 PJ in 2016 from 52.7 PJ in 2011 confirming the region’s reliance on imports overly which is trying to meet its energy demands due to the increase in population of the region. In the case of imported energy, the major share was from technical energy especially nonrenewable technical energy which constituted 112 GJ/cap in 2011 and 140 GJ/cap in 2016 of the total imported energy of 123.4 GJ/cap in 2011 and 154.54 GJ/cap in 2016. It was found from IESO (2016) that 100% of the electricity consumed in the Region of Waterloo was being imported from Ontario(IESO, 2016).

While imports of energy have been increasing, exports of energy have reduced from 5.74 PJ in 2011 to 4.36 PJ in 2016 and most of the exported energy was from feed biomass energy.

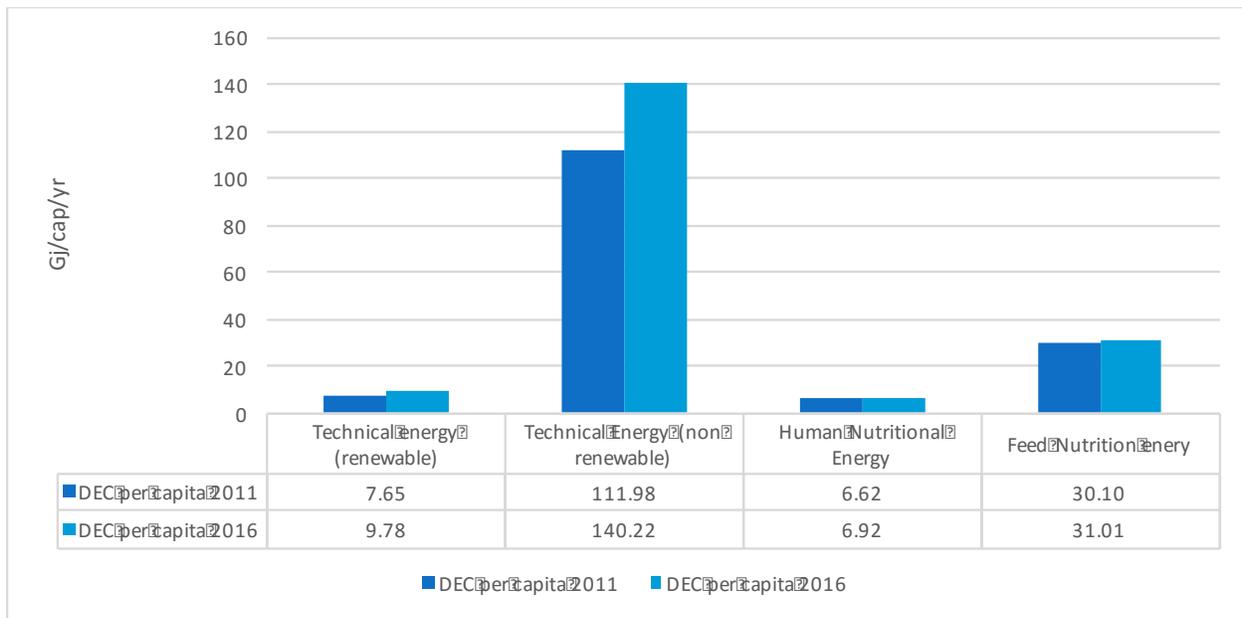


Figure 5-26 Domestic energy use of the region of Waterloo in per capita terms

Figure 5-26 indicates an increase in the energy consumption per capita of the region from 156.35 GJ/cap in 2011 to 187.9 GJ/cap in 2016 especially non-renewable technical energy have increased from 111.98 GJ/cap to 140.22 GJ/cap. The increase in DEC per capita of nonrenewable

energy is because of the increase in consumption of diesel in the region which is due to the increase in the number of personal vehicles in the region.

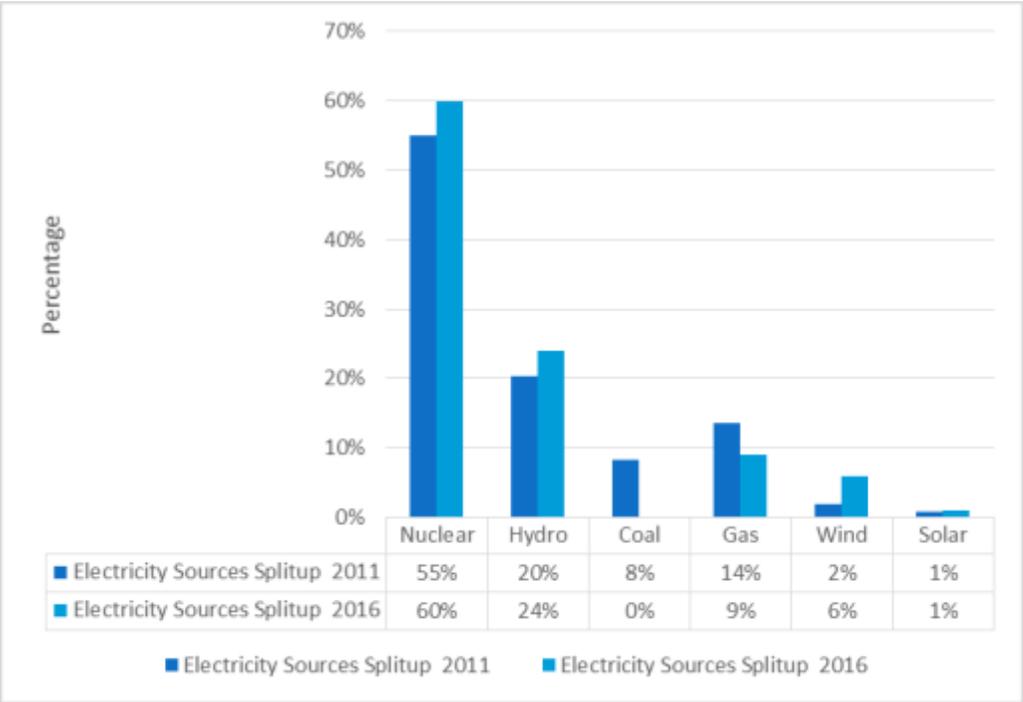


Figure 5-27 Change in Electricity sources over the years in the Region of Waterloo

Talking about energy it is necessary to signify the percentages of renewables and non-renewables in overall energy consumption of the region to comprehend the metabolic profile of the region. Figure 5-27 shows that renewables sources (Hydro, Wind, Solar) had increased significantly in electricity generation from 24% in 2011 to 31% in 2016 due to phasing out of coal and increase in hydro and wind sources in the province of Ontario’s electricity generation (IESO, 2016).

But the region still heavily relies on non-renewables for its energy consumption. Of the total technical energy consumption, the percentage of non-renewables is 94% in 2011 and 93% in 2016. Delving further, it was found that diesel consumption increased at 958% between 2011 and 2016 due to the increase in personal vehicle ownerships the growth in population of the

region which constituted to the rise in non-renewable energy consumption (Climate Action WR, 2017).

## 6 DISCUSSION AND CONCLUSION

### 6.1 Metabolism of the Region of Waterloo and its relationship with Food Security

The world will have 9 billion people to feed soon enough by 2050 and is projected to have more demand for food and meat which needs more farm lands for the production of crops to feed the humans and livestock (FAO, 2012). This demand for biomass will have various environmental repercussions which are overlooked by policy makers and political leaders. Based on the current pattern of food consumption the *FAO* estimates that there needs to be an increase of 60% of food production by 2050 to meet the needs of the human population (FAO, 2012). Also with looming issues in the form of climate change and extreme weather events along with the growing population, the sustainability of agrifood systems is under threat. *The International panel on climate change* also stresses on the potential food security issues disturbed by climate change of increase in temperature of 2-4 degree Celsius of 20<sup>th</sup> century temperature levels by stating that “All aspects of food security are potentially affected by climate change, including food access, utilization, and price stability” (Porter et al., 2014, p. 488).

This study quantified the Material and Energy flow analysis of the Region of Waterloo biomass available for food and feed was quantified. Moreover, this quantification of extraction and consumption of biomass for food facilitated in understanding the food system of the region and helped in finding some critical points where changes can be made to facilitate the food system in the region towards a more sustainable and localized system.

Considering the future population growth estimated for the Region of Waterloo which is expected to grow to 729000 by 2030 from the 2016 population level of 535154 (Statistics Canada, 2016) and the current reduced amount of food production locally (Desjardins et al., 2010) there is an undeniable need to produce more food in the Region of Waterloo to meet its own requirements. Also, currently the global food systems are propagating the idea of local agriculture production to meet food security of the world and to reduce the vulnerability of food systems in the wake of extreme weather events and climate change if in case their food supply chain are cut off from other parts of the world (Clapp, 2014). The need for the production of more food in the region can be only solved with the help of a sustainable agriculture and food system

which is local and self-reliant integrating sustainable food production, consumption, processing, and distribution. Such a sustainable food system will improve the health of the region economically, environmentally and socially (Desjardins et al., 2010; Feenstra, 2002).

Even though the region of Waterloo has fertile land for farming owing to the climate of the region and soil type, many crops cannot be cultivated to meet the requirements of the local population and are being imported like many urban regions around the World(Desjardins et al., 2010). This research has apparently shown that while many grains like corn, soybean, rye, and oats are grown well in the region most of the corn and soybean that are produced in the region are for feed and not for food which stresses that there is a need in shift of agricultural practices to synchronize local food production with local food consumption requirements. The increase in the production of commercial feed crops at the cost of food crops affects the food security of the region. The increase in feed crops production in the region is due to the rise in number of beef cattle in the region which increased rapidly in between 2011 and 2016. But the provincial government has taken necessary steps through its Growth plan for northern Ontario(2011) and Northern livestock pilot project (2017)to expand oppurtunities for farming in Norther Ontario, where abundant of land is available for agriculture which were not previously utilized considering its climate conditions(OMAFRA, 2017; Ontario Ministry of Infrastructure, 2013). But to provide food for the growing population and to increase its self food production capabilities in the face of global food insecurity and climate change, the Ontario government is encouraging livestock farming in the Northen regions of Ontario.

Considering that the possibility of expanding agricultural land area in the Region of Waterloo is low, previous studies on the food system of Waterloo region also suggests shifting the production of cash rich fodder crops to food crops such as fruits, vegetables, grains and legumes(Desjardins et al., 2010). This corroborates with the assertion made by this research that more cash rich fodder crops like fodder corn is domestically extracted in the region under the category of Primary crops than food primary crops like cereals, vegetables or fruits.

Desjardins et al (2010) in their paper *linking future population food requirements with local production in Waterloo region, Canada* have quantified the amount of food that can be produced in the region realistically to meet the healthy diet requirements of the future population of the

region of Waterloo. They have recommended the production of Asparagus, Bok choy, Lettuce , Melon, Sweet peppers, strawberries, other berries, Broccoli, green beans, Tomatoes, Sweet corn, Apples, Cabbages, Carrots, Potatoes, Squash, Peas, Rye, White beans and Oats which are both seasonal and independent of season and can be produced in the region with efforts from farmers and policy makers shifting from field crops such as feed corn and soybeans and from animal production to food production (Desjardins et al., 2010).

Previous studies also corroborate with the assertion of the thesis that even though the region has the capacity to produce more food crops, it is not producing currently enough citing various issues with the local farmers and people's buying behavior (Wegener, 2011). As a result, most of the food consumed by the region's populace are not produced in the region locally but imported while the crops that are produced in the region have to be optimized through support structures for farmers by policy makers of the region. The *Metcalf foundation* has also validated the claim for this study stating that over 50% of the products that are imported into Ontario can be produced in the province of Ontario which goes the same for the Region of Waterloo as well, the region being a part of Southern Ontario (Kubursi, Cummings, MacRae, & Kanaroglou, 2015). The same report also mentioned that Ontario imports twice as much as it exports and estimated that if 10% of the imports of certain types of fruits and vegetables were to be reduced and produced locally, it would result in a 59% reduction of CO<sub>2</sub> emissions by transporting the above-mentioned commodities (Kubursi et al., 2015).

One of the main challenges to food security is a reliable and stable food supply which are often disturbed by food price hikes and this is a threat to the food security of a region like Waterloo especially because it is very much dependent on outside markets or trade for its food supply. This can be prevented by increasing the self-sufficiency of the region's food system by domestically producing food that can be grown in the region to meet the needs of food consumption of its population (Clay, 2002).

The Region of Waterloo has high import dependency on other regions. Kubursi et al., notes that even though Ontario imports most of its imported food from USA, it also imports certain fruits and vegetables from developing countries like Mexico and in Asia (Kubursi et al., 2015). Unlike the countries of the global north, the countries of the global south are more vulnerable to

climate change(Edwards & Shultz, 2005). Also importing more food from developing countries incentivize farmers in the global south to produce more cash rich crops to export rather than to produce food for local consumption(Bumbacco, 2015; Mayer et al., 2015). From the analysis of metabolic profile of Region of Waterloo, it is also confirmed that the region exports feed crops to many regions in the global south (OMAFRA, 2016) while it imports food from the global south which raises the question of equity as the quality of crops the Region of Waterloo exports is inexpensive feed while the food they import is of higher quality and value from global south (Mayer et al., 2015).

Likewise, to achieve the sustainable development goals put forward by the *United Nations* “Goal 2.4 - By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality” (Group et al., 2016, p. 2) and “Goal 12.2 - By 2030, achieve the sustainable management and efficient use of natural resources” (Group et al., 2016, p. 2) it is vital that the Region of Waterloo make active and bold actions to solve the food security issues mentioned earlier with the help of the analysis done from this study.

Moreover, to have a sustainable food system it is also necessary to support and engage in alternative farming systems locally that have both social and environmental benefits by re-socializing and re-spatialization instead of conventional agricultural systems that damage the environment (Johnson, Fraser, & Hawkins, 2016). Re-socializing would be to improve the relationship between local consumers and producers as the consumers will be ready to pay more if they know the food they consume is not polluted by sprays and harmful chemicals and it will improve the livelihood of local small farmers in turn. And re-spatialization means consuming locally produced food (produce within the geographical region) which will significantly reduce the food miles of the food which will, in turn, reduce GHG gas emissions and may pave the way for consumption of seasonal dishes locally produced by importing only fewer but necessary food items.

In 2009, a report was released by *World Cancer Research Fund and the American Institute for Cancer Research* defining the policies and actions needed by governments and professional groups to prevent cancer-related to food, nutrition and physical activity (World Cancer Research Fund / American Institute for Cancer Research., 2009). This report outlined the needs for policies and actions by local actors and decision makers to address the rising diet related diseases which affect the health and well-being of the population with access to healthy food. Alternative retail food outlets namely urban farmers markets, country markets, community gardens, wholesale produce actions were seen as the potential recommendation to improve the access of healthy local and seasonally produced food to the community while increasing the livelihood of the farmers (Johnson et al., 2016). A study was done on direct marketing farmers in Southwestern Ontario by Amy Bumbacco also illustrates the necessity of the alternative retail outlets in the form of on farm stores that cut the intermediaries to sell the farm produce. The on farm stores marketed directly by the farmers have various sustainability benefits in the form of food security, climate change adaption, self-governance and community sense (Bumbacco, 2015).

Even though the recommendations made above to improve the food security of the region by implementing various policies holds good on regards with this study's findings. The recommendations are to be taken with a grain of salt as the system boundary of this study (Political boundary) is chosen for its analytical purposes. Also, the region is not very much food secure as the study predicts, as the region imports most of its food from its province Ontario due to the lack of required climate conditions and soil type for certain food crops(Desjardins et al., 2010).

## 6.2 Metabolism of the Region of Waterloo and its relationship with Energy Security

Sustainability literature indicates that there is an inevitable transition ahead away from the current society's energy system due to the exhaustibility of dominant fossil fuel systems(Fischer-kowalski, 2016; Haberl et al., 2008; Krausmann & Haberl, 2002). Hence, there is a need for a more sustainable and low carbon renewable energy system to meet the demands of energy throughput of the rising population and achieve energy security for the Region of Waterloo.

Figure 6-1 shows the energetic metabolic profile of the Region of Waterloo for the years of 2011 and 2016 which indicates that 100% of the domestically extracted energy is from biomass

for both the years of 2011 and 2016. It also shows that the region imports only 10% of its energy through biomass and 90% of the energy imported is technical energy. This high degree of reliability on outside markets for energy makes the Region of Waterloo vulnerable to cut off from other regions and in case of extreme weather events.

Figure 6-1 also indicates that even though per capita domestic energy consumption has increased 11% between 2011 and 2016 from 156 GJ/cap/yr to 187 GJ/cap/yr and also the renewable energy share has increased during that period from 7.6 GJ/cap/yr to 9.7 GJ/cap/yr as a result of Ontario's Provincial coal phase out program which is a intervention in policies at a higher scale modifying the energetic metabolism of the Region of Waterloo(Climate Action WR, 2017). GHG emissions have also been reduced by 5.2% in between 2010 and 2015 in the region as a result of the provincial coal phase-out program along with the conscious efforts of the community of the Waterloo region to reduce GHG emissions by 6% from 2010 levels by 2020(Climate Action WR, 2017).

Even though the percentage of renewables is increasing in the region, it is not very much compared to the expected global average of 2.3% rise in renewable resources per year till 2040(U.S. Energy Information Administration, 2017). Hence, the need for the region to invest more in the energy infrastructure especially in the renewable energy sector to improve its long-term energy security.

It has also been estimated and analyzed by the energy flow analysis that 55% and 63% of the Domestic energy consumption is from fossil fuels especially diesel which increased at a rate of 958% between 2011 and 2016(Climate Action WR, 2017). The number of personal vehicles in the region also have increased by 78% between 2010 and 2015(Climate Action WR, 2017). The rise in number of vehicles combined with the growth in the region's population and the lack of public transport in the Region of Waterloo has been identified as the primary causes for this predicament. It is also expected that the regional and provincial governments efforts to improve the public transportation in the rapidly growing Waterloo region in the form of ION light rail transport system will pay dividends in the future once completed by improving the public transportation system. Car sharing and the swiftly growing electric vehicles along with

technological improvements and increase in price of fossil fuels are also expected to reduce the use of non-renewable energy in the region (Climate Action WR, 2013, 2017).

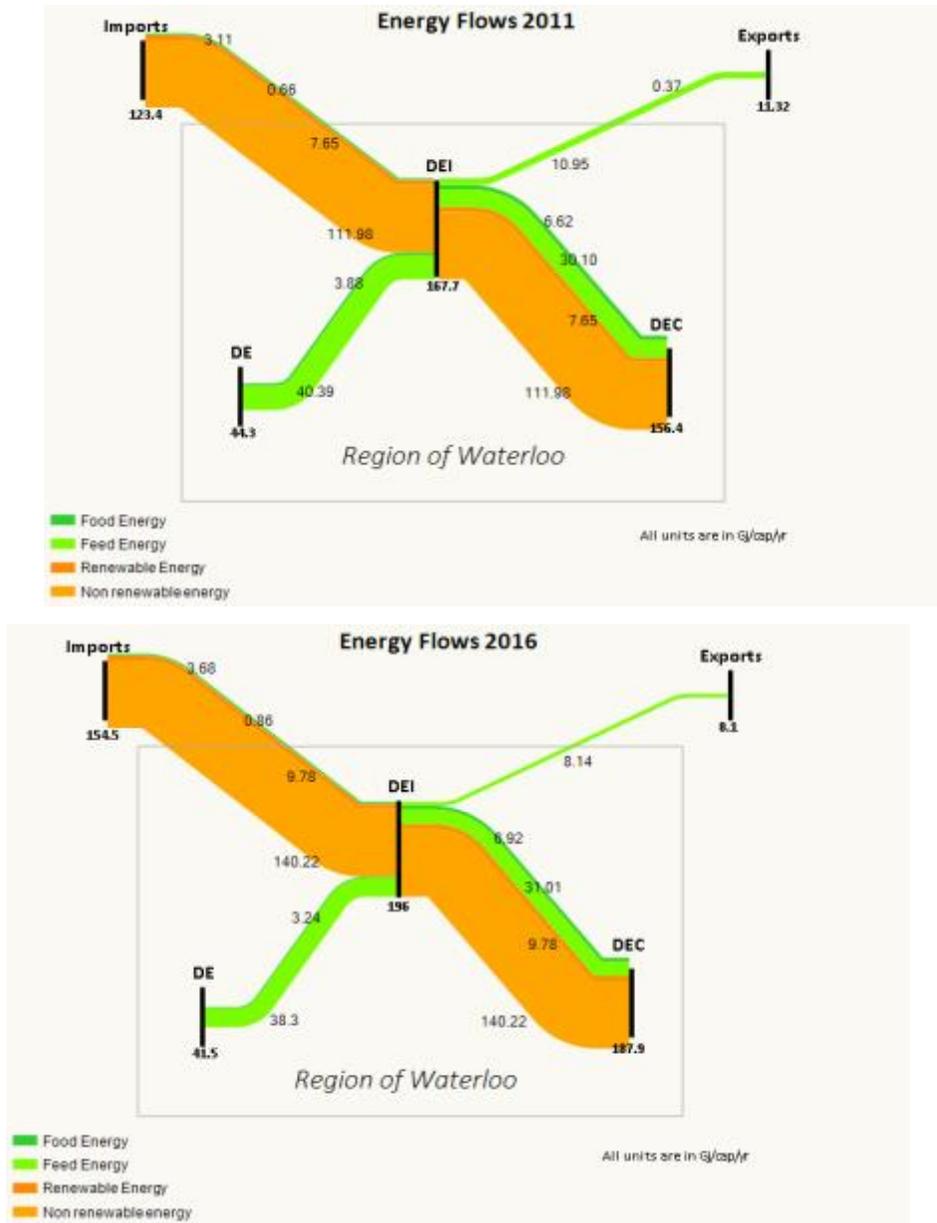


Figure 6-1 Sankey diagrams showing the Energetic metabolic profile of the Region of Waterloo a) 2011, b) 2016

There is a need for systemic change in the region to depend on low carbon renewable energies like solar and wind and move away from fossil fuel use. Lowering the use of fossil fuels

would also substantially pave the way for dematerialization and reduce GHG emissions, as fossil fuels constitute one-third of the overall global materials use and constitute two thirds of all the materials that are traded and transported (Marina Fischer-Kowalski & Haberl, 2015). Moreover, to achieve the Sustainable development goal “Goal 7.2 - By 2030, increase substantially the share of renewable energy in the global energy mix” (United nations, 2016) and to increase the region’s self-reliance on energy sources, there is an urgency for change in the energy metabolism of the region to produce more energy within the region.

Local actions are already taken by the Region of Waterloo to reduce its reliance on fossil fuels and prevent climate change by initiating *ClimateAction WR plan* by 2013 to reduce the region’s GHG emissions by 6% by 2020 from 2010 level (Climate Action WR, 2013) and move towards a low carbon future. There are various agreements and Action plans set forth by the global and national community that has preceded and inspired the policy changes and actions in the Region of Waterloo in shifting towards a low carbon future. *The Paris agreement* have united and collaborated nations around the world to reduce global GHG emissions to prevent climate change of rise in 2 degrees Celsius above preindustrial levels while the *Pre-Canadian Agreement on Clean growth and Climate change* outlined the need to corroborate between various regions in Canada comprising pricing Carbon, development of Zero energy buildings supporting innovation in Clean technology and entrepreneurship (Climate Action WR, 2013). This momentum building up towards preventing climate change has inspired the community of Waterloo region’s stakeholders to work towards reducing their fossil fuels use and thereby invest in low carbon technologies for the future (Climate Action WR, 2017).

It is believed this quantification and analysis of energetic flow socio metabolic data will serve as a tool to guide policy interventions and even for controlling policy outcomes for the Region of Waterloo by addressing the need to invest in sustainable energy/low-carbon infrastructure. Additionally, this study also showed the over reliance of the region on imports of energy while it has the capacity to produce more energy locally and increase its energy security.

### 6.3 Limitations

The Domestic material consumption data were determined based on a predictive study (Canadian Food Trends to 2020 report) from Agri-Canada in 2005 that predicted the consumption

of various categories of food till 2020. This study from Agri Canada has been relied for data purposes to a large extent and has been very crucial in calculating DMC, Imports and Exports in the absence of other data sources.

Most of the results and its recommendations are based on the choice of the system boundary which was chosen for the convenience of analytical purpose which in this study is the political boundary of the Region of Waterloo.. The results hold true for the chosen system boundary as substantiated by similar studies on the region which iterates the need for the region to improve its food and energy production to increase the region's food and energy self sufficiency. But it is to be noted that a different choice of system boundary might noticeably affect the results to a certain degree but might not affect the whole picture of the study.

With reference to the limitations experienced in this research, the lack of data sources for the Region of Waterloo were a huge challenge. Despite the data challenges, the results of the study corroborate with other studies done on the food and energy health of the region to a larger extent. Also, to depict the current state of the Region of Waterloo with regards to food and energy security, updated and concrete statistical data would be very helpful in the future.

#### 6.4 Conclusion

Overall this research of the metabolism of the Region of Waterloo has offered a quantitative view of the biomass flows, and energy flows in the region and in turn provided insights into the dynamics of those flows concerning food and energy security. This study has also provided insights for the policymakers of the region in adopting the SDG goals relating to food and energy security to increase the resiliency of the region's food and energy systems. Even though this study hasn't provided any definitive conclusions and strategies to improve the food security and energy security in the region, it has tried in providing patterns of extraction and consumption of biomass and energy in the region. Also, this research has stressed on the urgency in transition to a sustainable society to the policy makers to make informed decisions and also to the stakeholders of the region.

This research study has also assessed the metabolism of the Region of Waterloo from a bio physical perspective adding to the data points of various social metabolic studies done around the world both on national and locals scales. Also, it is anticipated from this research work that

this research will be expanded to conduct MFA of other materials and minerals as well to gain a complete understanding of the Waterloo region's material flows. Also, being one of the first studies to attempt and elucidate Material and energy flow analysis at a sub national scale it is anticipated that from this contribution many studies will adapt and expand in this path while improving the methodology of MEFA at sub-national scale.

It is apparent that to achieve the sustainable development goals (SDG's), changes have to be made not only at global and national levels but also at the local and subnational levels(Bringezu et al., 2016). It is expected from this research that it has shed some insights acknowledging the problems that the Region of Waterloo faces related to energy and biomass systems. Also, this research hopes it have helped in facilitating the policy makers of the region in adopting the SDG's at a regional level with the acknowledgement of problems in the region to meet Canada's commitment to meet the goals of the Paris agreement and guide sustainable development at different scales- regional, national and global.

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