Socioeconomic metabolism of Biomass in Jamaica in the Context of Trade and National Food Security: A time series biophysical analysis (1961-2013).

by

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AUTHOR'S DECLARATION

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

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Abstract

This thesis presents a novel study on the historical evolution of socioeconomic metabolism of biomass in Jamaica in the context of trade and national food security. The goal of this study was to provide empirical insight into the structure of Jamaica biomass system by analyzing biomass material flows (domestic extraction, imports and exports) from 1961 to 2013, and on this basis establish a link to the issue of national food security in Jamaica. A biomass material database in time series was constructed for Jamaica based on Eurostat methodological guidelines and general principles of economy-wide material flow account and analysis (EW-MFA). The constructed database allowed for the characterization of biomass production and consumption using the calculated material flow indicators- domestic extraction (DE), domestic consumption (DMC) and physical trade balance (PTB). The degree of import dependency was also calculated. To establish a link between patterns of biomass metabolism, trade and national food security, the scope of MFA was expanded to conduct a time series analysis of national food availability and progress towards food self-sufficiency based on analysis of dietary energy supply (DES) and dietary energy production (DEP) in Jamaica.

Results obtained revealed a declining trend in both metabolic scale and metabolic rate of biomass use in Jamaica. MFA calculated indicators showed two alternating phases of growth and decline in the evolution of biomass use- peak growth (1966 and 1996) and steep decline (1981 and 2006). Primary crops dominated DE (48%) and DMC (47%). Cereals (74%) dominated physical imports flows and export flows were dominated by sugar cane (76%). Jamaica agro-food system is characterized by export oriented production as the share of mainstay food crops in overall primary crop extraction was less than 10%. A high food Import dependency ratio was observed. Food energy availability has significantly improved since 1961 from 1740 kcal/cap/day to 2470 kcal/cap/day in 2013. Jamaica is yet to achieve food self-sufficiency as DEP remains critically below the minimum dietary energy requirement threshold for Jamaica.

This study contributes to the growing body of research on material flow analysis and socioeconomic metabolism. It offers a starting point for methodological enhancement of the MFA framework towards adapting it for food security studies.

Keywords: Jamaica, Biomass, Socioeconomic metabolism, Material flow analysis, National food security, Food availability, Dietary energy supply, Import dependency.

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Chapter 1
Background

1.1 Introduction

As the driving force in the development of human society, natural resources have long been the foundation of any economy, providing the raw materials and services required to maintain, sustain and reproduce its biophysical compartments for the proper functioning of its various socioeconomic systems (Behrens et al., 2007). Humanity through various economic activities organize the flows of materials in terms of extraction, production and consumption, in a society-nature interactional relationship conceptualized as social metabolism or socioeconomic metabolism (González de Molina Navarro & Toledo, 2014, Haberl et al. 2016).

The last decades have been marked by a progressive and tremendous surge in global demand for material resources, facilitated by increasing population, ongoing industrial transitions in developing economies and unabated consumerism in developed countries (Schaffartzik et al., 2014).The size of global socioeconomic metabolism has considerably increased since after the last century (Krausmann et al., 2013). It is estimated that humanity currently extracts about 70 billion tons of materials annually while per capita global material extraction has risen from 7 tonnes per capita to 10 tonnes per capita in the last four decades (UNEP, 2016). In recent years, growth of global material use has been extensively driven by both rising per capita income and increasing consumption levels which have been strongly linked to industrial and urban transformations in emerging economies of Asia and Latin America (UNEP, 2016). Additionally, rapid integration of different world regions into the global market economy has resulted in constant physical exchange of material and energy resources within a global production and consumption network facilitated by international trade (Steinberger, Krausmann, & Eisenmenger, 2010). The role of trade in driving global material use has risen quite significantly. A recent UNEP report on the biophysical assessment of international trade in resources noted that of the total material resources extracted and used globally in the year 2010, about 15% were traded (2015, p. 17). Also, the volume of traded material resources has currently outpaced the amount of extracted resources as various national economies have become increasingly dependent on foreign trade for the supply of vital commodities (UNEP, 2015). This has been accompanied by competition over key material resources and has undoubtedly influenced the patterns and compositions of material flows in terms of the Input, output, import and export of the four main material categories (namely- biomass, fossil energy, construction minerals and ore/industrial minerals) utilized in running and sustaining any physical economy (Giljum et al., 2014).

The socioeconomic metabolism of biomass in the food and agricultural systems are of particular relevance to the economy- environment interaction complex. As stated in the FAO sustainability assessment of food and agricultural systems guidelines, “the agriculture and food sector is at the nexus of the biosphere and the human economy and can thus be considered a custodian of land, crops, animals and other resources” (FAO, 2014, p. 85). Biomass refers “the sum of recent, non-fossil organic material of biological origin” (Krausmann et al., 2008a p. 472) derived from plants and also living organisms - in the form of meat (Mayer et al., 2015). The generation of biomass occurs through the process of cultivation of agricultural crops and plants, timber, firewood, cultivated animals and their respective products, cultivated fish and other aquatic products- under the control of humans and technology (EUROSTAT, 2013). Biomass material is thus produced from three main sources: agriculture (plants and animal cultivation), forestry and fisheries. Appropriation of agricultural or plant based biomass which makes up the largest share of extracted biomass constitutes about one third of the total material consumption globally (Krausmann et al., 2008a).

For much of human history before the advent of industrial civilization, biomass material dominated global material resource extraction and consumption. Despite the seemingly diminishing role of agriculture in global economic development given the rapid and ongoing transition of societies from agrarian- biomass-based to industrial- fossil/mineral resource dependent mode of production, agricultural production continues to play crucial roles in economy of every country worldwide (Cunfer & Krausmann, 2013; Weisz & Schandl, 2008). Most industrial processes require inputs from agriculture either directly or indirectly. An estimated 2.6 billion people around the world depends on agriculture for their livelihood (FAO, 2015a). In low and middle income countries, agriculture generates about 45% of total labour force and constitutes 10 percent of their gross domestic product (FAO, 2015a). Agriculture is the main source of livelihood for majority of rural households in developing countries and continues to play a crucial role in poverty reduction and economic diversification in developing countries (Dethier & Effenberger, 2012).

Further, as the leading and major source of biomass generation, the agricultural and food system is arguably the most important socioeconomic system in any national economy because of its crucial role in ensuring human subsistence. The role and functionality of biomass material as the only raw material source for food production- providing humans with nutritional energy necessary to maintain body functions is indispensable (Krausmann et al., 2008a; Singh et al., 2012). In addition to its human food supply functions, biomass material plays significant role in renewable energy production as the fourth largest energy carrier in the world after coal and fossil fuel. It is largely utilized in livestock production as animal feed and equally serves as an essential raw material input for manufacturing and construction in the form of wood and fiber.

Biomass production through agriculture and forestry activities has profound impacts on human society and the ecosystems. Agriculture has been established as the largest anthropogenic activities in ecosystem transformation (Giovannucci et al., 2012; MEA 2005). The generation and appropriation of biomass through agriculture and forestry is inextricably linked to alterations in land use with associated impacts of climate change, biodiversity loss and the alterations of biogeochemical cycles (Steffen et al.,2015; Krausmann et al., 2008a). Biomass production is a pervasive driver of deforestation; industrial agriculture requires high inputs of fossil energy, chemical fertilizers and pesticides which contributes to the risk of soil and water contamination (Kastner, Erb, & Haberl, 2014). In addition to the diversities of environmental problems, the current trends and patterns of global biomass metabolism presents a number of socioeconomic issues, of which one of them is national food security

The daunting challenge of meeting the food needs of a growing world population is putting demand pressure on global biomass production. Two third of the global terrestrial ecosystem is said to be currently under intensive use for agricultural biomass production and 77% of natural land has been converted to cropland (Erb et al., 2007; Niedertscheider et al., 2016). Changing global food and energy scenario, driven in part by dietary changes towards more meat consumption due to rising per capita income and biofuel imperative as a result of climate change threat has resulted in competing end uses of biomass (Nonhebel & Kastner, 2011); as a consequence, the patterns as well as compositions of biomass extraction, consumption and trade has considerably changed over time. Human food use is said to dominate biomass extraction pattern as global food demand has been on the rise (Kastner et al., 2014; Tilman et al., 2011). Tilman et al (2011) projects a 100-110 percentage increase in per capita global agricultural crop demand by 2050.

Because of the rapid globalization of food and agricultural production systems, international trade in agricultural biomass products especially in the area of food biomass has escalated (Mayer et al., 2015). It is estimated that the volumes of traded agricultural biomass products grew by over 300 percent from 0.3 Gigatonnes to 1.4 Gigatonnes in the last five decades (Mayer et al., 2015). While annual per capita availability of biomass has remained at 3 tons per person, global biomass consumption has more than doubled in the last six decades (Schaffartzik et al., 2014); driving changes in the structure of global biomass production. This is visible in the changing configurations of land use away from food production for domestic use towards production of commercially viable crops such as oil crops that serves as feedstock for bioenergy and other commercial non-food crops (Nonhebel and Kastner., 2011).

Quite obviously, there is an unprecedented shift from supply driven to demand driven biomass consumption, as trade in agricultural products has currently outpaced production. There is growing awareness on the socioeconomic ramifications of patterns of biomass extraction, consumption and trade in the face of rising food insecurity challenges across regions of the world. Underscoring this point, Giovannucci et al (2012) noted that while agricultural production output increased at an average rate of 2 percent per year between 1961 and 2007, about one billion people remain food insecure, with a vast majority in low and middle income countries (FAO, 2012). Consequently, the interaction between agriculture biomass trade and national food and agricultural systems in low and middle income economies has become a hotly debated issue amongst international policy makers and development practitioners (Clapp, 2015; Ford & Rawlins, 2007; Phillips, 2000). Specifically, contentions are rife regarding the impacts of current trends in agricultural biomass trade on national food security.

The small island developing states (SIDS) of the Caribbean region-specifically those in the Caribbean community (CARICOM) is of growing importance in this discourse on linkages between international agricultural biomass trade, domestic food production and national food security. The region has been recognized as intrinsically disadvantaged in terms of socioeconomic development imperatives, due to their narrow resource base, high population density, fragility of their land, coastal zones and marine ecosystems and the volatility of global economic system (Kendall & Petracco, 2009). As a net-food biomass importing region and as a traditionally export oriented agriculture economy, territories of the CARICOM are highly integrated into the international biomass market, albeit unequally (Kendall & Petracco, 2009).

Trends in global biomass trade presents a socioeconomic challenge for these traditionally agriculture export oriented countries facing supply-side constraint due to export restrictions related to trade policies, infrastructural challenges and other obstacle that impedes agriculture productive capacity; and are at the same time confronted with the burden of meeting the food and nutritional needs of its growing population as a result of inadequacy of domestic supply to satisfy domestic food demand (OECD, 2012). Already, there is an emerging recognition that current trends in patterns of international trade of biomass and biomass embodied products are not unconnected to rising food insecurity in the region (Horwitz & Bagley, 2016; Karfakis et al., 2011; Renwick & Patterson-Andrews, 2015). Confronting these challenges require an empirical insight into the dynamics of biomass production, consumption and trade and its link to national food security in this region.

Against this backdrop, this thesis presents a novel study on the socioeconomic metabolism of biomass in Jamaica food in the context of trade and national food security from a biophysical perspective. Using the industrial ecology tool- material flow accounting and analysis (MFA) in addition to complementary calculations to capture the national food security aspect of this study, a time series analysis covering 52-years reference period, from 1961 to 2013 is presented.

1.2 Thesis Structure

The thesis is organized in five chapters. The current introductory chapter provides the context and the background for this research. To provide valuable insights and to assist the understanding of this study and to clearly articulate the research, a review of relevant information on agriculture, trade and food security and the situation as it relates to Jamaica is presented in chapter one. In this chapter, the rationale for carrying out this study and contributions is also presented. Chapter two is an extensive literature review covering the framework used in this study to provide the reader insights to the main concept (social metabolism and material flow analysis) on which this thesis is subsumed. Review on the state of knowledge regarding research on social metabolism and material flow analysis covering socioeconomic biomass flows and island metabolism on various spatial and temporal scales is presented followed by the specific objectives of this thesis reflecting the overarching aim of the study. The research methods based on material flow analysis and complementary calculations are described in chapter three. Chapter four presents the results and discussion of the research. Finally, chapter five is dedicated to the summary and conclusion of the research.

1.3 Agriculture, Biomass Trade, and National food security

At the centrality of agricultural commodity policies in all national economies of the world is the growing concern to address the issue of food insecurity or to maintain the food security of its population (Sumner, 2000). The concept of food security has been defined as the ability of all people at all times to have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences in line with cultural customs for an active healthy life (Pinstrup-Andersen, 2009; Renwick & Patterson-Andrews, 2015). Due to the multidimensionality of the food security concept, the operational definition of in terms of measuring or assessing a food security or food insecurity condition at individual, household, national or global level has been numerous and varied (Jones et al., 2013). This study adopted the definition proposed by Paarlberg (2000) that allows for operational interpretation at either individuals, households, communities, nations, or the whole world which defines "food insecurity as any transitory interlude of below-trend food consumption that may threaten human health. Food insecurity is thus distinct from chronic malnutrition (which may be non-transitory) and from outright famine (which threatens not just health, but life itself)" (p.317). From the above definition, food insecurity maybe transitory which could gradually degenerate into a chronic state.

In food security literature, there is a constant reiteration that global food production is enough to feed the world population (Clay, 2002; Pingali, 2012; Pinstrup-Andersen, 2009). The food security/insecurity discourse is mostly conceptually centered on under-production in developing economies. On this basis, arguments have been made on the crucial need to restructure the governance of global food systems towards promoting local agricultural production;

propagating the idea of food sovereignty; a concept built on national self-sufficiency in food production and livelihood sustenance with the end goal of food security and environmentally sustainable agriculture (Clapp, 2014a; Agarwal, 2014).

However, the prevailing mainstream approach to food security advocates international trade in agricultural biomass as a necessary food security strategy, emphasizing on increasing global agricultural production (Clapp, 2014a). Therefore, as part of a broader global development agenda to boost agricultural production and ensure global food security, liberalization of agriculture trade has been vigorously pursued. An international agreement on trade liberalization of agriculture was reached at the Uruguay round table trade negotiations in 1994 under the aegis of World Trade Organization (WTO) policy framework. The policy foundations of the WTO agricultural trade regime -which is based on three negotiating nodes- market access measures[1], export competition through reductions in export subsidies and domestic support measures- induced a restructuring in the pattern of agriculture in both developed and developing countries (Clapp, 2015a; Mayer et al., 2015). For instance, while the richest countries continued to enjoy subsidy support, increasing their share of global export market, liberalization of market access has deepened in poorer countries as their share of export market dwindles (Clapp, 2015b; Mayer et al., 2015).

Government subsidization of large-scale commercial agriculture in western economies resulted in steep decline in real agricultural price of traded commodity, created agricultural surpluses and saturated local markets thus making it difficult for small farmers in developing countries to compete in the global agricultural market (Edelman et al., 2014; McMichael, 2011). As succinctly put by McMichael (2011) in his seminal paper on corporate food regime, “the decoupling of subsidies from prices removed the price floor, establishing an artificial world price (below production costs), deployed as a weapon of dispossession, or incorporation, against farmers everywhere through the dumping of agricultural surpluses” (p. 287). What we have is a situation where “artificial cheapening of traded food” creates growing import dependency in agricultural disadvantaged countries (McMichael, 2011) undermining domestic food production systems. This has created a condition of food- self-reliance in many developing economies. Food self-reliance

[1] conversion of quantitative restrictions and other broader measures into tariffs and the reduction of agriculture tariffs (see Clapp, 2015, p. 107).

basically rests on the premise of balancing supply and demand of food biomass through international trade (Godfray et al., 2010; Konandreas, 2006).

Further, the liberalization of agriculture trade in the 1970s and 1980s along with the neoliberal trade policies pushed through world trade organization (WTO) initiated a globalization of the food and agricultural system that have centralized 60% of global food stock in corporate agribusiness, enabled by a growing financialization of the global agro-food system (McMichael, 2011; Clapp, 2014b). The financialization of global agro-food system as articulated in Clapp (2014b) refers to increasing involvement of financial speculators, seeking financial returns, across the entire agricultural value chain. Heavy private financial investment (such as index funds[2]) has meant a shift towards production of commercially viable crops at the expense of food crops for human nutrition (Clapp, 2-14b). In view of the foregoing, the role of biomass trade in national food security have become a keenly contested issue; even more so in light of a rapidly changing global food and energy scenario characterized by volatile food prices, diet meatification, biofuel and agrofuel imperatives due to climate change (Weis, 2013; Kastner et al., 2012; Nonhebel & Kastner, 2011). Current structure of global food and agricultural systems engenders the vulnerability and subsequent redundancy of small-scale farmers- who in fact make up the vast majority of global farmers (Edelman et al., 2014). Hence, despite the increases in agricultural productivity and agricultural surplus, the world has continued to grapple with the challenge of food insecurity (FAO, 2015).

It has been argued that food security goes beyond just supply of food; the adequacy and appropriateness of what is being supplied is a crucial aspect that must be taken into consideration (Clay, 2002; Ford & Rawlins, 2007; Pinstrup-Andersen, 2009). Growing urbanization in developing regions has been linked to dietary shifts as a result of the proliferation of globalized supermarkets which grants urban households increasing access to industrialized food system (Cohen and Garret, 2010). This presents a growing concern of urban food insecurity. Urban food insecurity is an emerging research focus championed by the Hungry Cities Initiative. Also, the issue of reliability and stability of supply networks are further considerations that cannot be overlooked.

[2] Index funds is an exchange-traded funds that derive their value from changes in an index tracking the prices of commodities, farmland and agrifood firm shares in food and agriculture (Clapp, 2015, p. 798))

The series of global food crisis with the accompanying food price hikes in mid-1990s, 2007/2008 and 2011, reinforces the challenges of food systems in terms of disruptive supply which poses a national food security risk for countries dependent on trade for food supply (Dethier & Effenberger, 2012). The prevalence of transitory national food security has been ascribed to year-to-year variations in international, food prices, foreign exchange earnings, domestic food production and household incomes (Clay, 2002).

The interrelations between agriculture and food systems are quite intricate. The challenges that confront agricultural and food production sector are varied and peculiar to each region, even down to national economies. Hence, strategies or approach should be adapted to or interpreted on a context specific basis that reflects the realities in each country. In a globalized food system, the Caribbean community (CARICOM) are critically exposed to fluctuations in the agricultural market (Kendall and Petracco, 2009). Ensuring the sustainability of food and agricultural system have become more pressing than ever in these vulnerable regions in the face of rising food commodity prices, energy price volatility and climate change. It is important to note that, though countries in the CARICOM are often seen as a homogenous group, there is a great degree of diversity in their agriculture system stemming from economic imperatives and environmental realities which converge to define their agricultural landscape (Beckford & Campbell, 2013; Potter et al., 2015). The current structure of food and agricultural systems in each CARICOM State is therefore reflective of the historical dynamism that defined the development and evolution of agricultural biomass production and consumption.

1.4 The Jamaica Context

Historically, dating from the period of slave trade through to colonization till after independence in 1962, Jamaica was mainly an agriculture based economy; and as is the case with most CARICOM countries, the food and agriculture system has been historically embedded in international trade (Campbell & Beckford, 2009; Potter et al., 2015; Weis, 2004). Typical of most former British colonies in the Caribbean islands, the agricultural system of Jamaica is deeply structurally dualistic; broadly classified into a specialized commercial plantation agriculture farming system for largescale monoculture production of cash crops (sugar, banana, coffee, cocoa and of recent, citrus and chilies) destined for international export markets and small-scale[3] farming system that caters to domestic food supply and local market trade (Barker, 1993; Beckford et al., 2011; Selvaraju et al., 2013).

The structural dualism in Jamaica agricultural systems is characterized by a bias against the small farming subsector (Beckford and Rhiney, 2016. p. 269). Smallholder farmers are marginalized in terms of resource allocation, physical and institutional infrastructure such as financial credit access, support for research and development, distribution arrangements etc. that would help facilitate the growth and productivity of the subsector. Also, field observation from a visit to farm areas in Jamaica and reports from literature confirms the existence of a highly inequitable agrarian landscape in terms of the quality and size of agricultural lands accessible to farmers (Campbell & Beckford, 2009; Selvaraju et al., 2013; Weis, 2004) . While small farmers are confined to steep marginal lands in the rugged interiors, the productive fertile lands are dominated by large plantations and large pastures (Campbell & Beckford, 2009; Thomas, 2006). Based on the most recent and last agricultural census conducted in 2007, it is estimated that total agricultural land area in Jamaica is approximately 326, 000 hectares (STATINJa, 2015). According to the statistical institute of Jamaica, this represents a 20% decline of about 81, 624 hectares since after the 1996 census. Only 62% of the total agricultural land area is actively under crop cultivation and pasture utilization. Large-scale farms take up 39% of the agricultural farmlands even though they constitute only 1% of Jamaica farming community. About 187000 farms support smallholder farmers categorized as those with land holdings of 4.0-2.0 hectares (STATINJa, 2015).

The development of the Jamaica crop system has from inception been oriented towards export production (Lowitt et al., 2015; Thomas, 2006). Colonization birthed the plantation economy which was heralded by sugar cane plantations for the purpose of foreign exchange generation towards economic development (Barker, 1993; Barker, 1985; Prince, 2010). According to Timms, "the application of development theory in the Caribbean legitimized export agriculture at the expense of agricultural production for domestic market, thus maintaining the colonial legacy of

[3] Small-scale farmers here refer to both peasants and subsistence farmers. Though it is commonplace to associate small-scale farming to traditional subsistence farming, this often presents a distortion in meaning in terms of the type and scale of agricultural operations carried out by farmers grouped under this category. In Jamaica, small-scale farming provides food supply for the whole of the country and some smallholder farmers cultivate export cash crops particularly those with farm holdings of up to 10 hectares.

plantation economy" (p. 101). Efforts were concentrated in this regard as domestic agriculture (i.e. small scale farming) was perceived as a clog in the wheel of rapid development, sapping excessive amount of labour with marginal productivity (Timms, 2008). Up until the 1970s, agricultural export dominated production and even exceeded imports (Meditz & Hanratty, 1987). According to Timms (2008) this subsector makes a significant contribution to the Jamaican foreign earnings, with the sugar industry rated as the third largest foreign exchange earner after bauxite and tourism; constituting about 50% of annual agricultural exports.

Globalization and trade liberalization brought about economic restructuring that left the Jamaican agricultural sector in critical condition (Weis, 2004). Major economic policy shifts that were in line with WHO/IMF structural adjustment program which inter alia included elimination of food subsidies, abolition of foreign exchange control, elimination of quantitative import restriction and the use of reference prices were adopted and implemented starting from the late 1970s when the first IMF agreement was signed (Barker, 1985; Handa & King, 1997; Thomas, 2006; Weis, 2004). The conditionalities of the international, monetary fund (IMF) structural adjustment program included reductions of direct government involvement in production of goods and services, leading to the contraction of public sectors including the agriculture, forestry and fishery sector (Handa & King, 1997; Weis, 2004; Weis, 2005). Similarly, government spending on agriculture as percentage of GDP declined fourfold between 1981 and 1985, leading to tourism becoming Jamaica major economic sector in terms of GDP contributions in the 1980s (Weis, 2004).

The series of neoliberal trade and economic reforms implemented in Jamaica over 20 years coupled with the periodic natural and climatic hazards[4] has had tremendous impact on Jamaica food and agricultural sector. In recent times, export production has been declining as a result of the convergence of external and internal factors underpinned by globalization and trade liberalization. Most notably is the decline in price of sugar following competition from other regional markets and

[4] As an island, Jamaica sits on extremities of climate change- flood, mudslides and drought. Jamaica's location within the hurricane belt increases its vulnerability to hurricane disasters. Hurricane Gilbert-1988 destroyed 40% of agriculture and caused the government US$4 billion in damages, hurricanes charley and Ivan in 2004 destroyed 100% of banana and 190,000tonnes of sugarcane causing US$ million 85 damages. 2005 hurricanes Emily and Dennis as well as 2007 hurricane Dean caused further devastating damages to the agriculture and food system. Within these periods, the country experienced serious food shortages (McGlashan et al., 2008, p.9). Also there is increasing drought situation. A visit to St. Elizabeth parish- the breadbasket of the island revealed firsthand the challenging effects of drought to small farmers (source-fieldwork).

also the elimination of the European Union (EU) preference for major agricultural export commodity-banana and sugarcane which resulted in limited access to developed market (Kendall & Petracco, 2009; Meditz & Hanratty, 1987; Thomas, 2003). The resultant effect is a decline in foreign exchange earnings to support food imports. It is reported that the share of agriculture value added in GDP went down from 8 percent since the 1980s to about 6 percent (FAO, 2015).

It must be acknowledged that liberalization of agricultural trade also offered some benefits. Much of the benefits accrued to consumers particularly those of lower income level as heavily subsidized food commodity coming from external sources such as powdered milk became relatively affordable due to lower price of importation (Weis, 2004). However, the downside of this was the inadvertent impact on the viability of domestic agricultural production; domestic producers were unable to compete with cheap foreign imported products flooding the local market and the tourism sector in the face of rising agro-food imports (Weis, 2004; Thomas, 2006).

There is a growing concern on increasing dependence on international market to meet food supply and ensure food availability in Jamaica due to rising food import bills and increasing consumption of processed foods (FAO, 2015). According to Kendall and Petracco (2009), the level of import dependency in Jamaica is remarkably high-reaching and surpassing 80% (p. 784); food imports accounting for more than half of the total agricultural import bills. Jamaica food import bills has been on a progressive rise in the last 3 decades following liberalization. It was estimated that US$ 199 million was spent on food imports in 1991 and by 2001 this more than doubled to US$ 503 million (Beckford and Campbell, 2013). In 2011, Jamaica food import bill was put atUS$913 million and this is projected to further increase (FAO, 2013). With a current debt to GDP ratio of 126.8%, coupled with diminishing agricultural export production (CIA FactBook, 2015), Jamaica may not be able to sustain its current spending on food imports.

Literature confirms that the decline of Jamaica agriculture sector poses an undesirable effect on the food system (Prince, 2010; Karfakis et al., 2011; Beckford and Rhiney, 2016). It is important to point out that the responsibility of domestic agricultural production (crop and livestock production) is undertaken by small-scale farmers who constitute 78% of Jamaica farming community and produces the island staples- mainly root crops, pulses and vegetables; cereal production which includes maize and rice are relatively very marginal (Beckford & Campbell, 2013; Selvaraju et al., 2013). These group of people who depend on farming as livelihood strategy play a key role in ensuring food security. However, a great majority of these farmers still engage in traditional farming practices with crude implements which confronts them with enormous challenges that impinges on national domestic food sector (Beckford & Bailey, 2009; Beckford & Campbell, 2013). Thus the decline in domestic agricultural production has not only impacted the food system but has equally aggravated poverty in rural areas with implications on food security (Beckford and Rhiney, 2016).

The preponderance of food insecurity has been identified as a major public health concern in Jamaica (FAO, 2015b). The reality of food and nutrition security (FNS) challenges in Jamaica was rightly acknowledged in a 2013 policy report on national food and nutrition security released by the Jamaica ministry of agriculture and fisheries in conjunction with the ministry of health which unequivocally stated that issues related to food and nutrition is the country's main public health problem. According to this report, there is an ongoing adverse change in dietary patterns which is reflected in the type, amount and quality of food available for consumption in Jamaica. The prevalence of the 'overweight syndrome' resulting in obesity and diabetes is indicative of a nutrition transition away from the consumption of traditional healthy diets in favor of higher energy density diets mostly consisting of sugars, animal fats and highly processed imported foods (Weis, 2007, Karfakis et al., 2011).

The enduring role of peasant based agriculture in realizing food security and maintaining national food sovereignty has been acknowledged in both academic and non-academic literature (Pretty et al., 2001; Via Campesina, 2011; IFAD, 2013; Clapp, 2015a). According to Spence (1999), there is a general consensus among Caribbean development planners that small-scale agricultural producers, commonly referred to as small farmers, have an important role to play in sustainable domestic food supply and by extension, the food security of the region" (p. 296). In a similar line of logic, Barlagne et al. (2015), asserts that "ensuring the success of agriculture is at the heart of food security because food security partly arises from sustained food production" (p. 63). However, sustained food production can be achieved through uninhibited local production by mitigating those factors that engenders the vulnerability of small farmers. It has been established that the viability and sustainability of the domestic food and agricultural system is at the core of achieving food security in all parts of the world. A viable domestic agriculture sector will not only guarantee steady food supply but will ensure accessibility to quality food and significantly improve rural people's livelihood.

To this end, there is need for a systematic understanding of the evolution of patterns of domestic biomass production, international trade of agricultural biomass and food security in Jamaica. Till date, no empirical study has been done on the metabolism of biomass in Jamaica with regards to growing food import dependence and national food security, hence there is a research gap in this area which this thesis aims to fill.

1.5 Rationale and Contributions

The drawback of the structural programs on Jamaica food system resulted in a growing food import dependency and government neglect of the agricultural sector of the national economy in Jamaica. High dependence on importations to meet food supply and ensure food availability in Jamaica has become problematic due to rising food import bills and increasing consumption of processed foods (FAO, 2015). The annual food import bill of Jamaica is particularly worrisome, as low food production and high dependency on food imports combine to make Jamaica ever more vulnerable to food supply chain disruptions resulting from volatility of food prices. Literature confirms that the consistent and considerable decline of Jamaica agriculture sector has an undesirable effect on the food system (Beckford & Rhiney, 2016; Karfakis et al., 2011; Prince, 2010). National food security is linked to established structure and patterns of biomass metabolism. To confront the challenges of the future, it is important to understand the past. Therefore, this research project aims to analyze the historical evolution of biomass production and consumption patterns in Jamaica in the context of international biomass trade from a biophysical perspective. To the best of the researcher's knowledge, there is yet to be an empirical biophysical analysis of Jamaica agricultural and food sector from a historical perspective. The outcome of this study will help inform discussions on the sustainable development of Jamaica food and agriculture systems including strategies to improve national food security. This thesis makes a theoretical contribution to the growing body of research on island metabolism and island industrial ecology, and also a methodological contribution in enhancing the application of the material flow accounting and analysis tool to agriculture and national food security studies.

Chapter 2
Literature Review

2.1 Introduction

The general consensus within the industrial ecology, ecological economics, and more recently sustainability science literature, is that the ongoing anthropogenic global change as evidenced in climate change, land degradation, desertification, worsening food insecurity, biodiversity loss, water scarcity and resource depletion (Steffen et.al. 2011, Hoekstra & Wiedmann 2014) amongst others is tightly linked to the prevailing trajectory of socioeconomic use of natural resources that is characterized by unsustainable modes of production and consumption (Fischer-Kowalski & Haberl, 2007; Krausmann et al. 2008b; Singh et al., 2013; Weisz & Schandl, 2008). The definition of sustainable development by the Brundtland commission in their 1987 report "our common future" (WCED 1987) provides the foundation on which sustainable development and sustainability discourse evolves. It also influences how the various debates regarding the conceptualization and operationalization of sustainability problems are framed (Daly, 1990). The Brundtland definition hinges on rational and optimal use of material and energy resources in a way that balances economic, social and environmental concerns (Costanza, 1992; Mebratu, 1998). Thus a framework for addressing sustainability issues should be one that recognizes the interdependence between economic, social and environmental systems in relation to resource flows.

As many researchers have noted, the pressing demand for a sustainable development pathway and the challenges of addressing sustainability problems has shown that neither the social systems nor the natural systems can be studied in isolation (Fischer-Kowalski & Weisz, 1999; Singh et al., 2013). Hence the need for an interdisciplinary conceptual framework in which economic activities that facilitate physical exchanges between socioeconomic systems and biophysical systems can be conceptually grounded and empirically assessed as a starting point to addressing the various social, environmental and economic sustainability challenges.

Given its social, economic and environmental history, social metabolism or socioeconomic metabolism provides the epistemological basis by which human induced sustainability problems and sustainable development can be systematically framed and operationalized (Fischer-Kowalski

& Weisz, 1999; Fischer-Kowalski, 1998, Haberl et al. 2016). To understand the concept of social metabolism, it is important to grasp its theoretical underpinnings by reviewing the intellectual history behind the evolving use of metabolism concept in social science research. The term social metabolism, socioeconomic metabolism and society's metabolism connotes the same epistemological meaning hence are used to mean the same thing in this thesis.

2.1.1 The theoretical foundations of social metabolism.

The notion of metabolism has its root in natural scientific research tradition- physical and biological sciences (Fischer-Kowalski & Weisz, 2016). Natural scientists used the concept biological metabolism to describe the complex biochemical cellular processes by which organisms convert organic matter from their environment for the purpose of maintaining and sustaining their life functions (Fischer-Kowalski & Haberl, 1997; Fischer-Kowalski, 1998). Within this context, metabolism defines the endosomatic processes that occurs inside a living organism. Thereafter, the concept of metabolism which was very useful in advancing the field of evolutionary biology found usage in the interdisciplinary field of ecology to offer a comprehensive interpretation of ecosystem relations and its complexities (Foster, 1999). In this context, the ecosystem is conceived as a self-regulatory system with feedback mechanisms in which the production and transformation of energy occurs in organisms and ecological systems based on already established physical and chemical principles- the thermodynamics laws (Fischer-Kowalski & Haberl, 1997; Fischer-Kowalski, 1998; González Martínez, 2008). Metabolism concept became a central part of ecological and biological analysis as a core concept in systems theory for understanding and interpreting the interlinkages between the biological characteristics/functions of living things and the spatial and temporal dynamics of complex ecological systems (Brown et al. 2004; González Martínez, 2008).

Moving beyond its unique biological and ecological applications, academic interest in the use of metabolism concept subsequently expanded into the social science field. The use of the term in social context began with 19th century social thinkers. Early sociologists considered society's evolution and structure as constitutive and dependent on a non-human world whereby society is seen as a metabolic system with material necessities drawn from nature for economic and social benefit to humans (Dario Padovan, 2000; Padovan, 2015). Metabolism concept was embraced as a metaphor to explain the evolution, functions and reproduction of social systems for human advancement (González de Molina Navarro & Toledo, 2014). Positivists and organicists sociologists such as Émile Durkheim, Auguste Comte, Max Weber, argued that evolution of society is inextricably linked to the evolution of nature itself and hence analogous to the biological evolution of organism (Padovan, 2000). According to Padovan, “sociologist Jacques Novicow argued that the laws of Biology as applied to single cells, clumps of cells, plants and animals can also be applied to groups of humans organized in society " (2000, p. 1). The metabolic perspective thus became an analogy to illuminate the dynamics of transformations and exchanges that support the functioning of social systems and human development.

The adoption, by social thinkers, of evolutionary perspective which had made great scientific advances in the 19th century, was instrumental in theorizing social evolution as interdependent and interconnected with the evolution of nature (Padovan, 2000; Singh et al., 2013). The notion of metabolism as a construct in social science theoretical systems did assume various meanings amongst early social thinkers spanning across various research traditions notably: classical sociology and environmental sociology, cultural and ecological anthropology, social geography and geology, human and social ecology (Haberl et al. 2016). According to Padovan (2000) “for some authors it was one concrete way in which society was embedded in cosmic evolution, which simultaneously offered models to help understand how the social system functioned; for others it was a way of describing the exchange of energy and matter between society and nature, that which permitted the reproduction of the social system and of the social achievement needed for human advancement; for others again, social metabolism was one way in which society could renew its élite. (p. 1).

However, as widely acknowledged within the growing body of literature on socioeconomic metabolism, the application of the term metabolism to society within the nineteenth century foundations of social theory, is credited to the works of two social theorists- Karl Marx and Frederick Engels (Fischer-Kowalski, 1998; Foster, 1999; González de Molina Navarro & Toledo, 2014; González Martínez, 2008). Karl Marx used the term societal metabolism as an analogy to portray material exchange between man and nature or between man and land in the context of industrialized capitalist agriculture (Fischer-Kowalski, 1998). For Marx and Engels, the notion of metabolism (Stoffwechesel) is a perpetual dynamic relationship between nature and human society whereby man appropriates nature through production mediated by labour process. As succinctly captured in Fischer-Kowalski seminal paper on society's metabolism and intellectual history of material flow analysis part 1, Marx and Engel posits that "the labour-process . . . is human action with a view to the production of use values, appropriation of natural substances to human requirements; it is the necessary condition for effecting exchange of matter between man and nature; it is the everlasting nature-imposed condition of human existence, and therefore independent of every social phase of that existence, or rather, is common to every such phase" (Fischer-Kowalski 1998, p. 64). In this regard, Marx's dialectics of society's metabolism can be contextualized in two ways, as a recurring transformative exchange process in the evolution of human development underpinned by human appropriation of nature on the one hand, and development of the relations of societal production and consumption through the flows of goods and capital mediated and controlled by labour process on the other hand.

Critics of Marx and Engels dialectical conception of social metabolism contends that their views overly autonomized social processes (labour power) from the ontological materialism of natural world thereby placing more value on labour while de-emphasizing the value in ecological systems, which they reckon ignores the natural limits to material productive forces of society (Foster, 1999; González de Molina Navarro & Toledo, 2014). On the contrary, a critical review of Marx's social theory in which he noted that the metabolic relations between human beings and the environment under capitalist agricultural mode of production would result in an irreparable rift between economic production and its natural conditions would reveal that Marx in fact did put forth a socioecological argument. This was captured in Fosters "Marx's theory of metabolic rift" (see Foster, 1999, p. 378-381). Notwithstanding, as discussed in Fischer-Kowalski (1998) seminal paper on society's metabolism, the important contributions from Marx and Engel along with other 19^{th} and early 20^{th} century social scientists such as Herbert Spencer's "energetic theory of evolution" (1862), Podolinsky's "agricultural energetics" (1880), George Marsh's "man and nature" (1864), Morgan Julian (1877), Steward's "method of cultural ecology" (1968), Leslie White's 'metabolic theory of cultural evolution" (1949), Ordway's "theory of the limit of growth" (1956), among others- laid the theoretical foundations for the development of social metabolism as an interdisciplinary framework for conceptualizing relations of exchange and transformations between society and nature.

However, Marx's ruminations on the structure of social metabolism in a fast changing agrarian society; which was central to his critique of political economy (Foster, 2013; Foster, 1999; Padovan, 2015) did not resonate with most social scientist especially economics scholars of his life time but rather was a subject of scrutiny. Due to huge economic and technological success of industrial revolution, the economy was not viewed from a sociometabolic perspective as it was culturally unacceptable to critique economic growth.

The application of metabolism concept re-emerged into the discourse on how humans interact and relate with the environment following a reawakening of the growing anthropogenic impacts associated with economic growth in industrial societies (Fischer-Kowalski, 1998) and as the crisis of mass consumption of fossil fuel started to become apparent (González Martínez, 2008). In 1955, an international symposium that saw the gathering of seventy eminent scholars from both natural and social science disciplines was held in Princeton New Jersey in search of explanations to the growing problems of global change (Ayres & Ayres, 2002). The papers and discussions presented at the symposium were published in a 1,200-page compendium "titled Man's Role in Changing the Face of the Earth" (Fischer-Kowalski 1998, p. 68). The outcome of this conference acclaimed to be the "first high-level inter-disciplinary panel on environmental problems of human development" (Fischer-Kowalski 1998, p. 68) became the pioneering work in the field of environmental research. Two decades later- in 1971 precisely, the United Nations Education, Scientific and Cultural Origination's (UNESCO) "Man and the Biosphere" (MAB) program was launched as a response to the pressing need for a scientific base and a framework of action to respond to growing global challenges, aimed at providing an effective and functioning model for sustainable development towards improving societal well-being while maintaining ecological integrity (Haberl et al., 2016).

An earlier attempt to develop an operative conceptual framework analyzing the impacts of socioeconomic activities on environmental relations was championed by Abel Wolman (1965) and Robert Ayres & Allen Kneese (1968, 1969 1970). While the economy has traditionally been seen as a separate system from the environment and only described in monetary terms, "some natural scientists (Robert Ayres) along with some dissident economists (Nicholas Georgescu-Roegen, Kenneth Boulding, and K.W. Kapp, Herman Daly) started to see the economy as a subsystem embedded in a physical system described in terms of flows of materials and energy" (Martinez-Alier, 2009), thus espousing the conception of economic activities from a biophysical perspective. Abel Wolman in his 1965 case study of a model US city of 1 million inhabitants declared that "the metabolic requirements of a city can be defined as the materials and commodities needed to sustain the city's inhabitants at home, at work, and at play. . . . The metabolic cycle is not completed until the wastes and residues of daily life have been removed and disposed of with a minimum of nuisance and hazard" (Wolman 1965 p.179 as cited by Fischer-Kowalski, 1998). Ayres- who is believed to have introduced the notion of industrial metabolism, along with Kneese-an economist in their first material flow analysis for the United States between 1963 and 1965 conceived the metabolism of industrial society as an input problem. Further, Kenneth Boulding (1966) in his "The Economics of the Coming Spaceship Earth'' advanced the shift from a cowboy economy- one that emphasizes the maximization of material mobilization as a measure of societal progress to a spaceman economy- one whose main focus should be on reduction in material throughput for environmental preservation (Fischer-Kowalski, 1998). Similarly, Donella Meadows' "limits to growth"- a report for the club of Rome project, questioned the idea of continuous economic growth and asserts the need to recognize the biophysical limits to economic growth in order to remain within the earth's carrying capacity (Meadows et al., 1972).

These theoretical debates and deliberations culminated in the emergence of contemporary interdisciplinary research fields- industrial ecology, ecological economics and most recently sustainability science- that employ the metabolism approach in their various research agendas (Singh et al., 2013). Social metabolism offers an important research paradigm to bridge the once theoretical dissonance between social sciences and natural science vis-à-vis studying and understanding socioecological problems (Fischer-Kowalski & Weisz, 2016). Indeed, Marx's conceptualization of society's metabolism has definitely come to bear its full significance in designing socioecological research today, providing a valuable framework for a praxis-based approach to sustainable development and the questions of sustainability. In the words of Gonzalez de Molina Navarro & Toledo (2014), "Marx skepticism, which Engels nourished and shared left unaccomplished the development of a research line that has today become strategic" (p. 49). It is within the conceptual framework of social metabolism and the corresponding methodological tool -material flow accounting and analysis that this research thesis subsumed.

2.2 Social Metabolism

In both academic and policy sphere, sustainability and sustainable development has been recognized as a problem of society- nature interaction through socioecological systems (Haberl et al. 2004; Fischer-Kowalski & Erb 2016). To this, extended notion of metabolism which transcends beyond industrial application- (industrial metabolism) has been adapted into a broader analytic concept known as socioeconomic metabolism employed in studying the interrelations and interconnections between society and nature (Fischer-Kowalski & Weisz, 1999; Fischer-Kowalski & Hüttler, 1998; Pauliuk & Hertwich, 2015), thereby offering an important research paradigm to bridge the once theoretical dissonance between social sciences and natural science vis-à-vis studying and understanding sustainability in socioecological systems (SES) (Fischer-Kowalski & Weisz, 1999).

The operational model for socioeconomic metabolism concept derives from systems approach whereby the conception of society-nature interaction is seen as a complex co-evolutionary process occurring through socioecological systems (SES), with feedback mechanisms (Fischer-Kowalski & Haberl, 1997; Fischer-Kowalski & Weisz, 1999; Pauliuk & Hertwich, 2015). In systems approach, society is viewed as a complex autopoeitic system (Pauliuk & Hertwich, 2015; Rammel et al., 2007; Zurlini et al., 2008) capable of regulating, maintaining and reproducing itself including its biophysical stocks by organizing materials and energy flows from its environment into socioeconomic systems (Fischer-Kowalski & Haberl, 1997; Haberl et al., 2013; Pauliuk & Hertwich, 2015). The basic notion of society was well articulated in Fischer-Kowalski and Weisz (1999) as a hybrid of the natural realm - a system of biophysical regulations functioning by way of flows of material and energy and a symbolic or cultural realm- system of social regulations functioning by way of communication (p.23). It can therefore be said that socio-ecological systems (Figure 2.1) comprises of socioeconomic systems and ecological systems, having natural sphere of influence (with material realities) and cultural or symbolic sphere of influence (with social realities) which together constitutes the biophysical structure of society through which society-nature interaction occurs (Haberl et al., 2004; Pauliuk & Hertwich, 2015).

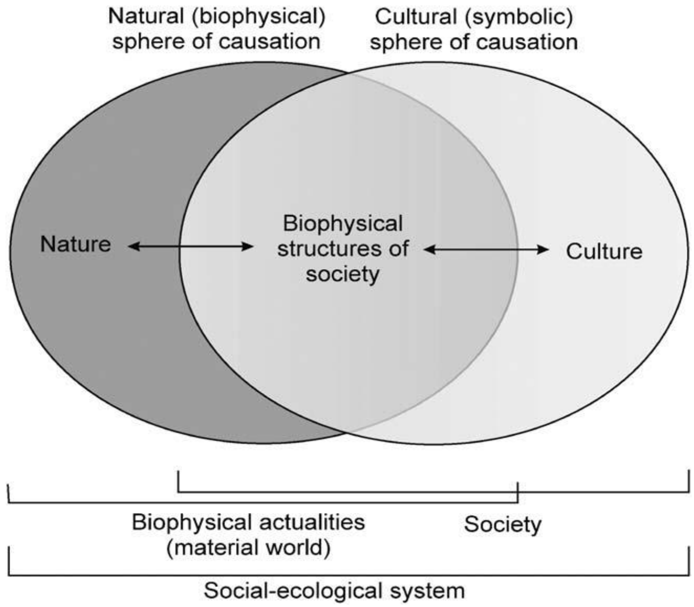


Figure 2.1 Social-ecological systems as overlap of a natural and a cultural sphere of causation (Source: Haberl et al., 2004).

From the above given perspective, socioeconomic metabolism encompasses events, processes that allow for the self-reproduction and evolution of the biophysical structures or material components of a society. The material components of a society comprise of those biophysical stocks that are created in a system through human labour (Fischer-Kowalski and Weisz,2016). In MFA literature, biophysical stocks refer to human population, domesticated livestock and durable artifacts such as buildings, roads, machines and anything that stays in the system for longer than a year (Haberl et al., 2016). Essentially, a certain level of biophysical stocks needs to be maintained for proper functioning of and overall sustenance of any system. To achieve this, society's biophysical stocks needs to be expanded and/or reproduced through constant flows of material and energy resources (Fischer-Kowalski and Haberl, 2007; Haberl et al., 2016). This interactional relationship between biophysical stocks and material and energy flows is enabled by two complementary metabolic activities; first is input process which involves appropriation or extraction of resources and services and the second is output process which involves excretion or expulsion of resources (Haberl et al., 2006; Pauliuk & Hertwich, 2015); this forms the underlying notion of socioeconomic metabolism.

To put it in definitive context, socioeconomic metabolism refers to an integrated physical process of materials and energy extraction from the natural environment, their transformation within economic process (production, consumption and transportation), accumulation of socioeconomic stocks and their maintenance and their eventual release into the environment as wastes and residues or as deliberate discharges such as fertilizer or pesticides (Fischer-Kowalski & Hüttler, 1998; González de Molina Navarro & Toledo, 2014; Haberl et al., 2016).

The notion of socioeconomic metabolism provides a useful heuristic model for understanding the biophysical basis of society. It scientifically articulates the interrelationships between economy and environment by examining how humans through socioeconomic activities appropriate natural capital to maintain material and energetic throughput (Haberl, 2006; Haberl et al., 2004), thus giving an empirical insight into the physical size of an economy. The underlying idea is that every socioeconomic system has a physical dimension or metabolic profile determined by the quantities, compositions and characteristics of their material and energetic throughput which bears on the size of the physical economy[5] (González Martínez, 2008; Haberl et al., 2004).

As a consequence, five basic metabolic processes -extraction, distribution or circulation, transformation, consumption and expulsion- that characterize the organization of SEM has been identified (see González de Molina Navarro & Toledo, pg. 18). Therefore, socioeconomic metabolism studies may be focused on any of the metabolic processes and may on the one hand be concerned with material metabolism which is mass flows of inputs of materials into socioeconomic system per time or over a chosen reference period whereby inputs transformed through economic process becomes outputs or accumulated as stocks and on the other hand focused on energetic metabolism which monitors energy flows within and between defined systems (Fischer-Kowalski & Haberl, 1997). The present study is focused on material inputs, covering two metabolic processes- extraction/appropriation (production) and consumption.

SEM has become well established in various interdisciplinary research field (sustainability science, ecological economics, industrial ecology, environmental history, human and social ecology) seeking to develop a scientific basis for sustainable production and consumption patterns

[5] The idea of a physical economy is analogous to a living organism, developing and growing under the combined influence of material, energy and information flow made possible through technological and scientific advancement which increases the productive power of society.

towards achieving sustainable development (González de Molina Navarro & Toledo, 2014; Haberl, 2006). These research are designed to explore various objectives that often aims at addressing specific social, economic or/and environmental research agenda. Thus, the application of SEM concept covers a wide spectrum and can be approached from various perspectives (González de Molina Navarro & Toledo, 2014; Singh et al., 2012). In addition, a number of quantitative system of analysis and methods that benefits from the underlying idea of SEM to assesses the biophysical basis of society have equally emerged and evolved overtime (Pauliuk & Hertwich, 2015). The economy-wide material flow analysis (EW-MFA) method which is employed in this study, has become well situated in SEM research as an empirical basis to operationalize research questions in this area.

2.3 Economy-Wide Material Flow Analysis

The history of the EW-MFA and its guiding principles as a methodological framework in socio-ecological research goes as far back as the late 1960s, and has been linked to the pioneers of the field of industrial ecology- Robert Ayres and Kneese who were said to have made the first attempt at developing an operational framework for metabolism of society (Ayres & Kneese, 1969; Ayres & Ayres, 2002; Fischer-Kowalski & Hüttler, 1998). Their work was focused on analyzing the metabolism of industrial societies, hence the notion of industrial metabolism which describes the process of material and energy flows through industrial systems (Ayres, 1978; Fischer-Kowalski & Hüttler, 1998). Ayres along with Kneese-an economist conducted the first material flow analysis for the United States between 1963 and 1965. Their work conceived the metabolism of industrial society as an input problem that can be solved through efficient use of material resources (Fischer-Kowalski, 1998; 1998; Singh & Eisenmenger, 2010). By the 1990s, MFA gained scientific ground in the field of industrial ecology and ecological economics a wave of research using the MFA approach to assess metabolism of national economies in Europe were published[6] (Bringezu et al., 2003; Singh & Eisenmenger, 2010). A comprehensive review of earliest national case studies on MFA study and their methodological approach is contained in Ayres and Ayres (2002) “Handbook

[6] According to Bringezu et al (2003), national material flow balance was developed to monitor the total material requirement (TMR) of these western economies.

on industrial ecology". In the field of Industrial ecology, MFA approach along with other relevant and related approach such as substance flow analysis (SFA), life cycle assessment (LCA), input-output analysis and more recently multiregional input-output analysis (MRIO) has become well-developed as an analytic methodological approach utilized in the systematic assessment of stocks and physical resource flows through a given socioeconomic or industrial system be it productive system, ecological system or socioeconomic system; defined in spatial and temporal scale (Ayres & Ayres, 2002; Bringezu et al., 1997).

The economy-wide material flow analysis was developed from the broader concept of MFA due to the need to enhance the comparability of MFA results across national economies. To this effect, the EW-MFA approach has undergone series of international methodological standardization and harmonization to improve its comparability (see Eurostat EW-MFA methodological guidelines 2001, 2009, 2012, 2013). EW-MFA is a physical accounting tool that provides an aggregate overview in tonnes of annual material throughput of a national economy which includes material inputs[7] from natural environment and material output[8] to the environment plus trade flows-physical imports and exports- of national economies, using the national economy-wide material flow accounts and balance (Bringezu et al., 2003; Fischer- kowalski et al., 2011). In EW-MFA, the economy is treated as a "black box", this implies that material or product flows moving between various sectors inside the economy are regarded as internal flows hence not considered (Fischer- kowalski et al., 2011; Kovanda et al., 2012). Therefore, this approach is concerned with quantifying/assessing the exchange of materials resources between the functional boundaries of a national economy, its domestic environment, and the rest of the world economy and environment (Krausmann et al., 2015), thereby establishing a link between inputs and outputs of material flows (Bringezu et al., 2003; Weisz et al., 2007). EW-MFA provides the empirical basis to operationalize socioeconomic metabolism- that is quantifying the biophysical basis/material basis of national economies. EW-MFA has gained acceptance as a system of environmental headline indicator for national economies in environmental accounting thus have become a political

[7] Material inputs is defined as domestic extracted materials (excluding air and water) from the natural environment of the domestic economy plus imported goods from the rest of the world.
[8] Material output is defined as all disposed materials to the natural environment plus all exports of material products to the rest of the world economy, including waste, emissions and dissipative losses.

relevant tool for monitoring economic and environmental progress towards sustainability and sustainable development especially in Europe (Haberl et al., 2004).

A general conceptual framework for EW-MFA (Figure 2.2) is based on the principle of mass balancing whereby the inputs entering a system equates to the output leaving the same system plus net accumulation of materials in the system -which makes up the stocks (Fischer- kowalski et al., 2011); in line with the logical reasoning of the law of conservation of mass (Singh & Eisenmenger, 2010). From the compiled EW-MFA, a number of resource use- input based, consumption and output based indicators can be derived (see Figure 2.2). Using this system of derived indicators[9], a holistic and integrated insight into the patterns, trends and compositions of physical resource flows in a national economy can be presented in a consistent and systematic manner.

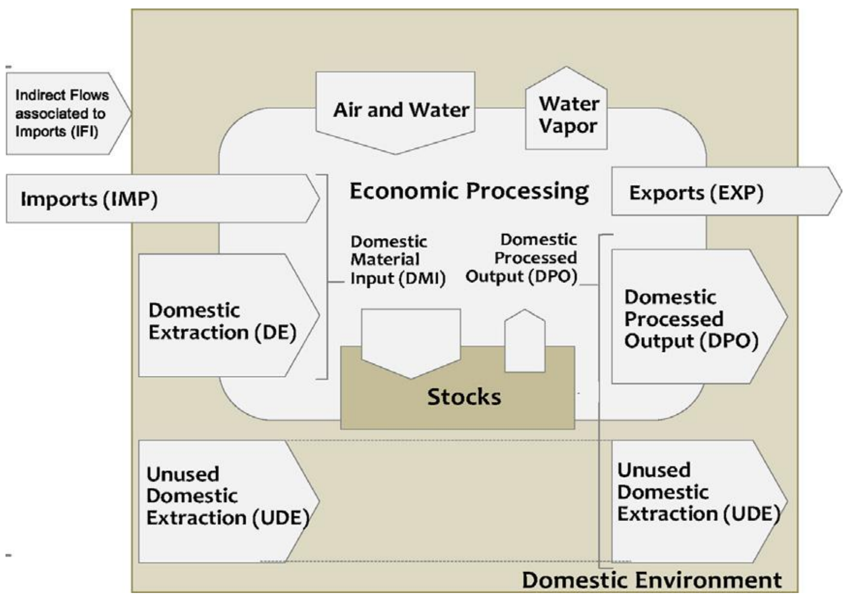


Figure 2.2 Schematic representation of the generic EW-Material flow framework showing the main material flow indicators (Raupova, Kamahara, & Goto, 2014)

An analysis of economy wide material flows offers details on the physical dimensions of the socioeconomic system being studied in terms of its material basis and biophysical limitations

[9] EW-MFA aggregate indicators are calculated from input and output flows (input indicators an output indicators) and may be differentiated as consumption or/and production indicators. These indicators may be combined with monetary indicators such as GDP to answer specific research questions on resource productivity. See Eurostat (2001) for details on material flow indicators.

(Giljum et al., 2010; Singh, 2012). Such analysis also helps to illuminate the complex and abstract relationship between ecological problems, social activity and socioeconomic development in a clear consistent and measurable and identifiable manner (Bringezu & Schütz, 2012; Kovanda et al., 2010). By analyzing the structure and processes of material flows, insights into their impacts on society, the economy, the natural resource base, and the environment can be gained.

Scientific research that employs the MFA methodology are usually carried out within two different frame of reference: environmental perspective or socioeconomic perspective and at different temporal and spatial scales and levels. The following conceptual considerations should be made when carrying out a MFA: the systems boundary, material representation (i.e. the inclusiveness or exclusiveness of materials to be studied), and the unit of analysis (Fischer-kowalski et al., 2011). When undertaking an EW-MFA of socioeconomic systems a clearly delineated system boundary defined in time and space has to be established (Eurostat, 2001). There are three categories of physical flows which are important in socioeconomic metabolism: water, atmospheric gasses, and materials from the earth crust (Eurostat, 2001; (Fischer- kowalski et al., 2011; Kovanda et al., 2012). The Eurostat EW-MFA methodology stipulates that water flows represent enormous mass flows in higher orders of magnitude hence excluded in the general scheme of EW-MFA (Eurostat, 2001). Air flows are equally excluded but may be used as a balancing item if a study is concerned with conducting a material flow balance analysis. Thus only the four main material categories extracted from the earth crust namely, biomass, fossil fuels, industrial minerals/ores, and construction minerals are assessed. EW-MFA studies may focus on analyzing bulk materials flow -the four material categories, or any specific material flows, and analysis may be conducted in time series or a particular year, depending on available data.

Further, an important distinction is made between used and unused material extraction in regards to input flows, as well as indirect flows resulting from imports and exports often referred to as hidden flows. Used extraction denotes those material flows that go into economic production processes while unused extractions are material flows moved in the process of resource extraction such as mining overburden, biomass waste left behind from wood logging etc. but do not offer any economic value and hence does not enter the economy (Fischer- kowalski et al., 2011; Ginley & Cahen, 2012; Haberl et al., 2004). The importance of accounting for unused extractions and hidden flows have been dully recognized (Matthews et al., 2000; UNEP, 2015; Haberl et al., 2016). In global sustainability context, accounting for these hidden flows have implications on evaluating environmental burdens associated with resource use and consumption. However, mainstream MFA approach currently follows a production logic. This means that only the mass of materials extracted within the territorial boundary of the focal country plus the weight of traded commodity arriving at its national border is accounted. The upstream resource requirements of traded commodities (resources used that are not physically traded, waste and emissions generated from production of the imported goods) are attributed to the producing or exporting countries (Schaffartzik et al., 2016). The present study follows the mainstream MFA approach, hence only used biomass material direct flows have been considered.

2.3.1 Empirical findings using Economy-Wide Material Flow Analysis

A survey of relevant literature revealed a variety of studies conducted using socioeconomic metabolism and corresponding MFA approach at different spatial scales- national, global and regional level. Extensive analysis has been conducted for the European union (EU) member States though these studies were carried out supra-national level as country aggregates in which material use size, structure and patterns of flows were compared across individual countries within the EU (Weisz et al., 2006), and past developments of material use, material productivity and efficiency and future patterns of resource use in the EU were assessed (Giljum et al., 2008; Kovanda et al., 2012; Tanning & Tanning, 2014).

In the light of increasing anthropogenic global change, the biophysical characterization of the global economy at aggregated level of material use illuminating world-wide patterns of resource extraction, trends in global material use and resource productivity as well as the compositions of global material use and a global perspective on metabolic transition has been conducted (Behrens et al., 2007; Krausmann et al., 2013; Schaffartzik et al., 2014). During the 20th century- a period characterized by rapid industrialization, the overall size of global material increased 8-fold alongside economic prosperity; since then global material extraction has grown by one order of magnitude from 60 billion tonnes to 70 billion tonnes (Krausmann et al., 2009; Krausmann et al., 2013). Changes in the scale and magnitude of material extraction corresponds to changes in population and primary energy consumption during earlier periods of industrial development.

However, global material use has continued to grow at an annual rate of 3.4% albeit faster than population growth (Schaffartzik et al., 2014); over 90% increase in global material extraction has been recorded in the last three decades (Giljum et al., 2014). In addition, significant changes in the composition of material flows have been observed over the past decades. According to Krausmann et al., (2013), since after world war 2-a period characterized by rapid industrial growth and demographic transitions, the share of biomass material in total material use declined while the share of fossil fuel and mineral materials increased considerably accounting for 70% of total used extraction globally. Further, between 1950 and 2010 per capita material use doubled from 5.0 to 10.3 tons per capita per year while annual material consumption grew from 3.7-71 gigatonnes (Schaffartzik et al., 2014).

While information and statistics on global material production and consumption illuminates the scale and rate of material appropriation globally, it does not reflect the dynamics of material use across the globe at such highly aggregated level of domestic material extraction and consumption. This is because different countries have different socioeconomic and political realities and differing patterns of demographic reproduction which contributes in defining resource use trajectories (Giljum et al., 2014; Weisz & Schandl, 2008). Research on size and structure of global material use has shown that the distribution of material flows and the patterns of material extraction and consumption as well as the composition of material flows is highly uneven across different countries and regions of the world (Schandl & Eisenmenger, 2006; Weisz & Schandl, 2008). The quantity and quality of material use varies across countries and across regions. According to Behrens et al. (2007) with only 15% of global population, western economies consume about "50% of global fossil fuel production, over 50% of global primary aluminum production, and almost 65% of global lead production" (p. 450). Krausmann et.al (2008b, 2013) also noted that disparity in material use per capita per year- in terms of production and consumption, varies even more significantly as you move from industrialized or high-income countries to middle and low-income countries- "per capita material and energy use in industrialized clusters is higher than in developing regions by a factor of 5 to 10" (2008, p.637). Whereas an individual metabolic rate in a fully industrialized country is estimated at 15 tonnes, per capita material consumption in developing countries stand at 3 tonnes per annum (Krausmann et al., 2013). A number of time series analysis at the national spatial scale has been carried out for high income countries such as the physical economy of the United States of America from 1870 to 2005 (Gierlinger & Krausmann, 2012); Australia's resource use trajectory over three decades (Schandl et al., 2008); historical perspective on resource use and metabolic transition in Japan from 1878 to 2005 (Krausmann et al., 2011) and United Kingdom (Krausmann, Schandl, & Sieferle, 2008). Using standard biophysical indicators[10] for resource use. These case studies addressed questions on resource productivity, material efficiency and material intensity. Given the compatibility of the EW-MFA with the already established system of national accounts (SNAs) from which the indicator GDP is derived to measure the magnitude of economic activity in monetary terms (OECD, 2012; Eurostat, 2001), EW-MFA research have been applied towards policy-oriented analysis such as measuring progress towards decoupling of resource use from environmental impacts and economic growth (Fischer-Kowalski & Swilling, 2011); material flow indicators are used alongside GDP to measure resource productivity and intensity as a measure of decoupling (UNEP 2011; Giljum et al., 2010; Giljum et al., 2014).

Further, centering national socioeconomic metabolism in global context, Singh et al. (2012) characterized the biophysical dimension of India's economy to illuminate the constraints and challenges that confront countries undergoing rapid sociometabolic transition in an era of declining global geologic stock, rising global material resource consumption and increasing global population. Empirical results from the study of Singh et al., (2012) study underscores the assertion that process of transitional change from agrarian sociometabolic regime to industrial regime induces a radical shift in the quantity and composition of material flows. This was underscored by (Krausmann et al., 2008b; Krausmann et al., 2011; Schandl & Schulz, 2000) in the sociometabolic transition of Japan, Austria and the United Kingdom. The development of a characteristic metabolic rate by economies undergoing rapid economic transition such as Czechoslovakia (Kovanda & Hak, 2011); Uzbekistan (Raupova et al., 2014), that mirrors that of industrialized economies raises questions on how to sustain the current structure of material production and consumption in the face of resource constraint and rising environmental concerns. Insights drawn from monitoring and

[10] Standard biophysical indicators are indicators developed within Organization for Economic Co-operation and development (OECD) and European Statistics (EUROSTAT) that provides a quantitative measure of material and energy flows and associated impacts, they are a range of derived material flow indicators.

analyzing material flows patterns in these transitioning societies can provide a baseline for projecting future trends in resource use and hence allow for the assessment of economic and resource use policies towards sustainable resource management through scenario modeling as demonstrated in Giljum et al., (2008).

Understanding socio-metabolic transitions of economies is very crucial because a successful sustainability transition requires that we understand the processes and path dependencies that have shaped the structure of contemporary physical economy. In Haberl et al. (2011), a theoretical insight into various sociometabolic regimes and characteristic metabolic profiles were presented. The study empirically demonstrated how historical transition process in the course of evolution of human society shaped our contemporary society and laid the foundations of today's global environmental change. While most societies still exhibit metabolic profiles characteristic of agrarian regime, transition to industrial mode of production is rapidly underway (Haberl et al., 2011); restructuring the patterns of material production and consumption in various economies with attendant environmental and social consequences. The patterns of material use and per capita material consumption at individual country level is highly varied and dynamic and this bears consequence on trajectory of national economic and social development. The variability and distributional inequality in material extraction and consumption raises the question of what drives material use? Using a material flow data set covering a 175 countries, (Steinberger, Krausmann and Eisenmenger., 2010) identified these geophysical and socioeconomic factors -climate, land area, population, income and GDP as the drivers of the observed differences in global material use.

Further, integration of different world regions into the global market driven by advances in global economic production due to progress in technological innovations is inevitably linked to resource appropriation beyond national borders (Bruckner et al., 2012; Schandl & West, 2012). The trade sector is a crucial part of the production system in national economies (Haberl et al., 2004). The patterns of exchange relations in foreign trade play key role in shaping resource use trajectories and hence the metabolic profile and metabolic rate of national economies (Bruckner et al., 2012; Giljum & Eisenmenger, 2004; Schütz et al., 2004). In this regard, the degree as well as nature of integration into the global economic market in terms of imports and exports weighs significant influence in patterns and compositions of resource consumption and production as well as how the structure of this trend evolves over time (Schandl & Eisenmenger, 2006; Schandl & West, 2010; Singh & Eisenmenger, 2010; West & Schandl, 2013).

However, the implications of trade and globalization on the socioeconomic development of national economies in the global south have long been a contentious issue (Muradian & Martinez-Alier, 2001). To further buttress this point, West and Schandl (2013) noted that extractive economies- those of middle and low income countries- whose development pathways are based on exploitation of natural resources are confronted with characteristic environmental and social impacts. Extractive economies as articulated by Schaffartzik et al (2016) depends on export of primary commodities as an important source of revenue. The largest share of GDP come from the extractive sectors of such countries and often times, natural resources are exploited beyond their regenerative capacity (p. 102). Rising conflicts resulting from expansion of extraction frontiers underlines changes in global socioeconomic metabolism, bringing to light the issue of unequal international trade dependencies in the context of resource appropriation and consumption (Schaffartzik et al., 2016). A number of studies have examined patterns and structure of global resource appropriation, consumption and trade in the context of North-South relations and how this engenders social and ecological distribution inequality (Giljum, 2003; Giljum & Eisenmenger, 2004; Martinez-Alier et al, 2010; Muradian & Martinez- Alier, 2001; Schütz et al., 2004; Singh & Eisenmenger, 2010). A key focus area is mining activities- extraction of industrial minerals and metal ores. Focusing on material extractivism, the metabolism of industrial minerals and ores was conducted by Schaffartzik et al. (2016) wherein the dynamics and patterns of global metal extractivism in the context of trade was evaluated in time series, expounding the associated social and environmental conflicts arising from global metabolism of industrial minerals.

The relevance and utility of EW-MFA as a sustainability assessment tool has been acknowledged in some studies that monitored the total material requirement of a physical economy; capturing indirect flows of material associated with trade (Bruckner et al., 2012). An analysis of the biophysical perspective of a typical middle income extractive economy illustrated the dynamics in resource use patterns for economies highly dependent on trade for its development and provided insights on the role of the primary sector economy in driving change in society relations with the environment. (Gonzalez-Martinez & Schandl, 2008; Manrique et al.,2013).

In recent times, the scope of application of EW-MFA has expanded beyond evaluating the biophysical basis or material basis of national economies, monitoring efficiency and productivity. Monitoring efficiency and productivity of resource use is important given that while rapid technological advancement may have led a more sustainable production process (e.g. green products requires less materials in its production chain), absolute decoupling is yet to occur due to rebound effect (Hertwich, 2005). The rebound effect is a behavioral response whereby "increase in efficiency are frequently overcompensates by "growth effect' hence do not translate to corresponding reductions in resource use" (Binswanger, 2001, p. 120). The robustness of MFA approach makes it flexibly adaptable to various research agenda within the sustainability science and industrial ecology field and can be easily combined with other research method to analyze material flows and associated impacts/challenges arising from socioeconomic development, thus making the application of EW-MFA in SEM research highly dynamic. In this regard, the EW-MFA has been applied in measuring the biophysical dimension of socioeconomic activities. For instance, in a time series study, Wang et al. (2012) and Xu & Zhang. (2004) conducted an EW-MFA of fossil fuel use in Chinese economy examining the relationship between supply and demand of fossil fuel using three derived indicators consumption and supply ratio (C/S ratio), resource consumption intensity (RCI), and fossil fuels productivity (FFP), and two socioeconomic variables- GDP and population.

Further, there is growing research interest in socioeconomic metabolism and EW-MFA of island socioeconomic systems, although analysis of certain activities using the MFA approach that have focused on small islands is not new. Given that the present study is focused on an island socioeconomic system- the food and agriculture system in Jamaica, it is important to review the current state of knowledge on material flow analysis and socioeconomic metabolism in island context.

2.4 Socioeconomic Metabolism and Material Flow Analysis in Island context

Islands systems have served a useful object of study for many successful scientific discoveries seeking an explanation on the occurrence of various phenomena in the course of human history (Chertow, Fugate, & Ashton, 2013). This is due to their unique geophysical, economic and ecological characteristics (Wong et al., 2005). Generally defined through a geophysical descriptive lens as small units of land mass surrounded by water with high proportion of coast to hinterland area, islands are close and bounded systems, separated by the ocean from continental landmasses (Chertow, Fugate, & Ashton, 2013; Douglas, 2006). Islands are faced with the challenge of limited land area and are intrinsically disadvantaged in terms of socioeconomic development imperatives, due to their narrow resource base, high population density, fragility of their land, coastal zones and marine ecosystems and the volatility of global economic system (Deschenes & Chertow, 2004; Owens, Zhang, & Mihelcic, 2011). From a social-ecological perspective, these peculiarities increase the susceptibility of island systems to natural disasters and also, exposes them to the pressures of global human interventions.

Island systems- particularly the low lying coastal countries- are the most vulnerable to global changes and thus face the greatest sustainability risk and threat to sustainable development. In recognition of this, the 47th session of the United Nations General Assembly (UNGA) at the 1992 Earth's summit held in Rio de Janeiro identified distinct groups of developing countries that are vulnerable to and confronted with specific sustainability and sustainable development challenges as Small Island Developing States (SIDS) in the context of agenda 21- chapter 17 G (UN-OHRLLS, 2013). There are presently 52 countries and territories spread across three geographical regions- the Caribbean, the Pacific and the Atlantic, Indian Ocean, Mediterranean and South China Sea (AIMS) classified as SIDS (UNOHRLLS, 2013). The Caribbean islands represents an economic grouping of 15 nations (called the Caribbean community market- CARICOM) in the SIDS (Saint Ville et al., 2015), with Jamaica being one of the member state.

There is a pervasive level of co-dependency in the interaction between socioeconomic systems and the natural environment on small islands. Due to their geographically small spatial size, their political, socioeconomic and environmental systems are strongly interconnected (McElroy & de Albuquerque, 1990). Socioeconomic development is reliant on narrow range of export commodities and services as well as on the import of vital goods and services needed to sustain their economy and maintain the wellbeing of their small but growing population (Wong et al., 2005). Hence, while SIDS have relatively small economy compared to Continental States, it is not always reflected in their material use trajectory and metabolic profiles as their physical economy is enormously influenced by trade flows.

Given their characteristic small undiversified economies and strategic locations to the ocean, SIDS are highly integrated into the global market hence are vulnerably exposed to fluctuations in economic globalization as they rely on the functioning of the global market for their export and import oriented physical economic structure (Chertow et al., 2013; Krausmann, Richter, & Eisenmenger, 2014). However, it is important to note that by virtue of their geospatial characteristics they act as "windows" and "bridges" (Singh & Grünbühel, 2003). This attribute act to either limit or increase the degree of their integration into the global economy, and also influences their development trajectory either towards dependency or self-sufficiency (Chertow et al., 2013; Deschenes & Chertow, 2004; van der Velde et al., 2007). The distinctive biophysical and socioeconomic characteristics puts small island states on a unique development pathway.

The unique physical and geographic characteristics of island systems offer a manageable unit of analysis or experimental model for scientific enquiry (Chertow et al., 2013; Deschenes & Chertow, 2004) and various research agendas that examine society-nature interaction can benefit in this regard. To quote Chertow et al. (2013), "islands provide a place to conceptualize human-nature interactions in socio-ecological systems and to explore how such phenomena occur within decisive boundaries" (p. 315). Despite this, the socioeconomic metabolism of SIDS on a national spatial scale is poorly researched. Conrad and Cassar (2014) examined economy-environment relationship of small island state of Malta focusing on assessing the extent to which decoupling of economic growth from environmental degradation has been achieved. While their study was not carried based on MFA approach, it nonetheless expounded the unique challenges that confront island systems sustainability. There are a number of studies though that have applied material flow analysis in evaluating regional waste water and solid waste management (Belevi, 2002) and assessment of long term waste management strategy in Oahu, Hawaii (Eckelman & Chertow, 2009; Houseknecht, 2006) and mapping and evaluating household solid waste generation and management (Owens et al., 2011). Concerns of these studies underpinned the utility of MFA in enhancing the understanding of waste generation and disposal so as to identify potential effective and sustainable management practices towards sustainability.

However, there are few research studies undertaken in socioeconomic metabolism and economy-wide material flow analysis of island systems. Singh et al. (2001) and Singh & Grünbühel.

(2003) analyzed the socioeconomic metabolism and environmental relations of Trinket Island (in the Nicobar archipelago, India), illuminating how externally driven metabolic transition towards dependency is gradually altering the pattern of local material consumption in a once remote self-sufficient island. Krausmann et al. (2014) conducted a time-series comparative study of island-wide material flow analysis for Iceland and Trinidad and Tobago in which the development of material use trajectories was empirically assessed illuminating how two island states exhibit different metabolic profile due to differences in institutional arrangements and the level infrastructural development. Although their study revealed a growing trend in overall material use (considering all four material categories) for the two island states, per capita biomass material use in Trinidad and Tobago -a Caribbean island nation- showed a declining trajectory, which is attributable to the ongoing sociometabolic transition from biomass to an oil based economy in Trinidad and Tobago (Krausmann et al., 2014). Also, an EW-MFA of the island of Cuba carried out by Eisenhut (2009) found a similar declining trend in biomass production. It is important to note that decline in biomass use may not be peculiar to Caribbean island states. A recent study on material flow trends in the Philippines- a non-Caribbean small island state revealed a decline in biomass use suggesting a shift from the consumption of dominance of renewable materials to non-renewable material (Martinico-Perez et al., 2016). A similar trend was also observed for Iceland- a non-Caribbean small island state (Krausmann et al., 2014).

2.5 Socioeconomic Metabolism and Material Flow Analysis in Agriculture

. The socioeconomic metabolism approach has been applied in assessing the biophysical dimension of agricultural activities through the analysis of patterns of biomass metabolism. Most researchers that have evaluated biomass flows have done so from socio-ecological perspective, using a hybrid analytical approach such as a MEFA and the HANPP[11] which stands for human appropriation of net primary production to relate socioeconomic metabolism of biomass to land use intensity and land cover change (Grešlová, et al. 2015; Grünbühel et al., 2003; Haberl et al., 2003; Haberl et al.,

[11] The human appropriation of net primary production (HANPP) is an integrated socioecological indicator quantifying effects of human-induced changes in productivity and harvest on ecological biomass flows"(Haberl, Erb, & Krausmann, 2014). Most research dedicated to land use accounting in relation to biomass flows employ this accounting framework.

2013; Imhoff et al., 2004; Kuskova et al., 2008). Assessment of biomass material flow in sustainability context is highly relevant given that biomass is the second largest material flow at the global scale and biomass production is directly associated with a lot of pressures on terrestrial ecosystems (Kohlheb & Krausmann, 2009; Haberl et al., 2016). Expansion of industrial agriculture is the largest driver of competitive land use and increasing biomass demand facilitates the ecological destructive conversion of wetlands, grasslands, and forested ecosystems to croplands which results in loss of wildlife and other important biological habitats (Haberl et al., 2010; Haberl et al., 2016). Importantly, as noted by Weisz et al. (2006), biomass is an irreplaceable raw material source for human food provisioning, this crucial role jeopardizes the common wisdom of weak sustainability which allows for perfect substitution of natural and man-made capital (p. 684). As a common practice in MFA literature, estimates of socioeconomic biomass flows are often conducted as part of overall EW-MFA or Energy flow accounts (EFA) within the material an energy flow analysis (MEFA) framework looking at bulk material flows wherein aggregate national estimates of the socioeconomic flows of biomass material are presented. These studies assess the metabolic scale (the overall size of extraction and trade flows) of biomass material relative to other materials, monitoring trajectory and size of flows over time, in a given economy, region or global scale (Bringezu & Schütz, 2012; Haberl et al., 2013; Krausmann et al., 2013; Schandl & Eisenmenger, 2006; Singh et al., 2012). The biophysical patterns of biomass extraction, consumption and trade has equally been carried out relating it to different forms of land use (Bringezu et al., 2014; Bringezu et al., 2009; Kastner et al., 2014; Kastner et al., 2012). A few studies have looked at selected categories of biomass materials such as analysis of wood biomass flows (Bais et al., 2015; Mantau et al., 2010; Mantau, 2012); assessment of crop residue flows (Smil, 1999) and biomass use in livestock systems (Herrero et al., 2013).Similarly, an analysis of plant biomass turnover in the food and agricultural system on regional and global scale was presented by Wirsenius (2003, 2000). The study was conducted using biomass survey model to calculate the share of plant biomass needed for the production of crop for food, feed and feedstock from a prescribed end-use and conversion of phytomass (plant biomass) with the goal of determining the physical efficiency of the global food system in terms of food production and processing. However, the focus of this study was on a global scale using a survey model rather than the metabolic accounting model.

Research efforts geared towards adapting the methodological principles of MFA approach to study the biophysical patterns of biomass metabolism are still emerging. On a national spatial scale Risku-Norja. (1999) and Risku-Norja & Mäenpää (2007) analyzed the patterns and structure of food production in Finnish agriculture using MFA and input-output analysis approach while on a global scale, Krausmann et al. (2008a) provided a comprehensive assessment of socioeconomic biomass flows covering 11 world regions where in the socioeconomic inputs of biomass for food, feed, wood and other biomass materials of biological origin were quantified. The temporal scale of these studies limit insights into development of socioeconomic biomass flow and how the trends and patterns of flow have evolved over time in shaping the structure of agriculture and food systems.

Biomass metabolism of national economies from a historical perspective based on the methodological principles of the EW-MFA analytic approach is under investigated. Survey of literature reviewed few published studies. A recent study analyzed the social metabolism of Spanish agriculture from 1900 to 2008 (Soto et al., 2016). In their study, Soto et al (2016) adapted the EW-MFA to analyze the historical evolution of terrestrial biomass flows in Spanish agro-food system noting the change in the functionality of biomass in socioeconomic metabolism of Spanish agriculture from food to feed end use which is characteristic of industrial agriculture systems. The outcome of Soto et al (2016) study accentuated the importance and role of trade in driving biomass consumption as well as changing compositions of biomass flows at national economy in this era of globalization and expanding liberalization of agriculture. The social, economic and political context that underpin biophysical patterns of biomass use was expounded in Mayer et al. (2015), thus shedding light on the socioeconomic consequence of biomass trade. In their study, Mayer et al. (2015) noted that extraction of primary material for export in the agriculture sector exacerbates land use conflicts, thereby linking biomass flows to socio-environmental conflict. Further, through the biophysical analysis of the evolution of global biomass flows from 1950 to 2010, the above study attempted to provide an empirical link between biomass trade and food security and food sovereignty.

The issue of national food security in relation to structure of agricultural production and consumption has come to feature strongly in political and academic debates. Scholars have largely discussed food security or insecurity from a conceptual and normative perspective focusing on governance and policy issues (Clapp, 2015b; Edelman et al., 2014; Exchange, 2011; FAO., 2003; Farsund, Daugbjerg, & Langhelle, 2015; Godfray et al., 2010; Hanson, 2013), though at research level, more attention has been paid to individual or household food insecurity often relating it to poverty and livelihood within development discourse. An attempt at biophysical analysis of food security that applied MFA methodology focused only on cereal crops to analyze resilience of global food system (Pina & Ferrão, 2016). Another global level measured trends in global food availability from a historical perspective (Porkka et al., 2013), and did not relate it to overall system of biomass production and consumption patterns. However, this study presented a useful method based on MFA logic that can be used to assess food security at national level. There is yet to be an empirical investigation on the links between biophysical dimensions of agriculture biomass production, consumption and trade and national food security on national spatial scale and in particular small island developing states from a historical perspective.

2.6 Research Objectives

The goal of this research project is to provide empirical insight into the structure of Jamaica biomass system by analyzing, in time series, biomass material flows from 1961 to 2013 as a basis to link patterns and compositions of biomass material flows and Jamaica's national food security, with focus on food availability -a key aspect of national food security.

Therefore, the specific objectives guiding this research are:

1. Quantification of biomass material flows in Jamaica from 1961 to 2013, including the characterization of patterns and compositions of biomass production and consumption

2. Establishing a link between patterns of socioeconomic biomass flow and national food security in Jamaica.

Chapter 3
Methodology

3.1 Introduction

The methodology used to carry out this study was based on the general principles and methodological guidelines of the economy-wide material flow accounting and analysis. As described in the literature review chapter, EW-MFA approach has shown to be an important industrial ecology tool for analyzing the physical base of socioeconomic systems or national economy. As reviewed in chapter two of this thesis, various researchers have utilized this approach to assess material flows associated with economic production or/and consumption activities. EW-MFA adopted for this study offered a quantitative methodological approach for analyzing Jamaica's biomass metabolism. To meet the stated objectives, a biomass material database in time series was established for Jamaica. The time series database was developed by compilation of yearly biomass material flow accounts (1961-2013), guided by processes and methods outlined in (Krausmann et al., 2015; Singh et al., 2010) which is consistent with Eurostat established methodological guidelines and general principles of economy-wide material flow account and analysis (EW-MFA). This was further complemented with supplementary calculations- as detailed in section 3.5 of this chapter, to meet objective two of this research.

3.2 Systems definition

Any study of material flows of a system requires that a theoretically plausible and operationally practical system boundary be set. A system boundary is guided by the unit of analysis (the study's focal system) defined based on spatial and temporal scale. According to Eurostat (2001) and Fischer-Kowalski et al (2011), two spatial considerations combine to delineate the system boundary for measuring biophysical exchange of material flows (input and output flows) in an economy. The boundaries are set between:

1. the reference system being assessed which could be a socioeconomic system or entire national economy - and the national territory's natural environment from which extraction of primary (i.e., raw, crude or virgin) materials takes place and to which wastes and emissions are discharged.

2. the political (administrative) frontiers to other economies which determines the material flows to and from the rest of the world (ROW) through foreign trade- that is imports and exports. Natural flows into and out of a geographical territory are excluded.

The system boundary for this research is delineated by

1. the inflows of biomass material extracted from Jamaica national territory (environment) plus biomass commodity flows (imports) from the rest of the world (ROW) into the Jamaica biomass system (which is the unit of analysis)
2. the biomass material export flows from the socioeconomic system into the rest of the world economy and environment.

Based on EW-MFA convention, biomass flows from the environment to the economy are recognized at the point of harvest (EUROSTAT compilation guide, 2013, pg. 10). This entails both used and unused domestic extraction as well as direct and indirect flows associated with trade. However, in line with the prevailing production approach in MFA studies, this study considered only direct and used biomass flows, that is domestic extraction of agricultural biomass that was put to use plus direct biomass material trade which represents the total mass of imported and exported agricultural biomass commodities.

3.3 Calculated and Derived MFA Indicators and Definitions

An overview of the MFA derived indicators calculated in this study is provided in this section. The definitions of indicators were taken from Weisz et al. (2006) and the Eurostat methodological guide, 'Economy wide Material Flow Accounts and Derived Indicators' (Eurostat, 2001).

1. Domestic biomass extraction (DE): covers the yearly amount of raw materials (except water and air) extracted from a country to be used as materials for inputs for purpose of economic production. This indicator measured the annual quantity of biomass material extracted from Jamaica domestic environment that serves as input for economic processing.
2. Imports: physical imports measured the annual quantity of imported biomass commodities at all stages of production, from basic commodities to highly processed products. Mass of

imported biomass commodities are accounted for as net weight of goods crossing/entering the political border of Jamaica national territory.

3. Exports: physical exports measured the annual quantity of exported biomass commodities at all stages of production, from basic commodities to highly processed products. Mass of imported biomass commodities are accounted for as net weight of goods leaving the political borders of Jamaica national territory.

4. Domestic material input (DMI): this indicator was used to quantify the yearly amount of biomass material input used in sustaining and reproducing Jamaica biomass system. This is defined by the yearly amount of primary biomass materials extracted from within Jamaica's national territory defined by the aggregate indicator used domestic extraction (DE) plus imports of biomass products and commodities. DMI was calculated as used domestic extraction plus imports

   DMI = DE + Imports

5. Domestic material consumption (DMC): this indicator measured the apparent consumption of biomass material in Jamaica. DMC is defined by all used biomass material extracted from Jamaica's national territory and all imported goods made of biomass material minus all exported biomass products.

   DMC = DE + Imports – Exports

6. Physical trade balance (PTB): the physical dimension of Jamaica biomass foreign trade was measured using this indicator. A physical trade surplus indicates that Jamaica is a net importer of biomass material, whereas a physical trade deficit is an indication of net export.

   PTB is calculated as: Imports – exports.

7. Import dependency ratio: measured the degree of Jamaica's dependence on international market for food biomass consumption, and is the ratio of imports relative to domestic consumption of food crops and animal biomass and was calculated thus:

   IDR= Imports/DMC*100

Per capita values for all indicators were calculated using statistical data on Jamaica population obtained from the World Bank Group (2015).

3.4 Methods and Data Sources

Data was collated from secondary sources both international and national database. The main source of data for compiling the biomass material flow account was the Food and Agricultural Organization Statistical database (FAOSTAT, 2015). Specifically, this study relied on FAO production and FAO food balance domain.

The FAO production domain was used to collate data for primary crops and livestock products while the food balance domain was used to collate data for food supply quantity available for human consumption. It was important to use the two FOASTAT domain in this study for the following reason; the production domain makes a distinction between primary crop and processed crop products including by-products. The primary crop data are reported at the time of harvest without having undergone any real processing other than cleaning (FAO, 2015); this is consistent with MFA convention for compiling domestic extraction account which requires that primary crop data should be reported “as is weight” (i.e. at the time of harvest). The food balance domain on the other hand provides data on a country's food supply during a specified reference period (FAO, 2015). This includes all edible food commodities of both plant and animal origin. The food balance domain makes a distinction between the food quantities exported, fed to livestock, used for seed, processed for food use and non-food uses, lost during storage and transportation, and food supplies available for human consumption (FAO, 2015). This level of distinction is lacking in the production domain. Considering the second objective of this study which centers on food security, the food balance domain presented a more reliable source to obtain data for food availability.

To corroborate and cross-check data collated from FAO for the time series analysis and to fill up data gaps, national data was obtained from the Jamaica ministry of agriculture and fisheries division. To gather the national data required for this study, two field trips were made to Jamaica. The first was a conference related to food security in Jamaica which allowed for establishing contacts and to get familiar with the context. The second trip was undertaken to source national data from Jamaica ministry of agriculture and fisheries department. The field trip also included interactions with farmers that provided an understanding of the crop and livestock production system in Jamaica. Data for the biomass categories not covered by FAOSTAT and national database were estimated using region specific factors, derived from published literature on biomass studies (Krausmann et al., 2015; Krausmann et al., 2008a; Wirsenius, 2000) and from Eurostat methodological guide for conducting MFA. All data were measured in unit of tonnes. Data reported in units other than tonnes were converted using the appropriate co-efficient. Data for explanatory variables such as population, agricultural land area, arable land per capita, GDP and population density were extracted from the World Bank data base (The World Bank, 2015).

3.4.1 Quantification of Biomass material flows

The quantification of biomass material flows in Jamaica was achieved through compilation of biomass flow accounts required to develop a biomass material database covering the 52-year reference period examined in this study. Accounting process involved collation of yearly production data of identified biomass material sub-categories in mass unit as well as trade data on the mass of imports and exports of biomass products. This study identified five biomass sub-material categories whose flows were accounted. These were crop harvest, used crop residues, wood removals, grazed biomass and fish capture which together form part of the three main sources of biomass- agriculture, forestry and fisheries. In addition, secondary flows comprising mainly of outputs of livestock products were equally accounted for. The yearly production and trade data of these flows were compiled to develop a biomass material database for Jamaica. The established database allowed for the characterization of patterns and composition of biomass production and consumption using the derived aggregate biomass material flow indicators. Methods of accounting for flows of the five biomass sub- material categories are described in the proceeding section.

3.4.1.1 Primary Production

In compiling the biomass flows account, Singh et al. (2010) recommends that a distinctions be made between primary production and secondary production. In line with EW-MFA nomenclature, primary production are direct extractions of biomass from domestic environment and hence is equivalent to standard material flow indicator used domestic extraction (Krausmann et al., 2008a; Singh et al. 2010). Domestic extraction (DE) provides a picture of the scale of resources extraction.

Secondary production are mainly livestock products. The reason for this distinction is to avoid double counting as livestock products are already fed from primary production flows.

Used Domestic Biomass Extraction- (1961-2013)

1) **Primary crops**

Data obtained from FAOSTAT (2015) production domain were used to calculate yearly domestic extraction of primary crops from 1961 to 2013. This biomass material flow category comprises direct extraction from cultivated land and permanent cultures. In accordance with agricultural statistics and MFA convention, primary crop data were reported at "as is weight" at the time of harvest. Therefore, this study identified harvests of 52 crop items that constitutes primary crops; to avoid the case of double counting of mass flows, derived products (by products) from primary crops (such as fruit juice from citrus, oil cakes derived from coconuts) were not counted. The 52 crop items were further aggregated according to the 3-digit levels of MFA standard table to 10 sub-group category (i.e. cereals, roots and tubers, sugar crops, pulses, nuts, oil bearing crops, vegetables, fruits, fibers and other crops) for ease of compilation and comparability with import data on crop commodities. Allocation of crops to the appropriate sub-group category followed FAO crops and product classification system and the indicative crop classification system.

2) **Used Crop Residues**

The FAO database does not cover data on crop residues, therefore, mass flow of used crop residues was estimated following the standard estimation procedure outlined in Krausmann et al. (2015). In the estimation of used crop residue, the first step was identification of primary crop cultivars that provide residues for further socioeconomic uses such as animal feed, beddings and litter and raw materials. This study identified eight primary crop cultivars based on information gathered from field work in Jamaica and confirmed in literature (Jennings, 1988; Ravindran, 1993; Smith, 1989). The next step was estimation of available crop residue by applying crop specific and region specific harvest factors (table 3.1) obtained from the literature (Krausmann et al., 2008a; Wirsenius, 2000).

Available crop residues [t (as is weight)] = primary crop cultivar$_{1\ldots x}$ [t (as is weight)] x corresponding harvest factor$_{1\ldots x}$

Not all available residue enters the socioeconomic system as inputs, only a fraction of the available residue is subjected to further use (Krausmann et al.; 2015). To obtain the used fraction of the available residues, region specific and crop specific recovery rate was applied to the estimated available residue.

Used crop residues [t (as is weight)] = primary crop cultivar$_{1\ldots x}$ [t (as is weight)] x corresponding recovery rate$_{1\ldots x}$

Table 3.1 Standard value for harvest factor and recovery rates for Latin America and the Caribbean region used in this study (Source: Krausmann et al, 2008a, 2015)

Primary Crop	Harvest Factor	Recovery Rate
Maize	3	0.8
Rice	1.2	0.8
Sugarcane	0.7	0.9
Cassava	0.8	0.75
Potatoes	1	0.75
Sweet potatoes	1	0.75
Groundnuts	1.5	0.8
Coconuts	2.3	0.8

Estimated used residue of each identified crop was standardized to air dry weight (at 15% moisture content-mc), a deviation from MFA convention. This was necessary to ensure compatibility with the estimation of grazed biomass given that a fraction of used crop residues is utilized as animal feed. This was done by applying specific moisture content factor to fresh weight of used residue of each crop (except cereals- maize and rice which has a moisture content of 14%-15%), based on the equation below:

$Factor_{mc}$ = (1-mcfresh) / (1-mcair dry) = 0.2 / s0.85 = 0.235

Air dry weight (at 15% mc) = fresh weight (at 80% mc) * $Factor_{mc}$

3) Grazed Biomass

This category of biomass encompasses roughages including fodder crops, meadows, and biomass directly grazed by livestock or mowed for livestock sustenance (Krausmann et al., 2015). Roughages and grazed biomass taken up by livestock in Jamaica were not covered by international agricultural statistics database and Jamaica national statistics. Therefore, in the absence of any official data, this flows category was estimated. As a consequence, no distinction was made between grass-biomass directly taken up by grazing and grass-biomass mowed or harvested for hay and silage in this study. In accordance with MFA convention, this biomass flow category was calculated in air dry weight at 15% moisture content. Estimation procedure followed the MFA demand side approach based on the logic of calculating the difference between total feed requirement and supply of market feed and non-market feed to obtain grazing gap which represents demand for grazed biomass.

Total feed requirement= annual feed demand [t per head and year] * livestock [number]

Demand for grazed biomass= total feed requirement – (supply of market + non-market feed).

Calculation of total feed requirement was based on yearly quantitative information on livestock numbers for 8 livestock species derived from FAOSTAT (2015) and regional species specific feed intake (demand) factors that reflects changes in livestock productivity overtime obtained from (Krausmann et al., 2008a) as shown in table 3.2. Estimated total feed requirement was reduced for feed supply (market feed and non-market feed) to derive biomass harvested from grassland which is depicted here as demand for grazed biomass. FAO commodity balance sheet provided statistical data used in calculating total quantity of available market feed per annum. As there were no records of fodder crops in both Jamaica national and FAO statistical databases, a fraction of used crop residue was assumed as non-market feed supply. Judgement on the fraction of used crop residue designated for animal feed was discerned based on information gathered from farmers in the course of the research. From expert opinion, residues from coconut and cereals do not serve feeding purpose but used as animal litters and as raw material, hence were not included. About 30% of realizable sugarcane residues may be used for animal feed. All other used residue crops were assumed to serve the purpose of animal feeding.

Table 3.2 Coefficient factors of regional species specific daily feed intake. Daily intake factors have been converted to annual feed intake at 15%mc (adapted from Krausmann et al., 2008a)

Livestock	Daily feed intake [kgDM/head/day]	Annual feed intake at 15% mc [t/head/year]
Cattle	9.5	4.1
Sheep and Goats	1	0.4
Horses	10	4.3
Mules and Asses	6	2.6
Pigs	1.4	0.6
Poultry	0.07	0.03

4) Wood removals

This biomass flow category subsumes two categories timber or industrial round wood and fuel wood, both assumed to represent the quantities of wood removed from forest, cultivated short rotation plantation or any other wooded agricultural land (Krausmann et al., 2015). Data for quantification of wood biomass were obtained from FAO forestry statistical database. Extraction of wood is reported in FAO forestry statistics as removals under-bark, given in volume unit and differentiating between coniferous and non-coniferous wood. Therefore, in calculating quantities of wood biomass flows, in accordance with MFA accounting convention, volume measures were converted to weight measure using standard wood density conversion coefficients at air dry weight (15% moisture content) given in table 3.3. Because wood extraction data are reported under-bark, the conversion coefficients of coniferous and non-coniferous wood groups were multiplied by a correction factor of 1.1 in order to account for wood bark that maybe put to further socioeconomic use.

Table 3.3 Conversion coefficients used to convert quantities given in volume (scm) into weight (at 15% mc) for coniferous and non-coniferous wood (Krausmann et al., 2015).

	Density incl. bark (t at 15%mc/scm
Coniferous	0.572
Non-coniferous	0.748

5) Capture Fisheries

This flow category subsumes fish capture (including recreational fishing) and other animals and plants extracted from unmanaged fresh and seawater systems (Krausmann et al., 2015). Note that cultivated fish-aquaculture and other cultivated aquatic plants and animal are not included in this group. Data used for yearly compilation of capture fisheries used domestic extraction account were obtained from FAO fishery statistics- (FISHSTAT, 2015). Jamaica national statistics was used to fill up data gaps for years in the time series where data were missing.

3.4.1.2 Secondary Production

Secondary production refers mainly to livestock products that are fed on primary production (Singh et al., 2010). Based on MFA system boundary conventions, livestock are regarded as biophysical components of socioeconomic system and the domestic production of livestock and products are considered as internal process within the economy, hence not included in domestic extraction account (Krausmann et al., 2015), although flows associated with livestock production which is the material requirement of the livestock such as feedstuff (domestically produced or imported) and biomass taken up directly through grazing are counted as primary production flows attributable to the system (Singh et al., 2010).

Accounting for secondary production involved compilation of production data of raw animal based product and livestock number which was obtained from FAOSTAT (2015) production domain. Products identified includes meat, milk, egg and other biomass of animal origin such as hides and skins.

3.4.1.3 Physical Trade Flows- Imports and Exports

Physical trade flows of biomass material constitute all primary and secondary biomass commodities and products brought in from other socioeconomic systems in the form of imports and transferred to other system in the form of exports (Singh et al., 2010). Data on Jamaica biomass import and export flows were obtained from FAOSTAT (2015) agricultural and forestry database trade domain and FAO fishery statistics. MFA treatment of trade flows is based on the international merchandise trade statistics territorial definition of foreign trade which complies with the residence principle (Krausmann et al., 2015). FAO approach to data reportage of trade flows corresponds to that of international merchandise trade statistics, hence, provided a valuable data source used in compilation of physical imports and exports. The quantity of traded agricultural biomass are reported in terms of net weight in FAO database, excluding weight of packaging materials. In contrast to domestic extraction which are primary materials, biomass trade flows constitute traded goods and commodities at different stages of processing, hence subsumes both primary and secondary biomass products and commodities (Krausmann et al., 2015; Singh et al., 2010). This study distinguished six sub-groups of biomass material trade flows in the aggregation of data on import and export mass flows. These includes imports and exports of: crop commodities, livestock commodities, woods and products, feeding stuff, fisheries, other agricultural biomass (raw materials incl. fibers).

3.4.2 Linking Biomass Flows with National Food Security (1961-2013)

The second objective of this research was to establish a link between patterns of socioeconomic biomass flow and the national food security of Jamaica. To address this objective, the scope of MFA was expanded to conduct a time series analysis of Jamaica national food availability. This research adopts the method used in Porkka et al (2013)- with some modifications- to analyze evolution of Jamaica national food availability - and it involved calculating Jamaica's dietary energy supply (DES) during 1961 to 2013. To further discuss food availability, dietary energy production during 1961 to 2013 was calculated as a measure of trends in food self-sufficiency. The present study focused on food availability (a key concept of food security) due to the type of data available to carry out the research.

3.4.3 Analysis of Food Availability (1961-2013)

3.4.3.1 Dietary Energy Supply.

Data on domestic supply quantity (FSQ) obtained from FAOSTAT (2015) food balance sheet domain was used as a proxy for food availability. FAO food supply quantity represents food supply available for domestic utilization and is measured as production + imports - exports + changes in stocks (FAO, 2015). The process of estimation follows the same logic used in deriving MFA indicator - domestic material consumption (DMC). It is important to note that food wastage or losses associated with distribution and consumption phases of food supply chain are not considered in the FAO food balance sheet data. In order to get a close approximation of apparent food consumption (i.e. food quantities available for human consumption) from 1961 to 2013, adjustments were made to derive loss adjusted domestic supply (LAFS) estimates for 53 food crops, 11 animal source products and 11 fish source products; by applying region specific consumption waste percentage factor for each food product denoted as (n) to the weight of corresponding food product ($_n$) based on the following equation:

$$LAFS_{n\ tonnes} = [FSQ_n - (\%waste*FSQ_n)]_{tonnes} \quad \ldots\ldots (1)$$

The region specific waste percentage factor was derived from Gustavsson et al. (2011) and shown in Table 3.4

Table 3.4 Waste percentages by commodity groups for the region of Latin America used in this study. (source: Gustavsson et al, 2011)

Commodity Group	**Distribution**	**Consumption at household level**
Cereals	4%	10%
Roots and tubers	3%	4%
Oilseeds and pulses (including nuts)	2%	2%
Fruits and vegetables	12%	10%
Meat	5%	6%
Fish and seafood	10%	4%
Milk	8%	4%

The estimated loss adjusted domestic supply quantities (LAFSQ) in tonnes- of the identified food products was then converted to daily per capita dietary energy supply (DES) in kcal/cap/day using food product specific conversion factors (CFactor) and population data as follows:

$$DES_n = \frac{\sum LAFSQ_n(t) * CFactor_n}{365 * Population *(t)} \quad \text{...} (2)$$

Where the CFactor is in calories per 100grammes

The level of food availability was analyzed by measuring the estimated per capita dietary energy supply (DES) relative to minimum dietary energy requirement (MDER) and average dietary requirement (ADER) as used in Porkka et al. (2013) for Jamaica, over the observed period. According to FAO (2015) MDER is the minimum amount of dietary energy per person that is considered adequate to meet the energy needs at a minimum acceptable body mass index (BMI) of an individual engaged in low physical activity. If referring to an entire population, the MDER is the weighted average of the minimum energy. FAO uses the MDER cut-off point or threshold to estimate the prevalence of undernourishment in a country population. The average dietary energy requirement is a proper normative reference for adequate nutrition in the population of a country. ADER however is not the cut-off point to determine the prevalence of undernourishment. Its values give a measure of the amount of dietary energy that would be needed to ensure that, if properly distributed, hunger would be eliminated. Because both MDER and ADER values are calculated based on age/sex category, these values changes with time on a national level as national demography changes/shifts.

Data on MDER and ADER for Jamaica were sourced from FAO (2015). An MDER of 1800 kcal/cap/day and ADER of 2250 kcal/cap/day were used as thresholds to determine periods of critically low food availability, low food availability, adequate food availability and high food availability. The MDER and ADER values reflect the average from 1990 and 2013. Based on these values, food availability was classified as follows:

Critically low food availability: DES < MDER at 1800 kcal/cap/day

Low food availability: MDER at 1800 kcal/cap/day<DES< ADER at 2250 kcal/cap/day

Adequate food availability: DES >ADER at 2250 kcal/cap/day to 2500kcal/cap/day

High food availability: DES of > 2500kcal/cap/day

Defined threshold

Critically low	1799
Low	1800-2249
Adequate	2250-2500
High	2500-3000

Since FAO statistical information on MDER and ADER covers time period between 1990 to 2013, in order to make a fair analysis this study assumed that the ADER and MDER for Jamaica starting from this study base year 1961, remained constant till 1991. Hence, ADER and MDER values from 1961-1989 was assumed to be same as that of 1990. It is important to note that the loss adjusted yearly food availability quantities were assumed to be equivalent to yearly total food consumption in Jamaica. Additionally, global ADER is 2100kcal/cap/day (FAO, 2015), while recommended dietary energy is 2500kcal/cap/day (FAO, 2015).

3.4.3.2 Dietary Energy Production

Food energy production, also referred as dietary energy production (DEP) was estimated as a measure of food self-sufficiency. This study adopts the operational definition of food self-sufficiency given by Porkka et al (2013) which refers to country's domestic food production in relation to the statistical food supply requirements of its population. In line with Porkka et al (2013) this study estimated domestic food production quantity (FPQ) for Jamaica from 1961 to 2013 using national data on food supply quantity, exports, imports and stock variation for each identified food product denoted as (n) following the MFA basic logic thus:

$$FPQ_{n(t)} = FSQ_{n(t)} - E_{n(t)} - I_{n(t)} - dS_{n(t)} \quad \text{.........................(3)}$$

Where FSQ represent food supply quantity, E represent exports, I represent imports and dS represent change in stock.

The FPQ compiled data was then converted to per capita dietary energy production (DEP) thus:

$$DEP_n = \frac{\sum FPQ_n (t) * Cfactor_n}{365 * Population *(t)} \quad \text{.. (4)}$$

Trends in development of DEP was analyzed same way as trends in DES; by measuring the estimated per capita DEP (kcal/cap/day) relative to MDER at (1800 kcal/cap/day) and ADER at (2250 kcal/cap/day) as thresholds to determine periods of low food production, insufficient food production, sufficient food production and high food production.

3.5 Data Challenges and Assumptions

The quantification of biomass flows and food availability relied on secondary data from FAO database and to some extent the Jamaican national statistics. The FAO statistical database has been identified as an international standardized database with a long history of compiling national statistical data related to agriculture and forestry (Krausmann et al., 2008a), offering the most reliable data source for material flow analysis studies on biomass. However, there were some challenges associated with use of secondary data in this study that required certain assumptions. These challenges and assumptions are outlined below.

1. There was no information available in FAOSTAT on the quantities of roughages or forage crop used as feed. As this information was also not available in Jamaica national statistics, estimation of grazed biomass relied on the assumption of most substantial use of crop residues as non-market feed. It was assumed that with the exception of cereals and coconuts, all other identified used crop residues listed in table 3.1 may be used as animal feed including 30% or recovered residues from sugarcane. This assumption was guided by expert opinions provided by some farmers in Jamaica.
2. FAO food balance sheet data on food supply quantity, exports, imports and stock variation used in the estimation food production quantity (FPQ) did not make any differentiation on the quantities of commodities that may be used for purposes other than human food use such as further processing or animal feed. In the absence of this information, this study assumed that all imported and exported agricultural commodities are used for human food.
3. FAO statistical information on Jamaica MDER and ADER covers time period between 1990 to 2013. Considering this study analysis considered the period 1961 to 2013 and in order to

fill data gap, it was assumed that the ADER and MDER values for Jamaica from 1961-1989 remained constant and is equal to that of 1990.

4. To address challenge in data not available for actual food intake, this study assumed that the loss adjusted yearly food availability quantities to be equivalent to yearly total food consumption in Jamaica. This approach is consistent with food security studies that focus on the aspect of food availability (Porkka et al., 2013)

Chapter 4
Result and Discussion

This chapter presents the main results and interpretations of empirical evidence obtained from the time series analysis of socioeconomic biomass material flows in Jamaica in the context of trade and national food security. As already mentioned earlier the biomass flows quantified and assessed by this study are used and direct biomass material flows. Indirect and unused biomass flows were not quantified. Classic material flow indicators calculated in the method section of this thesis are used to present and discuss the findings obtained from time series quantification and characterization of patterns and compositions of biomass material flows in Jamaica from 1961 to 2013. Due to the long time series examined, results from calculation of biomass material flow indicators are presented in five year intervals.

4.1 Domestic Extraction (DE)

The DE indicator measured how much biomass material resources were extracted from the domestic environment of Jamaica. Jamaica total biomass DE have significantly changed in the last five decades. Findings show that total DE decreased from 9.6 Megatonnes (Mt) in 1961 to 5.7 Megatonnes (Mt) in 2013, representing a 41% reduction of mass flow in absolute terms (Figure 4.1 A), and 64% decline in per capita units (from 5.8 to 2.1 tonnes per capita) over the same period (Figure 4.1B).

Trends in DE show two alternating phases of growth and decline. Beginning from 1961, total DE grew steadily reaching its maximum at 10.6 megatonnes in 1966 (5.9 tonnes per capita). It is not quite clear what precipitated the steady growth recorded in this period. One explanation might be that Jamaica plantation economy during this time frame was more viable given that Jamaica was mainly an agriculture-based economy historically till after independence in 1962 (Weis, 2005).

A B

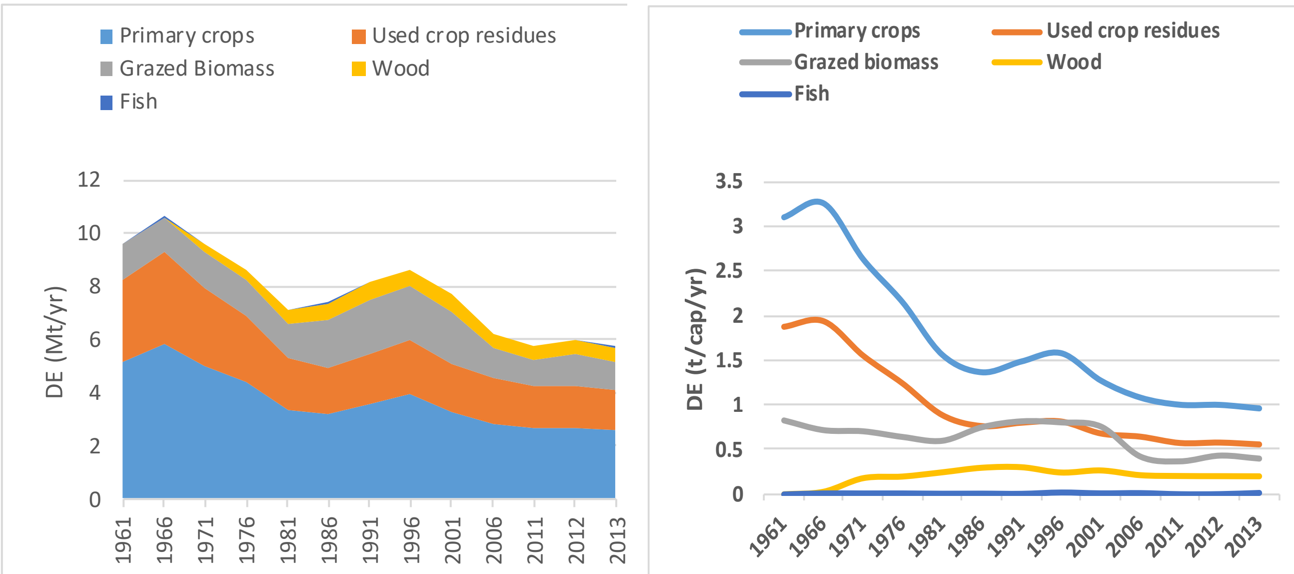


Figure 4.1 : Evolution of biomass domestic extraction from 1961 to 2013 by main biomass categories; A) DE in absolute units. B) DE in per capita units. Note that the material group fish is very small (<0.0001%) hence not visible on the chart.

After 1966, growth in DE began to decline progressively and lasted through the 1980s. Within this time period, a steep decline in the yearly quantity of DE occurred specifically around mid-1970s to the early 1980s. This period corresponded with the implementation of the International Monetary Fund (IMF) dictated structural adjustment policies in Jamaica. The conditions of the IMF structural adjustment program included reductions of direct government involvement in production of goods and services, which led to the contraction of public sectors including the agriculture, forestry and fishery sector (Weis, 2004; Weis, 2005). The quantity of DE increased again starting in in mid-1980s through to around 2001, peaking in 1996 at 8.6 Megatonnes (3.4 tonnes per capita). However, this growth was not sustained as total DE started to decline around 2006 and did not recover through the remainder of the studied reference period.

Although DE on an aggregated level declined during the 52- year reference period analyzed, findings show a varied behaviour in its components, that is for each biomass sub-material category extracted (primary crops, used crop residues, grazed biomass, wood biomass and fish capture).

While reductions in quantities of extraction was observed for primary crops (-50%), used crop residues (-51%) and grazed biomass (-21%), wood biomass and fish capture increased by 9643% and 124% respectively during the 52-year reference (table 4.1).

Table 4.1Changes in compositions of DE over five decades, in Megatonnes and percentage change in the size of flow between 1961 and 2013 for the five biomass sub-material category.

Megatonnes/year	1961	1966	1971	1976	1981	1986	1991	1996	2001	2006	2011	2012	2013	% Change (1961 to 2013)
Primary crops	5.12	5.81	4.98	4.37	3.36	3.17	3.56	3.94	3.29	2.84	2.67	2.68	2.58	-50%
Crop residues	3.11	3.46	2.95	2.53	1.92	1.79	1.93	2.05	1.78	1.72	1.56	1.57	1.52	-51%
Grazed biomass	1.37	1.28	1.34	1.31	1.30	1.76	1.97	2.02	1.98	1.12	1.00	1.17	1.09	-21%
Wood biomass	0.01	0.05	0.33	0.39	0.51	0.66	0.69	0.58	0.66	0.54	0.53	0.53	0.52	9463%
Fish capture	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.00	0.00	0.02	124%

In terms of weight, the percentage compositions of each flows relative total DE showed that agricultural biomass constituted the largest fraction (94%) of all extracted biomass throughout the entire reference study period and primary crop harvest dominated with a percentage share of 48%, followed by used crop residues (27%) and grazed biomass (19%) as shown in Figure 4.2

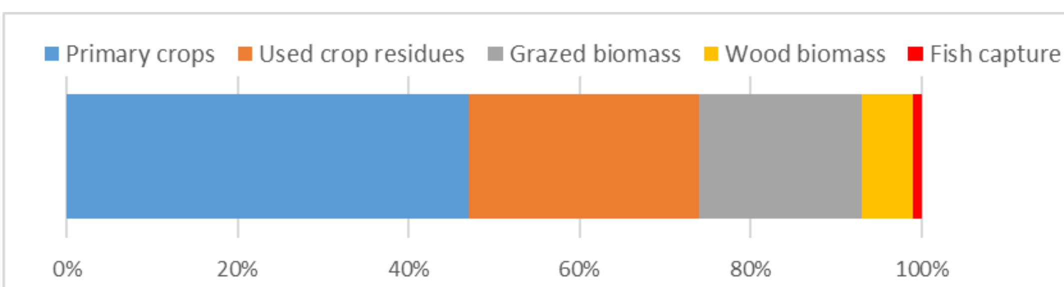


Figure 4.2. Break down of total DE flows by percentage composition of each material flow categories for 52 years

With less than 7% contribution to the total domestic extraction flows, it appears that forestry and fisheries relatively play minute role in Jamaica biomass system. This however does not mean that they are not relevant to socioeconomic metabolism of biomass with respect to the wider economy. For instance, fuelwood provided 37% of all household energy in Jamaica in the early 1990s (Weis, 2001); as shown in table (4.1) the quantities of wood extraction increased tremendously over the 52-year reference period. With regards to fish extraction, the obtained result is quite surprising considering that for most island systems, fisheries play major role in their biomass system. However, it is important to note that Jamaica fisheries system is mostly artisanal and presents a challenge that puts limitations on comprehensive data collection and management (Pauly & Zeller, 2014). In this regard, there is a high probability that the annual fisheries extraction data as reported by FAO fishery statistics which was utilized in this study may not be representative of actual quantities of all yearly fish extraction flows in Jamaica.

Since the largest biomass extraction comes from cropland (primary crops 48% plus used crop residue 27%) amounting to 75% of total DE, the magnitude of the DE flows and to a large extent the evolution of DE is determined by primary crop extraction. The observed trend in overall DE mirrors that seen in primary crop extraction (Figure 4.3). The domestic extraction of primary crops reached an annual maximum of 3.3 tonnes per capita in 1966 and an annual minimum of 0.9 tonnes per capita in 2013. The major share of primary crop extraction is sugar cane (the only sugar crop cultivated in Jamaica) and accounted for 76% of total primary crop extraction.

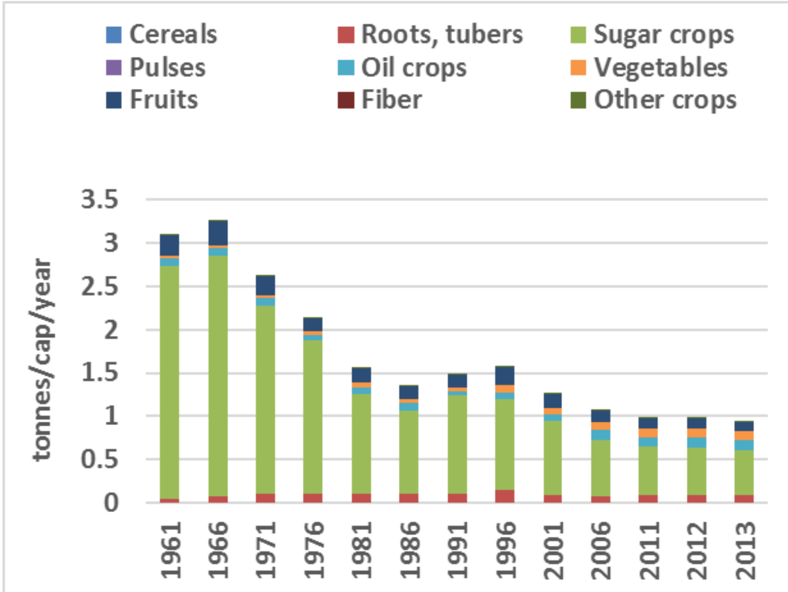


Figure 4.3 Patterns of primary crop biomass extraction in per capita units (1961-2013). Category other crops subsumes stimulants, beverages, and spices.

The extraction of primary crops showed prolonged period of reductions beginning from mid 1960s till early 1990, with lowest level of extraction in 1980s, owing to economic policies that affected the agricultural sector in the late 1970s and 1980s that particularly affected the sugar cane industry in Jamaica. Average domestic extraction of sugar cane reduced by 57% within this period. Primary crop extraction rebounded between 1991 till about 2001, and thereafter a steep decline could be observed around mid-2000s. Jamaica witnessed three series of hurricanes (2004, 2005 and 2007) that caused devastating damages to the agriculture system (McGlashan et al., 2008); this explains the significant drop in quantity of primary crop extraction which also reflected in total DE (see Figure 4.1); total DE of primary crop declined to its lowest average mass quantity at 0.8 tonnes per capita between the period of 2004 and 2006 (Figure 4.3). Reductions in aggregate extraction of primary crop biomass corresponded to reductions in arable land per capita. Over the time period assessed, arable land per person per year has decreased by over 56%. Correspondingly, the size of agricultural land as a percentage of total and area declined from 49% in 1961 to 2013 41% (The World Bank Group, 2015).

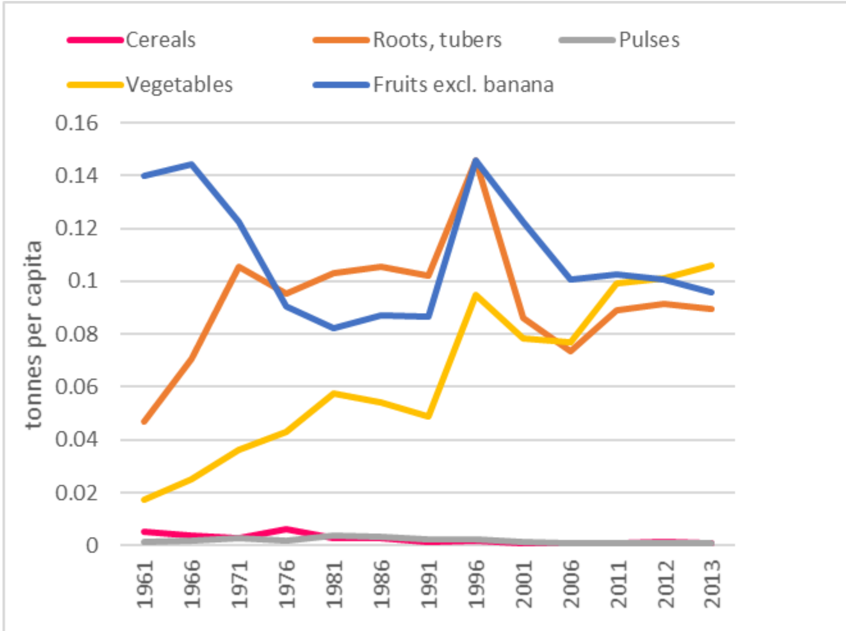


Figure 4.4 Patterns of primary crop biomass extraction in per capita units (1961-2013).

Study results show that the share of mainstay food crops- cereals, pulses, roots and tubers, vegetables which aggregated to about 10% of total primary crop extraction (in per capita terms) is comparatively lower than the share of commercial crops despite declining output in commercial crop extraction in Jamaica over the 52-year reference period examined. However, looking exclusively at the evolution of mainstay food crop domestic extraction, result show 39% increase in extraction from 0.21 tonnes per capita in 1961 to 0.29 tonnes per capita in 2013 (Figure 4.4). From this outlook, it could be argued that substantial improvements have occurred in Jamaica domestic food production sector. But when examined at individual food category level, changes that could suggest poor performance of the sector can be seen. As shown in Figure 4.4, a common pattern that show considerable reductions in quantity of extraction occurred in the years between mid-1970s and about 1990. The reason for this trend could be explained by relaxation of import restrictions in line with IMF dictated economic policies resulted in influx of cheap food with associated impact on the viability of Jamaica domestic agricultural production; therefore, domestic producers were unable to compete with cheap foreign imported products flooding the local market (Thomas, 2006). Also, in 1996, analysis show a common pattern of peak increase in extraction quantities for only vegetables, roots&tubers and fruits exc. banana. Cereals and pulses in Jamaica contributed the least quantity with a ratio of 0.0013 and 0.0012 respectively and has drastically declined by 78% (cereal) and 40% (pulses). In general, result of analysis shows a fluctuating declining trend in extraction of mainstay food crops with the exception of vegetables. On this basis, it can be inferred that findings corroborates theoretical assertion on weak performance of domestic food production in Jamaica has over the years (Beckford & Campbell, 2013).

4.2 Imports

Result of analysis show an increasing trend in Jamaica total import flows. Total imports grew by 78% between 1961 at 0.28 Megatonnes and 2013 at 1.33 Megatonnes in 2013 (Figure 4.5 A). The largest physical import in terms of weight came from primary crops and represents 59% of total import flows, followed by wood biomass imports (28% of total import flows) over the 52-year reference period that was analyzed. Thus the evolution of the total imports was to a large extent determined by the trends of the primary crops and wood biomass import flows which altogether accounted for 91% to 83% of the total imports between 1961 and 2013. The mass flows of other import categories (feed, fish, livestock products and other non-edible products of animal and plant origin) are relatively small. For primary crops, the largest import flows were cereals which accounted for 74% of total imports flows, followed by sugar crops (11% of total primary crop imports); other primary crops import flows as shown in (Figure 4.5 B) were of small quantities.

A B

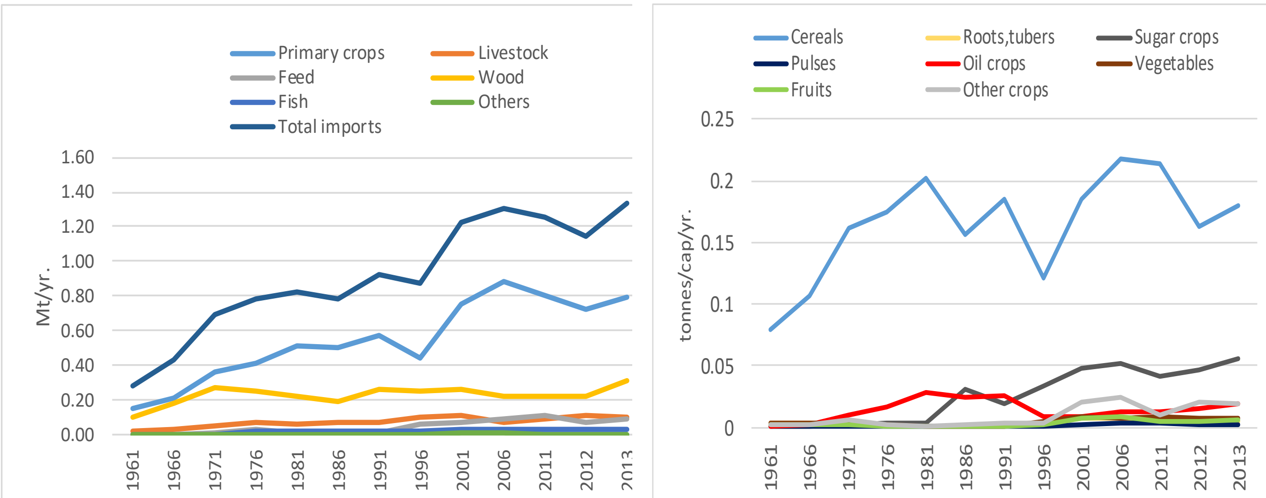


Figure 4.5 (A) Physical imports by biomass material categories. The category others subsume non edible products of both animal and plant origin (hides, skin, cotton etc.) (B) Imports of primary crops products. Other crops represent stimulants, spices and beverages.

Total import flows steadily increased alongside flows of primary crops and wood biomass from 1961 until around 1981; however, wood imports started to decline earlier beginning from 1970s and primary crop followed in 1981. After 1986, the volume of both wood and primary crop increased resulting in slight increase of total import. The sharp decline of primary crop imports is reflected on the decline of total import in 1991. Although the most important biomass imports in terms of total weight came from primary crops and wood biomass, a growing trend in imports of animal products (meat, diary, egg and other raw materials of animal origin) and feed import can be seen (Figure 4.5 A). Specifically, while the import of primary crops started to decline from around 1991 and plunged in 1996, Jamaica feed imports rose in 1996.

Overall, the increasing trend in the evolution of Jamaica physical imports in biomass has not been linear; three phases of steep decline can be seen (Figure 4.5 A). The first phase of decline occurred in 1986 as a result of a progressive decline in wood biomass imports that began in early 1970s and a slight reduction in primary crop imports that started after 1981. The second and third phase of decline which occurred around 1996 and 2012 was mainly due to reductions in primary crop import flows (in particular cereals -see Figure 4.5 B) as wood biomass remained relatively stable. Important trend emerged in the import flows of cereals. Importation gradually rose from 1961 at 0.07 tonnes per capita to 0.19 tonnes per capita in 1978; within this time period, there were periods of fluctuating reductions in quantity of cereal import around mid-1970s. A steep decline in per capita cereal import, at 0.09 tonnes per capita occurred in 1979. Significant reduction in the quantity of imported cereal was equally found to have occurred in mid-1990s and around 2008/2009 and 2011. These drastic reductions in cereals import flows (Figure 4.5 B) could be as a consequence of the series of global food crisis and the accompanying food price hikes that occurred in the same periods (FAO, 2003). Findings also revealed a growing trend in the importation of sugar beginning from early 1980s and this has remained on a relatively steady increase throughout the period analyzed except for 2011 when the surge in sugar import flows was interrupted (Figure 4.5 B).

4.3 Domestic Material Input

Domestic material input (DMI) show the biomass material throughput required to sustain socioeconomic production and consumption and constitutes the weight of domestic extraction plus weight of imports. Study result shows that total per capita DMI decreased by 50% from 6 tonnes per capita in 1961 to 3 tonnes per capita by 2013 (Figure 4.6). Trends in the evolution of DMI shows a growing shift towards dependence on imports for biomass supply. Very early on- 1960s, import trade played very minimal role in (DMI) biomass supply in the system. From 1961 until around 1969/1970, almost 97% of total DMI were extracted from Jamaica domestic environment, reaching its maximum at 6.2 tonnes per capita in 1996. By 1971 this trend had changed significantly; imports constituted almost half of DMI. Beginning from mid 1970s, the share of total imports in DMI increased to almost half of total DMI (96%) before plunging around 1996. While imports share of per capita DMI fell significantly in 1996 after prolonged incremental growth the quantity of DMI per capita reached its next highest level at 3.9 tonnes per capita.

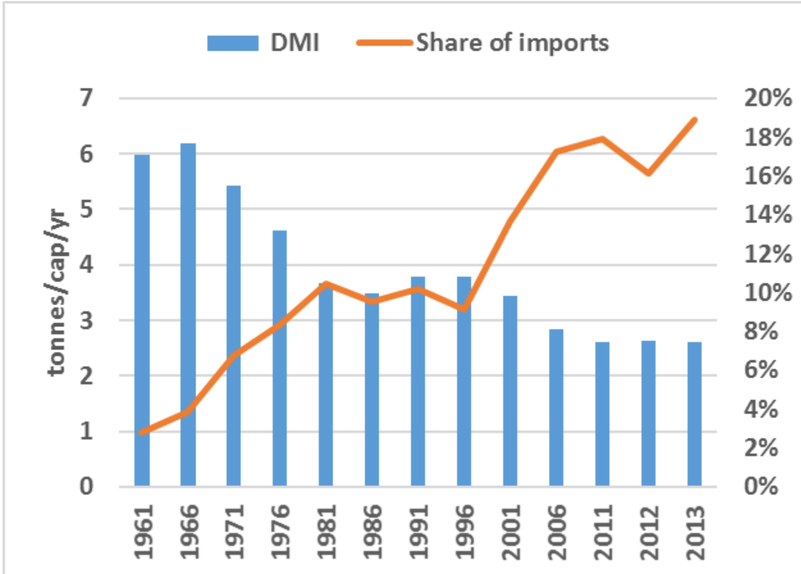


Figure 4.6 Evolution of domestic material input and share of imports in DMI (1961-2013)

In the period covered by the time series, share of imports in DMI increased from 3% in 1961 to 19% in 2013. The growth of imports in DMI hints at a decoupling trend between biomass material use and environmental pressures on Jamaica agro-ecosystems due to lower domestic extraction. Although, such growth may suggest reduced adverse environmental repercussions from Jamaica's biomass use, mitigation of environmental impact from biomass use may come at a cost of internal resource scarcity triggering more and more dependence on external sources hence posing another problem of supply risk in the event of market disruptions. Not only that, Jamaica's import dependence presents a global environmental sustainability concern of shifting of environmental burdens to foreign countries agro-ecosystem through outsourcing of biomass material intensive production.

4.4 Exports

In contrast to import flows, result show a declining trend in Jamaica physical export flows. Overall, total exports decreased by 257% from a total export of 0.70 Megatonnes in 1961 to 0.20 Megatonnes in 2013 (Figure 4.7 A). The main export flows were primary crops which represent 95% of total export mass flows. Thus the evolution of the total exports was largely determined by the trends of the primary crops export flows, specifically sugar crops (in the form of processed sugar and sugar products) which represents 65% of total export flows (Figure 4.7 B). With the exception of fruit flows, other primary crops categories made minimal contributions to export flows (Figure 4.7 B). Thus the overall decline in total exports in the period analyzed was for the most part, precipitated by reductions in sugar exports which accounted for a maximum 76% in 1961 and minimum 40% in 2013 of total exports.

A B

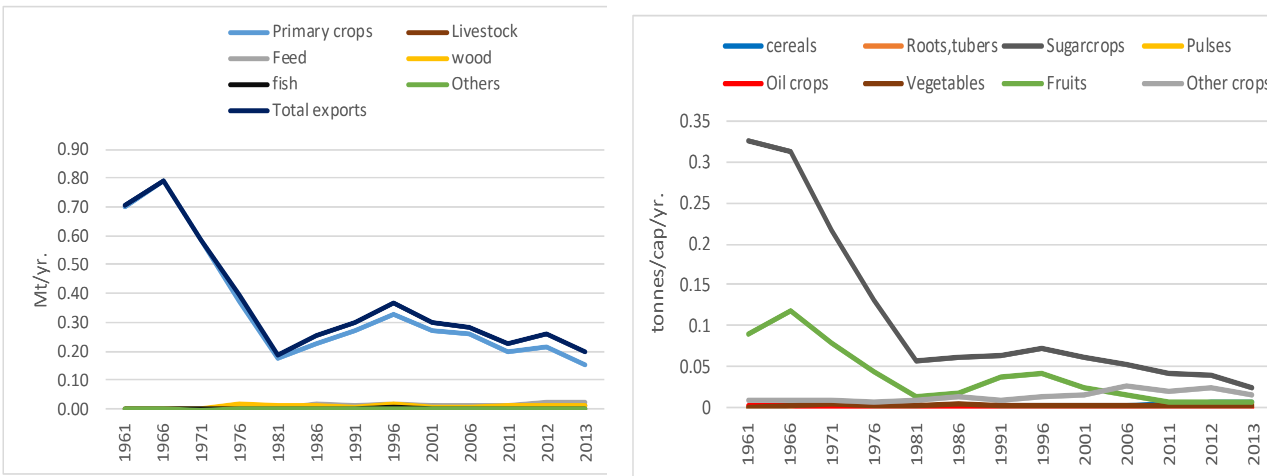


Figure 4.7 Physical exports by biomass material categories. The category others subsume non edible products of both animal and plant origin (hides, skin, cotton etc.) (B) Exports of primary crops products. Other crops represent stimulants, spices and beverages.

Total exports reached its maximum (0.79 Megatonnes) around 1966 and after 1966, total export dropped drastically by 75% from 0.79 Megatonnes to 0.19 in 1981. The sharp decline in total exports within this period was due to significant drops in sugar cane and to some extent fruits flows (Figure 4.7 B). In the case of fruits, the major share of exports flows was banana -which reduced by 68% (FAOSTAT, 2015). Overall decline in export was as consequence of globalization and WTO trade liberalization policies. As underscored in literature, Jamaica historically enjoyed preferential market prices for its sugar and banana export US and the EU. Reductions in world price of raw sugar and competition from other regional players like Brazil, Thailand and India resulted in elimination of preferential market and thus limited Jamaica access to developed market (Thomas, 2003). Additionally, economic diversification in Jamaica placed more emphasis on the tourism sector and bauxite industry at the expense of agricultural production (Handa et al., 2003; Thomas, 2003). Findings show that total exports slowly rebounded in the 1990s, peaked in mid-1990s during which an increase in fruits export and to some extent sugar crop (processed sugar and sugar products) can be seen, however, this was not sustained.

4.5 Domestic Material Consumption

Domestic material consumption is comprised of DMI - Exports, and measures the apparent consumption of biomass in the Jamaican physical economy. Result show that total DMC decreased by 26% from 9.2 Megatonnes (Mt) in 1961 to 6.8 Megatonnes (Mt) in 2013, in absolute terms (Figure 4.8 A). In per capita units, DMC decreased by 55% from 5.5 to 2.5 tonnes per capita over the same period (Figure 4.8B). Per capita DMC declined faster than absolute DMC because population grew by 64% from 1.6 million people to 2.7 million people (World Bank, 2015) in the observed period (1961-2013).

A B

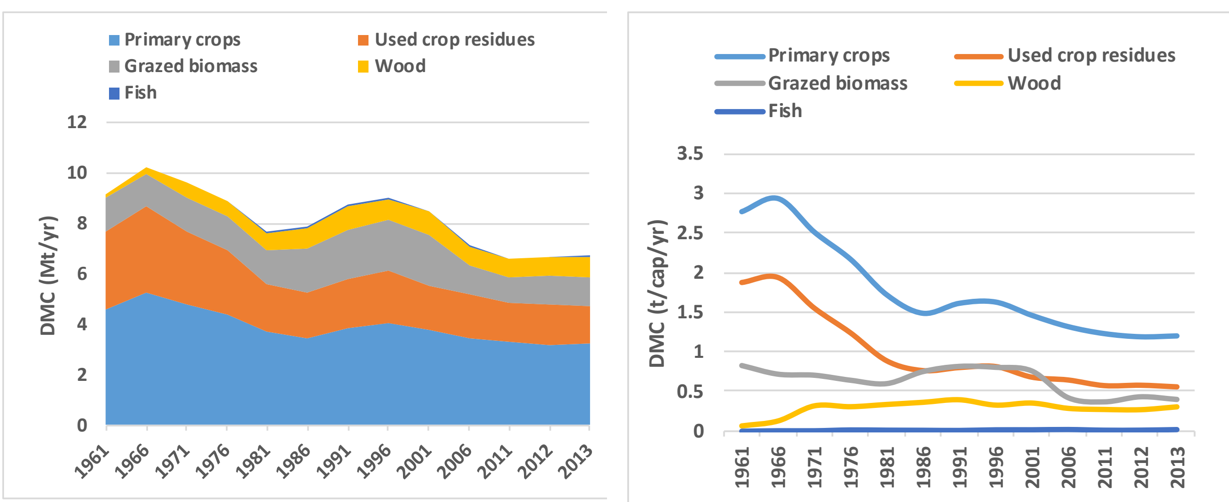


Figure 4.8 Evolution of biomass domestic material consumption between 1961 and 2013 by main biomass categories; A) DMC in absolute units. B) DMC in per capita units. material group fish is very small (1%) hence not visible on the chart.

Findings demonstrates convincingly that the evolution of DMC followed similar pattern as DE in both absolute and per capita units. Trends in per capita DMC reveal that while material categories primary crops (-57%), used residues (-70%) and grazed biomass (-52%) decreased from 1961 to 2013, wood (363%) and fish (21%) increased through the period analyzed (Figure 4.8 B). Increasing trend in wood consumption is typical of developing economy undergoing socio-metabolic transition. In specialized MFA literature, same pattern has been observed for most industrializing economies (Singh et al., 2012).

The share of the individual biomass sub-material categories of the total DMC was relatively the same during the 52-year reference period analyzed. Primary crops dominated at (48%), used crop residues (26%), grazed biomass (17%), wood biomass (8%), and fish (1%) as shown in Figure 4.9.

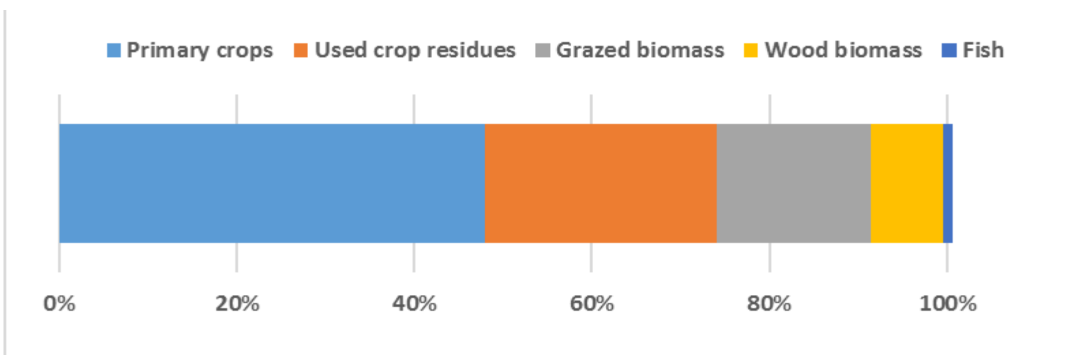


Figure 4.9 Break down of total DMC flows by percentage composition of each material flow categories for 52 years

In the last four decades, the observed trend in DMC of primary crops is similar to that of DE of primary crops despite the considerable reductions in crop export flows. This suggests that Jamaica biomass system is still characterized by export oriented agriculture production and thus corroborates theoretical literature. Another reason is growing food imports which offsets declining production to meet domestic demand. As already mentioned in section 4.2, imports flows have been increasing since 1990s and mostly in the area of primary crops (specifically for cereals and sugar), which suggests a progressive decoupling of biomass production and consumption.

Overall, biomass metabolic rate (DMC per capita) for Jamaica at 2.5 tonnes per capita is comparably lower than global biomass DMC per capita rate of about 3.5 t/cap/yr. obtained by Krausmann et al (2009). Apparently, the declining trend in evolution DMC per capita in this study is quite different in relative terms to other biomass consumption trend in MFA specialized literature at mainland scale level. Singh et al (2012) study shows increasing per capita DMC for India. Similarly, same increasing trend was seen with Spain (Soto et al., 2016), USA (Gierlinger et al., 2012) and Japan (Krausmann et al., 2011). Among the explanation put forth for these regional differences are land availability, trade and income (Krausmann et al., 2008a). Generally, resource use pattern in small island developing states is said to exhibit different dynamics due to their geographically small spatial size and their high integration in global market that predisposes them to fluctuations in economic globalization (Chertow et al., 2013). Although paucity of EW-MFA studies on the Caribbean region limits extensive comparison, it should be noted that the observed DMC trend for Jamaica corresponds with that obtained for MFA study on Trinidad and Tobago by Krausmann et al. (2014), and MFA study on Cuba (Eisenhut, 2009).

4.6 Physical trade balance (PTB)

The PTB represents the difference between the quantities of biomass imports and exports and measures Jamaica physical net trade in biomass. Result of analysis show that Jamaica is currently a net importer of biomass (Figure 4.10 A). However, from the evolution of PTB, it can be seen that Jamaica was a net exporter of biomass from 1961 until about 1971. Examining the different categories of biomass traded reveals that Jamaica’s position as a net exporter of biomass in the 1960s was primarily driven by increasing quantities of primary crops export (Figure 4.10 B).

A B

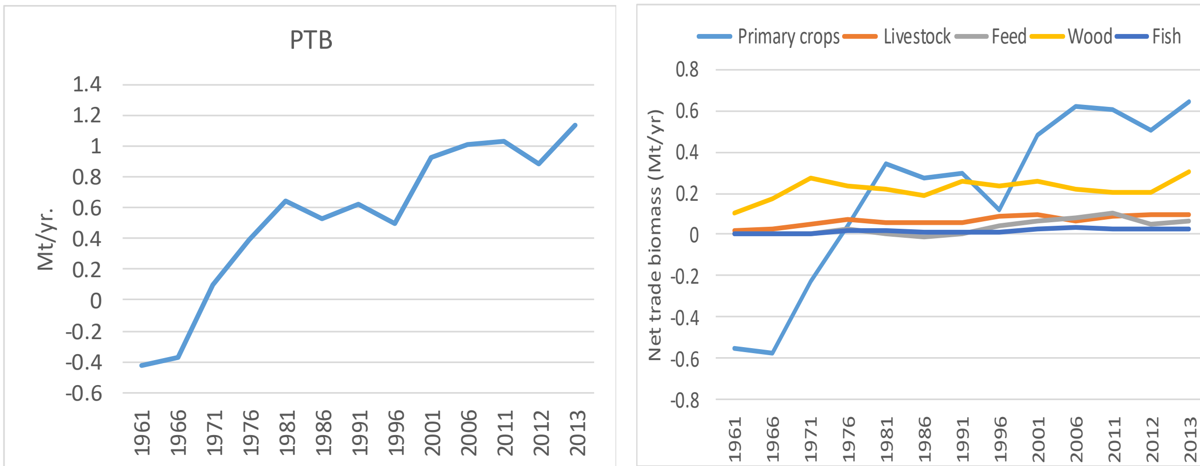


Figure 4.10 A) Physical trade balance. (B) Physical trade balance by biomass material categories. Other crops represent stimulants, spices and beverages

On the whole, Jamaica international trade with biomass (which is an aggregate of all import and export flows) grew by 55% from 0.98 Megatonnes to 1.53 Megatonnes in absolute terms over the observed period (Figure 4.11). The evolution of Jamaica biomass trade show significant changes supports result of PTB indicator was found. Total mass flows for international trade began to decline in 1970 as a result of drops in exports. Total trade flows rebounded in mid- 1980s as exports slowly picked up but growth in biomass exports was not sustained. Trade flows on the other hand continued to increase due to influence of import flows underlining Jamaica current physical trade balance status as a net importer of biomass. While total biomass export decreased more than 3-fold from 0.43 tonnes per capita to 0.07 tonnes per capita between 1961 and 2013, total biomass imports grew by over a 100% from 0.17 tonnes per capita to 0.49 tonnes per capita between 1961 and 2013 (Figure 4.11).

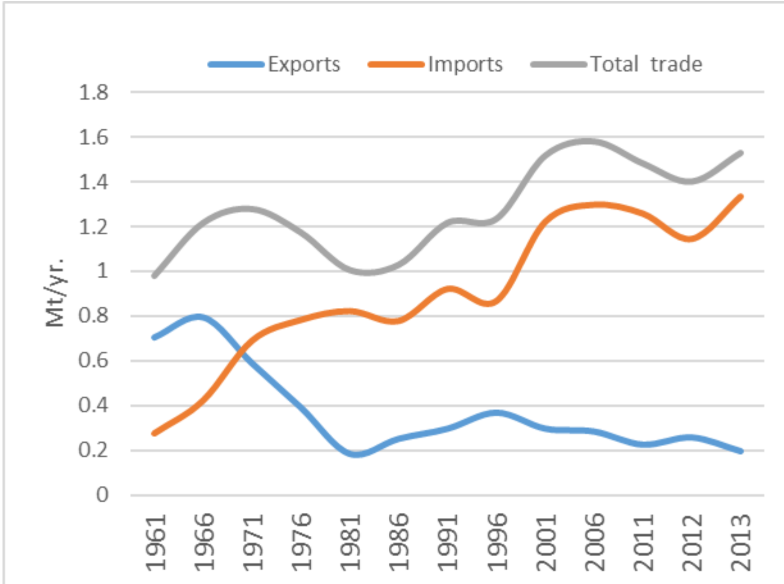
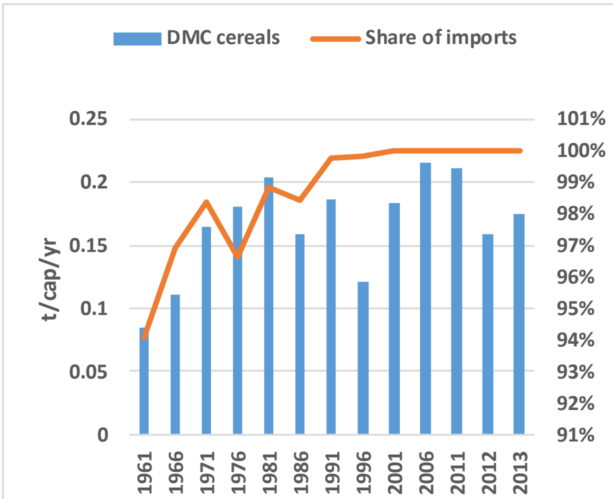


Figure 4.11 Evolution of Jamaica international trade with biomass (1961-2013). Total trade represents aggregate imports plus exports.

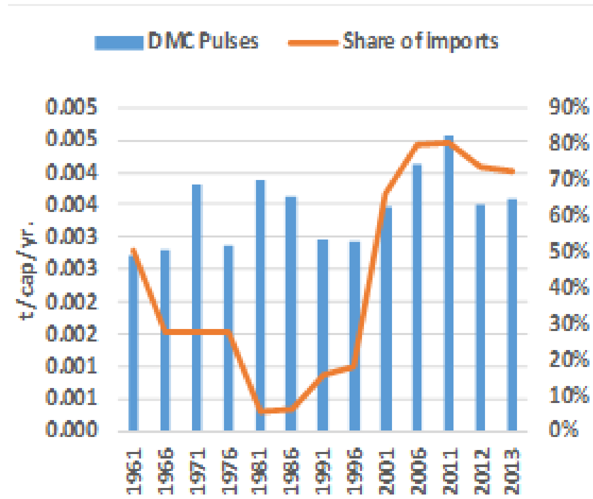
4.7 Import Dependency Ratio of Food crops

Findings show a growing trend in Jamaica food import dependency ratio, though the degree of import dependency varies across the 7 food crop categories (cereals, pulses, fruits, roots&tubers, vegetables, oil crops and sugar crop) analyzed (Figure 4.12 A to G). The strongest import dependency ratio was seen in cereal crops. Trends in cereal import dependency show a historically high ratio ranging from 94% in 1961 to almost 100% in 2013 (Figure 4.12 A).

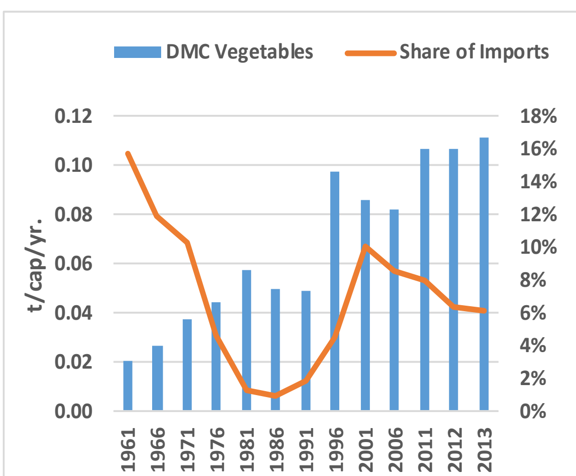
A


DMC cereals
Share of imports
t/cap/yr
0.25
0.2
0.15
0.1
0.05
0
101%
100%
99%
98%
97%
96%
95%
94%
93%
92%
91%
1961 1966 1971 1976 1981 1986 1991 1996 2001 2006 2011 2012 2013

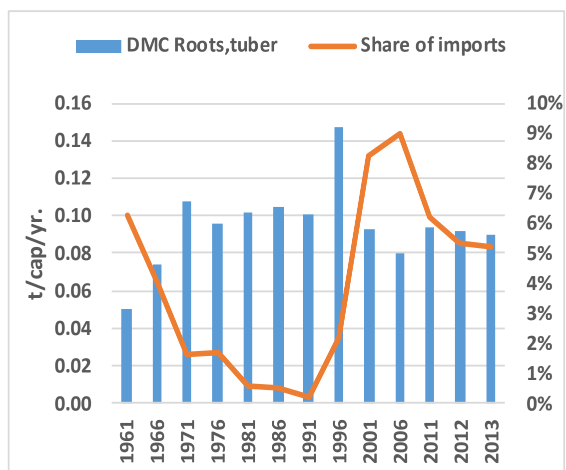
B


DMC Pulses
Share of imports
t/cap/yr.
0.005
0.005
0.004
0.004
0.003
0.003
0.002
0.002
0.001
0.001
0.000
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1961 1966 1971 1976 1981 1986 1991 1996 2001 2006 2011 2012 2013

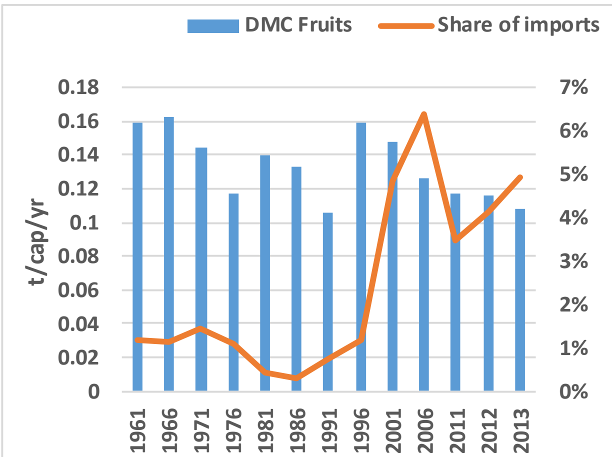
C


DMC Vegetables
Share of Imports
t/cap/yr.
0.12
0.10
0.08
0.06
0.04
0.02
0.00
18%
16%
14%
12%
10%
8%
6%
4%
2%
0%
1961 1966 1971 1976 1981 1986 1991 1996 2001 2006 2011 2012 2013

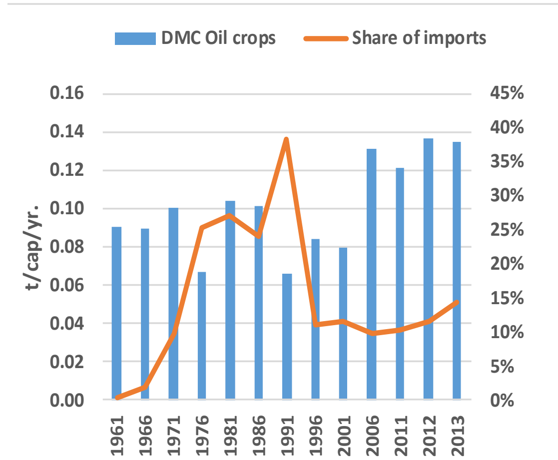
D


DMC Roots,tuber
Share of imports
t/cap/yr.
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
10%
9%
8%
7%
6%
5%
4%
3%
2%
1%
0%
1961 1966 1971 1976 1981 1986 1991 1996 2001 2006 2011 2012 2013

E



F



G

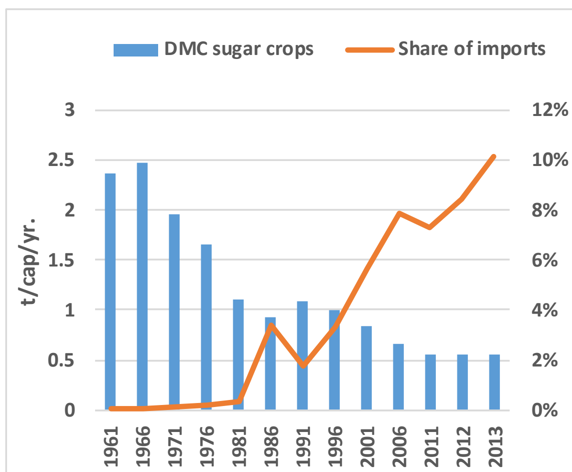


Figure 4.12 (A to G): Patterns and trends in import dependency for seven food biomass crops on per capita basis.

Pulses had the second highest import dependency ratio with more than 80% of consumption between the periods of 1961 and 2013 coming from imports (Figure. 4.12 B). From the present study result, it was observed that the import dependency ratio for food categories pulses, vegetables and roots&tubers displayed a somewhat similar trend between the periods of 1961 to early 1980s (Figure 4.12 B, C and D B). Very early on, dependence on imports for the consumption of these specific food crop categories was very minimal, as trends in import dependency ratio showed a regressing pattern, falling to its barest minimum in the period of the 1980s. However, beginning from the 1990s, Jamaica dependence on importation of these food crops started to increase (Figure 4.12 B, C and D). The gradual rise in increase in import dependency around the 1990s was also found with fruits (4.12 E). Importantly, consumption of sugar crops which was historically not dependent on imports, revealed a growing rise in share of imports beginning from 1986 at 3% ratio and has since accelerated (Figure 4.12 G). As can be seen from Figures 4.12 C and F, the dependence on imports for vegetables and oil crops consumption has significantly declined from their maximum of 16% in 1961 to 5% 2013 for vegetables (Figure. 4.12 C) and 40% in 1991 to less than 15% in 2013 for oil crops (Figure 4.12 F). One explanation of Jamaica growing food import dependency as shown in this study is low yield of food crops. Study result on the yield of two food crop categories that demonstrated highest import dependency ratio (cereal) and lowest ratio (vegetables) show increase in vegetable yield at from 7.0 tonnes per hectare to 13.4 tonnes per hectare while no significant improvement in cereal yield occurred throughout the reference period analyzed (Figure 4.13).

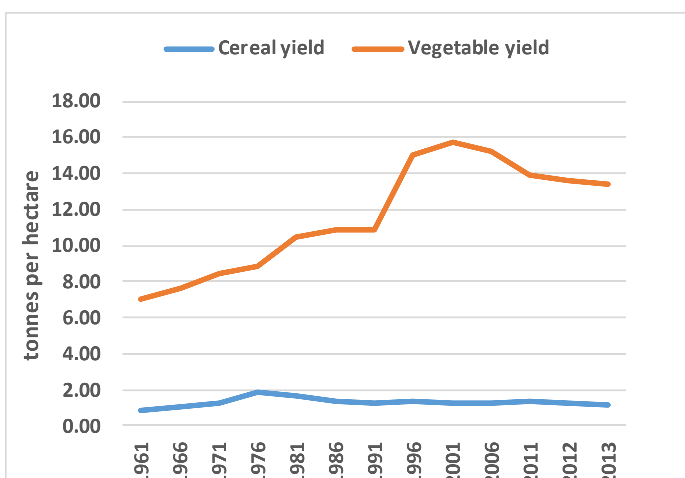


Figure 4.13 Yield of highest import dependent food crop cereal (maize and rice) and the least import dependent food crop (vegetable).

The disparity in yield of cereals and vegetables may be as a result of climatic element such as flood and drought. Jamaica as an island system is highly vulnerable to climate change which impacts on crop production at varying degrees.

Overall, Jamaica has a very high import dependency relying more on international market for supply of food biomass. Degree of import dependency for all food crop categories peaked between the periods of 2001 to 2011, the only exception was oil crops. Jamaica's continued dependence on imported food products as shown by the growing import dependency ratio presents a national food security concern. For instance, as food prices increase, import demand may reduce and this could result in food deficit especially if domestic production is insufficient to meet growing per capita food demand.

4.8 Livestock

From the 1960s, the number of livestock maintained in Jamaica increased up until mid-1980s (Figure 4.14 A). The only exception here is goat which dropped sharply by 45% from 1961 through to 1970s. Fundamental changes in the species of livestock in terms of number of heads occurred beginning from the decade of 1980s. Sheep production declined and did not rebound while number of farmed goats increased. The most significant change occurred with cattle which grew rapidly in the 1980s till around 2001 (Figure 4.14 A). It is important to note this period corresponded with peak growth in the quantity of DE of grazed biomass (Figure 4.14 B) indicating an intensive utilization of pasture land by cattle system. In the same period, reductions in feed consumption was observed (Figure 4.14 B). Number of cattle started to reduce from 2001, at the same time, grazed biomass extraction reduced. The cattle curve reflects the trend of grazed biomass extraction. Findings show that decline in number of cattle and corresponding reductions in grazed biomass extraction impacted on production output of cattle meat within the same period (Figure 4.15).

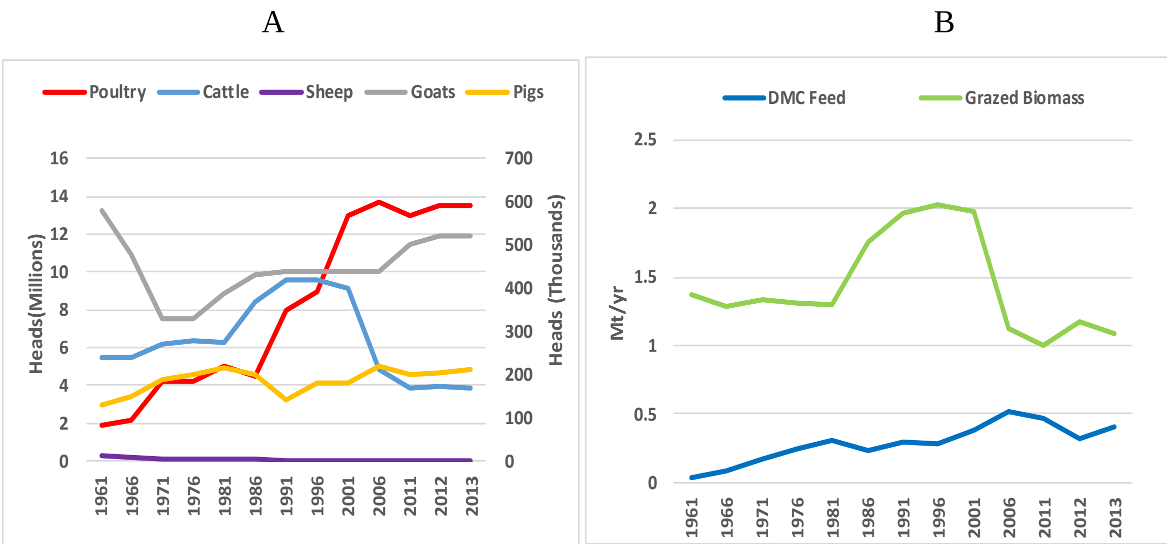


Figure 4.14 (A) Evolution of livestock, and (B) livestock feeding (grazed biomass and feed) 1961-2013. In Figure 4.9A, primary axis represents only chickens which has more numbers in millions, while secondary axis represents cattle, sheep, goat and pig. Number of sheep is very small relative to other livestock

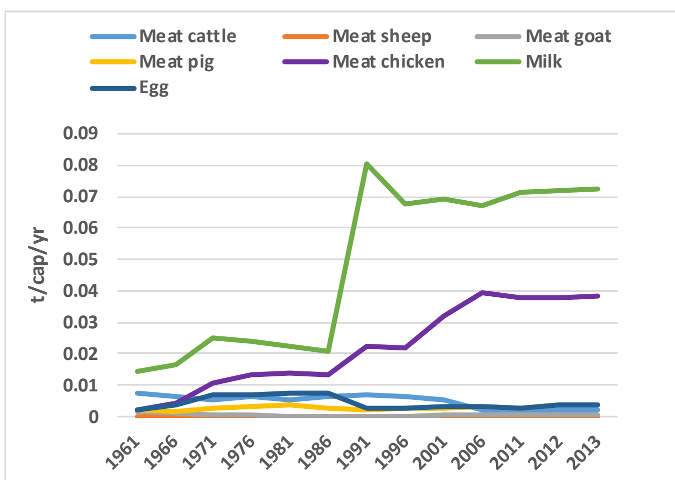


Figure 4.15 Trends in production output of animal products by livestock species (1961-2013). Output of sheep meat is relatively small and hence not visible from the graph

Starting from 2001, consumption of feed rose progressively and peaked in 2006 at 0.5 megatonnes (see Figure 4.14), correspondingly output of chicken meat accelerated peaking in 2006 and has relatively been stable the remaining period in the time series analyzed (Figure 4.15). An increase in milk production output starting from 1986 till about 1991 was observed, and may be as a result of intensive utilization of pasture given that extraction of grazed biomass rose significantly within the same period. As shown in figure 4.15, output of milk began to reduce around 1991, same period as grazed biomass extraction, though this reduction was not sustained as milk production has since increased. Although reductions in pasture utilization translates to decrease in environmental pressures on land, dependence on feed in the context of food security, presents a potential problem given that the main feed component is maize and production output of maize is very low.

Table 4.2 Production, consumption of livestock products and degree of import dependency

	1961	1966	1971	1976	1981	1986	1991	1996	2001	2006	2011	2012	2013
Meat production (t/cap/yr)	0.015	0.018	0.029	0.036	0.036	0.036	0.053	0.053	0.071	0.084	0.080	0.082	0.083
Meat consumption (t/cap/yr)	0.018	0.024	0.041	0.054	0.051	0.052	0.067	0.076	0.090	0.100	0.102	0.103	0.103
Share of imports	19%	28%	29%	32%	29%	31%	21%	31%	22%	16%	22%	21%	20%
Milk production (t/cap/yr)	0.014	0.017	0.025	0.024	0.022	0.021	0.080	0.068	0.069	0.067	0.071	0.072	0.072
Milk consumption (t/cap/yr)	0.018	0.023	0.035	0.035	0.029	0.028	0.087	0.073	0.076	0.072	0.075	0.076	0.076
Share of imports	23%	28%	28%	31%	25%	29%	8%	8%	10%	7%	5%	6%	6%
Eggs production (t/cap/yr)	0.002	0.004	0.007	0.007	0.007	0.007	0.003	0.003	0.003	0.003	0.003	0.003	0.003
Egg Consumption (t/cap/yr)	0.002	0.004	0.007	0.007	0.008	0.008	0.004	0.004	0.005	0.005	0.004	0.005	0.005
Share of imports	6%	8%	8%	11%	10%	4%	31%	32%	36%	35%	34%	28%	25%

From 1961-2013, output of total meat production went from 0.015 tonnes per capita to 0.08 tonnes per capita., an increase of 460% and that of milk increased by 410% from 0.014 tonnes per capita. to 0.07 tonnes per capita respectively (table 4.2). Despite significant increase in production output of meat, result of analysis show growing trend in meat imports. The share of meat imports relative to consumption (import dependency ratio) increased from 19% in 1961 to 20% in 2013 (Table 4.2). A similar trend is seen with eggs. Egg production has intensely declined despite increasing stock of chickens. Import dependency ratio of eggs has risen to about 317%% since 1961. This suggest that chickens are mainly raised for meat than egg in Jamaica. Milk consumption which was historically depended on international market has drastically reduced to less than 50%. This may be as a consequence of increased production output in milk (Figure 4.15).

4.9 Linking biomass flow and national food security

Present study MFA biomass analysis allowed for estimation of food available for human consumption in Jamaica. In the context of this research, national food security was analyzed based on Paarlberg (2000) operational definition of food insecurity- “food insecurity as any transitory interlude of below-trend food consumption that may threaten human health. Based on this definition, this study focused on analyzing trends in dietary energy supply and dietary energy production as a measure of evolution of food availability in calorie unit. Analysis was limited to food availability due to the type of biophysical data that was available to carry out the research. Measuring the amount of food calories available to a given population is a useful indicator for assessing food security in national context (Mayer et al., 2015).

4.9.1 Analysis of Food Energy Availability

Figure 4.16 illustrates the evolution of food availability represented by trends in dietary energy supply (DES) relative to minimum dietary energy requirement (MDER) and average dietary energy requirement (ADER) in Jamaica over the reference period examined by this research project (1961-2013). Findings shows that the periods between 1961 to before 1966 was characterized by critically low food availability as DES kcal/cap/day (that is calories available per person day), was below MDER (Figure. 4.17). Since 1966, Jamaica has moved from critically low food availability at 1740 kcal/cap/day in 1961 to maintaining an adequate food availability at 2470 kcal/cap/day in 2013, achieving a 42% increase in food energy availability. It was observed that Jamaica attained high food availability in the periods between 2001 and 2006 as the DES kcal/cap/day based on defined threshold, exceeded the approved daily calories limit (Figure 4.16). On an aggregated level, food energy availability and hence calorie consumption in Jamaica has exceeded the average dietary energy requirement (ADER) global standard of 2100 kcal/cap/day since after 1966 thus resulting in Jamaica achieving a high level of food energy adequacy in the observed period.

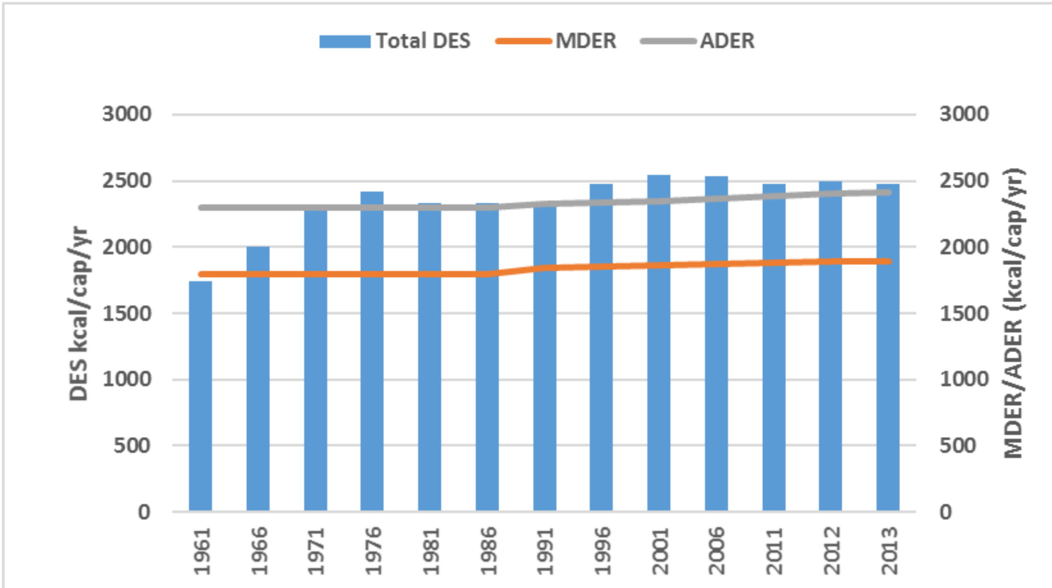


Figure 4.16 Trends in development of dietary energy supply depicting the evolution of food availability in Jamaica from 1961-2013. Defined threshold based on Jamaica averages of MDER at (1800 kcal/cap/day) and ADER at (2250 kcal/cap/day). Critically low food availability: DES < MDER at 1800 kcal/cap/day, Low food availability: MDER at 1800 kcal/cap/day<DES< ADER at 2250 kcal/cap/day, Adequate food availability: DES >ADER at 2250 kcal/cap/day to 2500kcal/cap/day, High food availability: DES of > 2500kcal/cap/day.

The most striking development in this study's analysis of food availability is that after an initial rise, the yearly available food calories decreased, beginning from late 1970s till around 1992, albeit still within adequate food availability limit. A similar trend occurred between the periods of 2008-2009 and 2011. This changes are attributable to domestic policy changes and global events. These periods were fraught with fiscal spending cuts in Jamaica due to structural adjustment policies in the face of growing debt burden (Weis, 2004, 2005), and also a global food crisis that occurred in 2008, 2009 and 2011 (Dethier and Effenberger, 2012).

As a measure of historical changes in the composition of national food diet contributions of each food categories to food energy availability depicted by their share of total DES over the period examined were assessed. Figure 4.17 below displays results obtained.

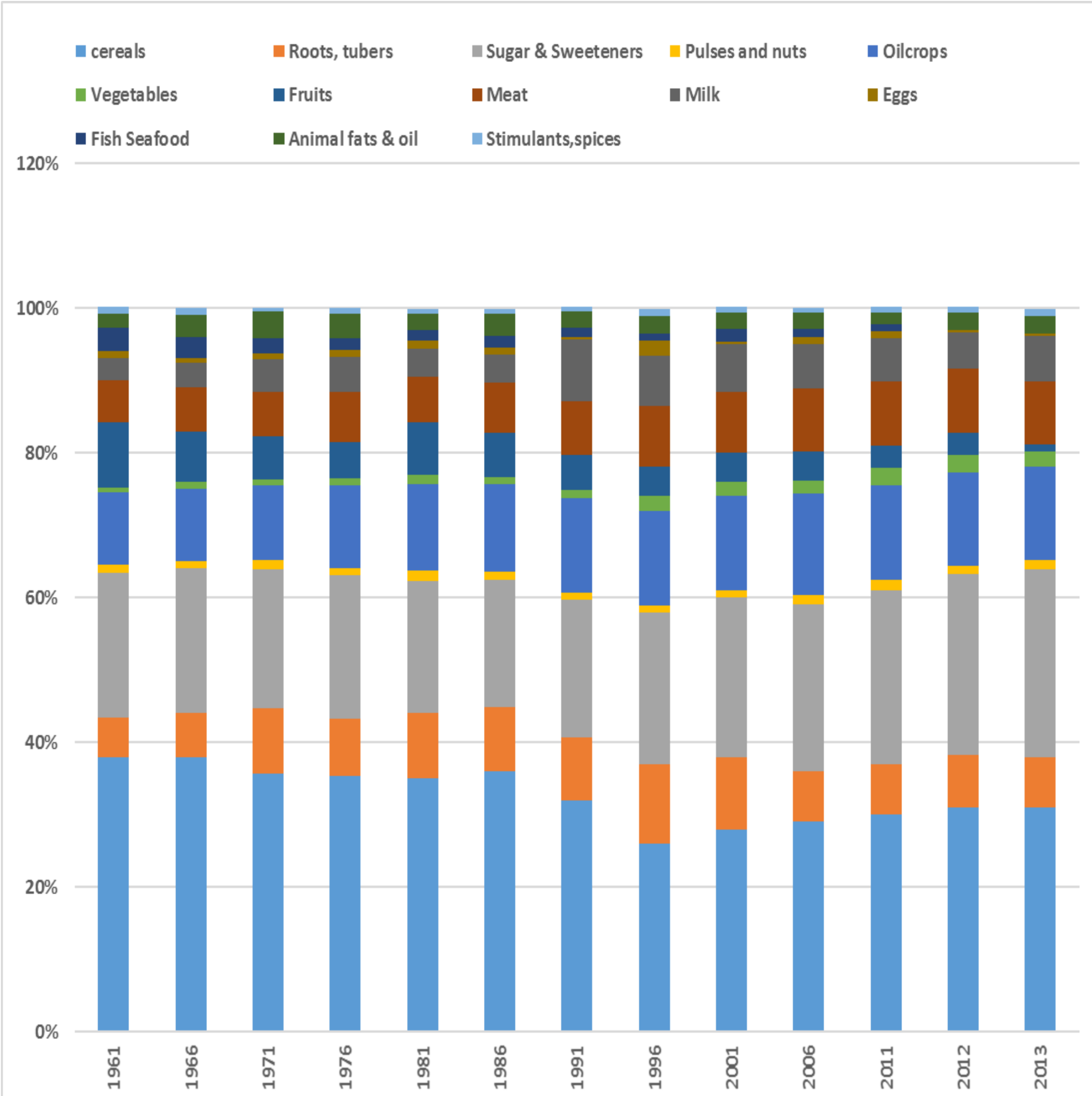


Figure 4.17 Trends in percentage contributions to food calorie availability by food categories as an indicator of changes in national diet compositions from 1961 to 2013.

Amongst the basic food categories (cereals, roots & tubers and pulses), cereals made the highest calorie contributions accounting for 34% of total DES. However, there have been slight reductions in calorie supply from cereal over the years. Trend in calorie contributions from roots and tubers depicts a moderate increase; an appreciable increase was found to have occurred in 1996 coinciding with a substantial reduction in calorie availability from cereal in the same year. Pulses made the least contribution to per capita food calorie availability amongst the basic food categories as well as in overall national diet compositions throughout the reference period. Calorie contributions from fruits has seen a marked decline while that of vegetables have modestly increased.

Looking at animal products, results indicates a growing and sustained increase in calorie contributions from meat. Additionally, milk calorie grew steadily, recorded its highest percentage contribution between early 1990s and mid-2002, but unlike meat, this was not sustained. Calorie supply from eggs has drastically declined. Growing presence of animal product -meat and milk in national diet may be as a result of rising per capita income. Increasing consumption of meat and dairy products has been associated with rise in per capita income (Nonhebel & Kastner, 2011). In the period analyzed, Jamaica per capita GDP grew approximately by 1118% from 429 (current US$) to 5226 (current US$) in 2013 (The World Bank Group, 2015).

Further, result of quantitative analysis of contributions of different food categories to calorie availability reveals a growing trend in share of oil crops products (mainly vegetable oil), and sugar (processed) and sweeteners which may suggest possible changes in the food consumption pattern in Jamaica towards more energy dense food. One of the major food security challenges in Jamaica identified in literature is the prevalence of overweight syndrome associated with increasing consumption of processed sugars and fats (Karfakis et al., 2011). Considering the results of analysis, it can be inferred that changes in compositions of national food diet may have significant influence in this regard given that what is supplied and available is what will be consumed.

4.9.1.1 Dietary Energy Production

Figure 4.18 illustrates trends in evolution of dietary energy production (DEP) relative to minimum dietary energy requirement and average dietary energy requirement in Jamaica over the reference period analyzed (1961-2013). The analysis offered an indicator to measure progress towards food self-sufficiency a requisite and strongly advocated strategy to achieving national food security. It is important to note that the production data provided by FAO statistics represents total domestic production which includes crop production for non-food purposes (Porkka et al., 2013). For this reason and given that this study is concerned with the quantity of commodities produced for human food consumption, it was necessary to estimate food production quantity to avoid overestimating the amount of food calorie supply from Jamaica domestic food production that is for human food use. It should be noted that the DEP is not equivalent to domestic extraction (DE) of primary crops. This is because DE of primary crops contains the weight of exports while the estimated food production quantity used in deriving the DEP does not contain the weight of exports.

Findings show that in the period analyzed, DEP ranged from 870 kcal/cap/day in 1961 to 1387 kcal/cap/day in 2013 (Figure 4.19), suggesting a progressive trend towards food self-sufficiency.

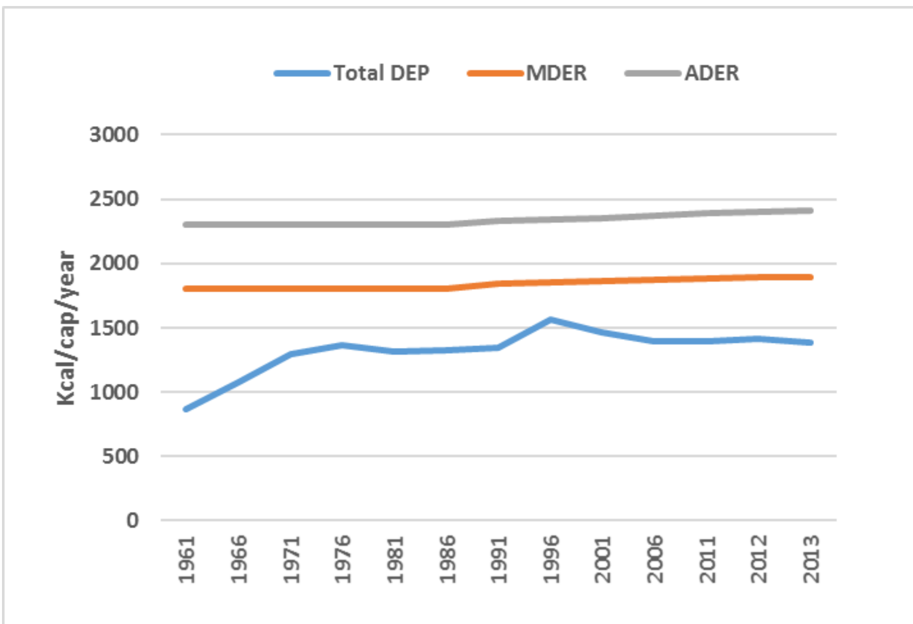


Figure 4.18 Trends in development of dietary energy production from 1961-2013; as an indicator of food self-sufficiency.

However, observed trend in DEP convincingly shows that Jamaica domestic food system is characterized by low food production as DEP was consistently below the minimum dietary energy requirement (MDER) threshold of 1800 kcal/cap/day. Hence while DES has increased substantially attaining a high level of energy adequacy (as shown in section 4.9.1), the DEP results underscores

Jamaica historical dependence on imports to close production deficit and thus satisfy domestic food demand of its population. Present study result is similar to Porkka et al (2013) global studies, where Jamaica is among the countries that have DEP below global MDER threshold and thus characterized by low food production.

Chapter 5
Summary and Conclusion

5.1 Summary of Research Contribution

This thesis presented a novel study on time series analysis of socioeconomic metabolism of biomass in Jamaica, providing an analysis of extraction, consumption and trade from a biophysical perspective. The goal of this study was to provide insight into the structure of Jamaica biomass system by analyzing biomass material flows (domestic extraction, imports and exports) from 1961 to 2013, and on this basis establish a link to the issue of national food security in Jamaica.

5.1.1 Jamaica Biomass System

From the analysis of this research, it was observed that significant changes in the structure of Jamaica biomass system has taken place since 1961. Overall, between 1961 and 2013, total quantities of domestic extraction (DE) declined by 41% from 9.6 megatonnes to 5.7 megatonnes and domestic material consumption (DMC) by 25% from 9.2 megatonnes to 7.1 megatonnes in absolute terms. The years between mid-1970 and early 1980s appear as period that marked substantial reductions in biomass material use. This result provides empirical evidence of the effect of changes in the late 1970s and 1980s characterized by major fiscal and monetary economic policy shifts that entailed cut backs in government spending in public sector under the specific guidelines of International Monetary Funds (IMF) and The World Bank, as discussed in chapter one section 1.4 of this thesis. The consequence of these policy shifts triggered fundamental changes in Jamaica agriculture sector such as elimination of export subsidies which impacted on commercial primary crop production specifically sugar cane thus reducing competitive advantage of Jamaica sugar industry as the cost of production input increased. In support of this assertion, findings of this research showed that on the average domestic extraction of sugarcane drastically reduced by about 57% between the periods of 1970s and 1980s.

With respect to the overall decline in agricultural biomass production, global environmental change is perhaps the biggest challenge to increasing agricultural productivity in Jamaica. Being an island system, Jamaica agriculture sector is challenged by periodic natural and climatic hazards that often results in yield losses and crop damages. As literature review suggests, the 1980s hurricane and a prolonged drought in 2005-2006 resulted in significant drop in primary crop extraction. Empirical evidence from this research showed that primary crop extraction reached its barest minimum mass flows at 0.8 tonnes per capita within this period, providing an empirical basis that contributes to support theoretical academic literature.

Another challenge to agricultural crop production is lack of government support in terms of provision of resources and infrastructure to support small scale farmers (as discussed in section 1.4). In the course of carrying out this study, the field trip to Jamaica by the researcher provided ground information in relation to crop production. Interaction with small farmers in Clarendon and St Elizabeth- the parish reputed for growing most of Jamaica food crops revealed the absence of irrigation infrastructure despite the region facing seasonal droughts due to irregular rainfall patterns resulting from climate change impacts. Under such circumstances, the decline in agriculture crop production output is bound to become inevitable as evidenced in the overall decline in primary crop extraction.

Considering domestic food production, this research revealed a disproportionately low share of mainstay food crops- cereals, roots&tubers, pulses, vegetables in the overall primary crop extraction. The literature alludes to a number of factors that converge to challenge domestic food production. A major factor is the dualistic nature of Jamaica agriculture system stemming from colonial legacy of land use pattern whereby a larger portion of fertile agricultural land are committed to large scale monoculture production of cash crops (Barker, 1993). Inequitable land distribution has meant that cultivation of Jamaica mainstay food crops takes place on steep marginal lands in the rugged interiors that are over-exploited and degraded due to intensive use (Weis, 2005). What is apparent from this research is the fluctuating decline in production output of mainstay food crops. Cereals and pulses production remained dismally low while roots tubers and fruits showed periods of low and high production, hence contributes empirically in support of theoretical literature perspective which affirm to weak performance of Jamaica domestic food sector.

Progressing, this research shows fundamental changes in Jamaica trade with biomass. As demonstrated by the patterns of biomass metabolism in Jamaica, overall quantity of main commercial export crops- sugar cane and banana showed an 80% and 68% decline over the study reference period. As the major agriculture foreign export earner in Jamaica, the decline in sugar cane and banana exports impacted on Jamaica monetary economy. Although literature alludes to efforts being made towards reviving the dwindling export producing sector through public and private sector collaboration and transfer of efficient technology, empirical evidence from this study cannot conclusively say if any improvements has yielded in this regard. Conversely from the results of analysis of import dependency, it was observed that importation of refined sugar has accelerated. Generally, Jamaica total biomass import has risen, import flows grew by 78% in the 52-year reference period analyzed. This growth was to a large extent driven by importation of staple foods particularly cereal. An interesting result of the research regarding the trends in cereal imports was the huge reductions in the quantity of imported cereal that occurred in mid-1990s and around 2008/2009 and 2011; the same periods the global food system experienced high volatility that resulted in food prices inflation. This reinforces Jamaica's vulnerability to food supply chain disruptions that could arise from volatility of international food market and export restrictions.

Result of analysis of Jamaica food import dependency ratio depicts a growing trend across all of the food crops categories (except for vegetable) which empirically supports what has been said in literature concerning Jamaica rising food import bills which has skyrocketed in last three decades from US$ 199 million in 1991 to US$913 million in 2013 (FAO, 2013). With dwindling export production, sustaining the current reliance on international market to meet growing food demand would be challenging in the absence of inadequate agricultural foreign earnings to sustain the funding of food imports in the face of rising import bills. As per capita income increases and population growth accelerates, per capita food demand in Jamaica is likely to increase. Growing trend in import of food crop presents a potential risk to the overall sustainability of the current structure of Jamaica agro-food system. Notwithstanding, this research observed that improvement in crop productivity may contribute to reducing Jamaica growing food import dependence as shown by the increasing trend in vegetable yield and corresponding reductions to its import dependency ratio.

As evidenced from this thesis, fundamental changes have occurred in Jamaica livestock system. The most significant change was observed in cattle system. Findings availed from this study showed reduction in the number of cattle stock and in the production output of cattle meat. Conversely, result revealed a growing trend in milk production and meat production from chicken, suggesting possible transition towards a more productive livestock system. It will be interesting to assess the productivity of livestock system in Jamaica. Thus, further studies may look at the overall efficiency of Jamaica livestock system when a more comprehensive dataset is available.

5.1.2 Socioeconomic Biomass Flows and National Food Security

In the context of national food security, Jamaica has made substantial improvements in raising the level of per capita food availability and thus food consumption per person going from a dietary energy supply (DES) of 1740 kcal per person per day to 2470 kcal per person per day between 1961 and 2013; which is well above the global average dietary energy requirement standard at 2100 kcal per person per day. From this outlook, it would appear there are no cases of food deprivation or under-nutrition. However, drawing such conclusion would be misleading in practical terms. This is because the food calorie availability estimated in this study does not represent actual food intake or pattern of food intake of each individual in the population nor does it differentiate food calories intake based on demographics. Such specific details are often captured with studies that examine individual level food security. Biophysical data available at national level food security limits such analysis. Notwithstanding, improvements in calorie availability observed in the present study supports FAO (2013) report that the prevalence of undernourishment as a percentage of total population in Jamaica has been reduced by 14.3% since 1990.

Analysis of dietary energy production as a measure of progress towards food self-sufficiency provided additional insight on linking patterns of socioeconomic biomass metabolism and national food security. Food self-sufficiency in the context of this research refers to country's domestic food production in relation to the statistical food supply requirements of its population (Porkka et al., 2013, p. 3). From this perspective, this study demonstrate that Jamaica is yet to attain food self-sufficiency as food energy availability from domestic production depicted by analysis of dietary energy production remained consistently below the minimum dietary energy requirement throughout the period examined. Relating to result of analysis of dietary energy supply (DES) which showed adequacy of per capita food availability, it is apparent that calorie production deficit has been satisfied by food imports as also evidenced in the results of import dependency ratio.

Findings of this research contributes empirical evidence that suggests an ongoing change in food consumption patterns of the Jamaican population. A key observation from this study in this regard is the growing share of oil crops products (mainly vegetable oil), and processed sugar and sweeteners in total dietary energy supply. This indicates a shift towards consumption of energy dense food often associated with overweight and obesity. Although it is difficult to make a conclusive positive association of overweight or obesity with this study result, the observed trend nonetheless suggests a food security concern in this direction given that what is supplied and hence available is what will be consumed. Study result therefore partly corroborates assertions in literature regarding the preponderance of overweight syndrome and obesity as the main food security concern in Jamaica. Overall, in order to provide an in-depth insight regarding the dimension of food security in Jamaica, further research on the evolution of dietary choices and patterns of Jamaica population at individual and household level needs to be carried out.

5.1.3 Sociometabolic Transition and Island Context

From a systems thinking perspective, transition occur as a non-linear behaviour reflected in the changing patterns of material flows and facilitated by biophysical and socioeconomic factors that trigger structural change in a system (Fischer-Kowalski, 2011; Rotmans et al., 2001). In relation to this research, it can be inferred that the observed patterns of socioeconomic biomass flow in Jamaica portrays a characteristic feature of a system in transition. The evolution of biomass material flows in Jamaica depicted by MFA indicators showed two alternating phases of growth and decline suggesting a biomass transition. While it is beyond the scope of this thesis to assess the various biophysical and socioeconomic factors driving biomass transition, literature provide some explanation as to possible cause. For instance, the decline phase in biomass extraction that occurred in the 1970s through to 1980s can be attributed to effects of structural changes in Jamaica agro-food system due to the International Monetary Fund (IMF) structural adjustment program that entailed cutbacks in government spending on agriculture (Weis, 2004, 2005). The aftermath effect of the 1970s/1980s IMF Structural Adjustment Program may have resulted in overall poor performance of Jamaica agriculture sector in favor of the service sector. Literature asserts that government spending in agriculture as a percentage of GDP declined fourfold within that period whereas the share of GDP from service industry increased (Weis, 2004).

In the most recent years, contributions of agriculture to GDP has declined from 9% in the 1990s to 6.6% in the 2000s (The World Bank, 2015), while the service industry contributions to GDP has grown from about 65% in the 1990s to about 80% presently (Central Intelligence Agency, 2015), suggesting a transition from agriculture economy to a service based economy. Further underscoring this assertion, the number of agricultural labour force in Jamaica declined from over 30% in 1970s to about 24% in 1985 (FAO, 2015). The most recent report suggests that percentage of employed labour force in agriculture has further decline to about 17% while the number of employed labour force in the service industry has grown from 60% as of the 1990s to about 70% (Central Intelligence Agency, 2006).

Another indication of biomass transition is seen in the strong change in Jamaica trade with biomass that occurred beginning from 1970s wherein biomass imports rose sharply exceeding export flows. The 1970s and 1980s period were characterized by agricultural trade liberalization and agro-food globalization that created a condition of artificial cheapening of traded food with attendant growing import dependency (McMichael, 2011). It is likely that reductions in government spending on domestic agriculture system may be responsible for the transition to dependence on international market which precipitated the rise in food biomass imports. Jamaica growing food import dependency presents a food security concern stemming from increasing consumption of processed foods as underlined by present study result on rising import dependency ratio of processed sugar and oil crops.

It must be acknowledged that this thesis is limited in the extent to which the observed changes in patterns of biomass use in Jamaica can be interpreted as socio-metabolic transitions. In order to present a robust discussion on the process of sociometabolic transition in Jamaica, an economy-wide material flow analysis for Jamaica which characterizes all four main material categories (biomass, fossil fuel, industrial minerals/ores and construction minerals) will be required. This thesis provides a credible basis for an analysis to clearly articulate the processes of transition in Jamaica. It has not only contributed to the understanding of biomass flows in Jamaica system but stands as a stem for further analysis of other material flows in Jamaica economy.

Situating this thesis in Caribbean island context, findings of this research speaks to key concerns of island sustainability in this region. Though there are not many MFA studies on

Caribbean islands which limits extensive comparison, the declining pattern of biomass material use obtained in this study was also found in two separate Caribbean island MFA studies; Cuba by Eisenhut, (2009) and Trinidad and Tobago by Krausmann et al (2014). As mentioned earlier (chapter 2, section 2.4), the declining trend in biomass production and consumption has been found in 2 known island MFA studies that are non-Caribbean: Iceland and the Philippines (Krausmann et al., 2014, Martinico Perez et al., 2016). However, this pattern of metabolic profile is quite uncharacteristic to what has been found in previous MFA studies that focused on mainland societies. For example, Singh et al (2012) study found increasing per capita DMC for India, Soto et al. (2016) study also found an increasing trend in Spain biomass use, similar increasing trend has equally been seen in MFA studies on USA (Gierlinger et al., 2012) and Japan (Krausmann et al., 2011). To what extent, and why such declining trends in biomass use is characteristic of island systems warrants further research.

The dynamics behind this uncharacteristic trend in the Caribbean region are still not well understood from literature. While findings from this research cannot provide conclusive evidence that may explain this trend, policy related factors hinged on economic development, resource availability (such as arable land per capita) and vulnerability to natural disaster appear to provide some level of explanation in this regard. As already mentioned, fiscal and monetary economic shifts that were in line with WHO/IMF structural adjustment program impacted on Jamaica agricultural production. Additionally, findings from this study showed that over the time period assessed, arable land available per person per year decreased by over 56% and the size of agricultural land as a percentage of total and area declined from 49% in 1961 to 2013 41% (World Bank, 2015). Although this study cannot conclusively make a positive association of the decline in agricultural land area and arable land per capita with the decline in overall biomass, literature suggest the existence of a significant relationship between land area per capita and biomass use (Steinberger et al., 2010). Further studies would be required in order to explicitly identify possible drivers of biomass material use in Jamaica.

5.2 Strengths and Limitations

The limitations associated to this study relates mostly to data constraint. Even though the study set out to analyze national food availability, the analysis was limited to dietary energy supply, and did not quantify the shares of different elements of food supply (carbohydrates, proteins, fats, etc.) that are required for a healthy and balanced diet. However, the intention of the study was not to give a detailed picture of diet composition or dietary pattern, hence differentiating between all these elements would have added another level of complexity to this research which given the constraint of time and data would not have been met. Notwithstanding, through the analysis of contributions to calorie availability by food categories, this study provided strong evidence to a potential food security concern linked to an ongoing changing dietary pattern towards unhealthy diet amongst the Jamaican population.

Further, due to constraint of data, this research only examined one aspect of food security (i.e. food availability) hence is limited in its ability to provide sufficient understanding of the real nature of food insecurity situation in Jamaica. Nonetheless, the present study outcome of the trend in food energy availability which suggest that Jamaica on a national scale has attained a high level of food energy adequacy provide a credible evidence in support of policy intervention towards addressing food insecurity concern from the point of accessibility and utilization.

There is also methodological limitation to this study. This work is the first attempt at linking food security to socioeconomic biomass metabolism using the MFA framework. Although the study desire was to estimate food supply quantity from MFA classic indicator domestic material consumption (DMC), this was not entirely achievable. This is due to the difficulty in disaggregating macro level data and allocating individual biomass item that serve non-human food use (such as fibers and feed) to their primary crop equivalent which would have enabled the ease of estimating biomass that serve food use from the DMC indicator. Nonetheless, FAO estimation procedure for domestic food supply quantity which was used in this study follows MFA methodological logic as already mentioned in section 3.4.3.1, this allowed for a connection to be made between biomass metabolism and national food security. As this study has shown, there is value in the applicability of MFA approach in food security studies if micro level data and factorial equivalent is available to enable estimation of constituents of the individual biomass mass flows in an aggregated mass flow data.

Another limitation is that MFA relies mainly on secondary data sources and this in itself present uncertainties on the quality of input data on the main material flow indicators. However, there has been improvements to develop statistical methods of addressing data uncertainties (Patrício et al., 2015). For this research, data uncertainties were addressed by getting expert opinions during the researcher's field visit to Jamaica.

5.3 Conclusion

In conclusion, this research has provided an empirical overview of historical evolution of biomass material flows in Jamaica and by so doing offered insight into the structure of Jamaica biomass system while relating it to national food security. The descriptive analysis of biomass metabolism and national food security nexus presented by this thesis is able to contribute to the ongoing discussions on food security in Jamaica. The intention however, is not to provide a conclusive answer on the state of Jamaica food security or insecurity but to offer insights on how the patterns of biomass metabolism in Jamaica may influence on national food security in Jamaica. From the findings of this work, it is possible that the weak performance of Jamaica domestic food sector and continued dependence on international food market may further exacerbate its vulnerability to food insecurity; hence there is need for policy interventions to strengthen the resilience of Jamaica agro-food system and reduce external dependency. The outcome of this study offers a basis for more research in Jamaica agro-food system to inform policy intervention geared towards ensuring the sustainability of Jamaica food and agriculture system. Considering that similar research conducted on the issue of biomass metabolism as it links to food security on a national scale is limited in the MFA literature, it is hoped that this work will expand and simulate research directions in this area as there is potential for methodological improvements from this first attempt at linking MFA to food security. MFA offers a promising tool for analysis of food systems as this study have attempted to illuminate.

Overall, this research fills existing knowledge gap on empirical analysis of Jamaica biomass system. and opens up research endeavors on the assessment of food and agriculture systems in the Caribbean region from a biophysical perspective, towards devising strategic policies that will ensure sustainability of their agro-food systems. It contributes to the growing research literature on socioeconomic metabolism and material flow analysis.

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Appendix A

Biomass Domestic Extraction, Import and Export Data

(Units: Megatonnes (1000000 tonnes)

	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
DOMESTIC EXTRACTION										
Primary crop harvest	5.1229	4.8893	5.3453	5.5099	5.6199	5.8110	5.3919	5.2536	4.7628	4.8725
Used crop residues	3.1057	2.9316	3.1806	3.2936	3.3450	3.4646	3.2170	3.1688	2.8510	2.8974
Grazing biomass	1.3689	1.3786	1.3474	1.3039	1.2996	1.2832	1.3070	1.2674	1.2971	1.3708
Wood biomass	0.0055	0.1911	0.2025	0.0094	0.2257	0.0533	0.0534	0.3079	0.3180	0.3322
Capture fisheries	0.0090	0.0090	0.0100	0.0100	0.0090	0.0090	0.0090	0.0085	0.0085	0.0085
Total DE	9.6030	9.3905	10.0858	10.1269	10.4993	10.6210	9.9783	10.0062	9.2374	9.4814
TRADE										
IMPORTS										
Primary crop products	0.1515	0.1629	0.1628	0.1897	0.1927	0.2148	0.2265	0.2495	0.2781	0.3264
Wood	0.1035	0.0978	0.1182	0.1088	0.1579	0.1749	0.1939	0.1893	0.2494	0.2496
Livestock Products	0.0204	0.0246	0.0265	0.0321	0.0305	0.0311	0.0357	0.0393	0.0395	0.0493
Feed	0.0014	0.0017	0.0013	0.0024	0.0020	0.0032	0.0040	0.0036	0.0106	0.0073
Fish	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Others	0.0028	0.0061	0.0061	0.0070	0.0046	0.0032	0.0033	0.0033	0.0032	0.0034
Total Imports	0.2797	0.2933	0.3150	0.3401	0.3967	0.4367	0.4734	0.4950	0.5963	0.6516
EXPORTS										
Primary crop products	0.7017	0.6752	0.6934	0.7206	0.7721	0.7920	0.7035	0.7197	0.6225	0.6207
Wood	0.0004	0.0004	0.0002	0.0001	0.0001	0.0000	0.0000	0.0002	0.0005	0.0006
Livestock Products	0.0006	0.0005	0.0004	0.0005	0.0006	0.0006	0.0006	0.0007	0.0005	0.0007
Feed	0.0007	0.0012	0.0008	0.0003	0.0005	0.0002	0.0000	0.0018	0.0015	0.0010
Fish	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Others	0.0004	0.0006	0.0046	0.0010	0.0026	0.0007	0.0006	0.0007	0.0005	0.0004
Total Exports	0.7038	0.6778	0.6994	0.7225	0.7760	0.7935	0.7048	0.7231	0.6256	0.6233

	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
DOMESTIC EXTRACTION											
Primary crop harvest	4.9845	4.9993	4.3850	4.5965	4.3136	4.3658	4.0579	6.8973	3.8737	3.6867	3.3559
Used crop residues	2.9498	2.9111	2.5506	2.7068	2.5128	2.5326	2.3689	2.6358	2.2436	2.1751	1.9220
Grazing biomass	1.3395	1.2945	1.3154	1.3259	1.2978	1.3099	1.3167	0.5308	1.2944	1.3539	1.2982
Wood biomass	0.3274	0.2503	0.2932	0.3256	0.3379	0.3874	0.4130	0.4097	0.4325	0.5011	0.5071
Capture fisheries	0.0093	0.0095	0.0096	0.0101	0.0101	0.0101	0.0101	0.0096	0.0096	0.0090	0.0078
Total DE	9.6106	9.4646	8.5539	8.9649	8.4722	8.6059	8.1666	10.4833	7.8538	7.7259	7.0910
TRADE											
IMPORTS											
Primary crop products	0.3573	0.3928	0.3397	0.3695	0.3577	0.4146	0.3511	0.4964	0.2779	0.5344	0.5136
Wood	0.2745	0.3269	0.3269	0.3269	0.3269	0.2525	0.2420	0.2166	0.2149	0.1599	0.2250
Livestock Products	0.0515	0.0561	0.0465	0.0596	0.0653	0.0721	0.0609	0.0749	0.0478	0.0590	0.0613
Feed	0.0072	0.0061	0.0315	0.0246	0.0404	0.0258	0.0409	0.0204	0.0063	0.0084	0.0057
Fish	0.0000	0.0000	0.0000	0.0000	0.0000	0.0177	0.0116	0.0153	0.0192	0.0154	0.0166
Others	0.0037	0.0040	0.0047	0.0047	0.0042	0.0035	0.0033	0.0033	0.0030	0.0015	0.0030
Total Imports	0.7101	0.7974	0.7593	0.8014	0.8115	0.7863	0.7099	0.8267	0.5692	0.7785	0.8252
EXPORTS											
Primary crop products	0.5865	0.5372	0.4899	0.4428	0.3661	0.3745	0.3543	0.3460	0.3144	0.2053	0.1744
Wood	0.0004	0.0004	0.0004	0.0004	0.0055	0.0149	0.0105	0.0168	0.0155	0.0134	0.0080
Livestock Products	0.0008	0.0010	0.0022	0.0018	0.0022	0.0018	0.0020	0.0014	0.0018	0.0016	0.0020
Feed	0.0004	0.0000	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Fish	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001
Others	0.0003	0.0004	0.0013	0.0010	0.0010	0.0012	0.0012	0.0008	0.0013	0.0010	0.0011
Total Exports	0.5884	0.5391	0.4941	0.4460	0.3748	0.3924	0.3681	0.3649	0.3329	0.2214	0.1854

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
DOMESTIC EXTRACTION											
Primary crop harvest	3.3271	3.1579	3.3411	3.1938	3.1679	2.9954	3.5305	3.0858	3.3096	3.5580	3.5068
Used crop residues	1.8588	1.7353	1.8354	1.7434	1.7890	1.6718	2.0568	1.6453	1.7538	1.9348	1.8857
Grazing biomass	1.3936	1.5793	1.6796	1.5611	1.7576	1.7556	1.6477	1.6473	1.8319	1.9692	2.0923
Wood biomass	0.5084	0.4040	0.4713	0.6839	0.6599	0.7352	0.7399	0.7457	0.7937	0.6925	0.5268
Capture fisheries	0.0077	0.0085	0.0093	0.0096	0.0094	0.0085	0.0114	0.0128	0.0132	0.0075	0.0113
Total DE	7.0957	6.8851	7.3366	7.1917	7.3837	7.1665	7.9863	7.1368	7.7022	8.1620	8.0229
TRADE											
IMPORTS											
Primary crop products	0.4707	0.5340	0.5695	0.4845	0.5016	0.5672	0.5473	0.5131	0.4908	0.5679	0.6160
Wood	0.2042	0.2342	0.2065	0.1862	0.1934	0.1703	0.2742	0.3632	0.2579	0.2620	0.2822
Livestock Products	0.0674	0.0536	0.0507	0.0578	0.0656	0.0786	0.0646	0.0689	0.0586	0.0647	0.0649
Feed	0.0007	0.0004	0.0086	0.0040	0.0027	0.0050	0.0244	0.0092	0.0314	0.0119	0.0232
Fish	0.0173	0.0131	0.0159	0.0119	0.0146	0.0157	0.0178	0.0176	0.0150	0.0141	0.0132
Others	0.0025	0.0021	0.0016	0.0013	0.0018	0.0020	0.0016	0.0030	0.0018	0.0029	0.0028
Total Imports	0.7628	0.8373	0.8527	0.7457	0.7797	0.8388	0.9299	0.9749	0.8554	0.9235	1.0022
EXPORTS											
Primary crop products	0.1959	0.2067	0.2155	0.2162	0.2255	0.2217	0.2582	0.2165	0.2648	0.2720	0.2722
Wood	0.0050	0.0080	0.0110	0.0110	0.0080	0.0080	0.0084	0.0168	0.0112	0.0068	0.0168
Livestock Products	0.0016	0.0019	0.0022	0.0027	0.0042	0.0029	0.0027	0.0030	0.0036	0.0048	0.0059
Feed	0.0025	0.0012	0.0000	0.0023	0.0136	0.0079	0.0050	0.0032	0.0091	0.0113	0.0113
Fish	0.0000	0.0000	0.0001	0.0004	0.0003	0.0004	0.0003	0.0003	0.0011	0.0016	0.0018
Others	0.0010	0.0014	0.0011	0.0010	0.0011	0.0012	0.0010	0.0006	0.0007	0.0004	0.0003
Total Exports	0.2060	0.2193	0.2298	0.2336	0.2527	0.2421	0.2756	0.2404	0.2904	0.2969	0.3083

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
DOMESTIC EXTRACTION										
Primary crop harvest	3.7416	3.6598	3.6205	3.9434	3.5724	3.3741	3.4417	3.0301	3.2899	3.0441
Used crop residues	2.0266	1.9128	1.8564	2.0512	1.8925	1.7763	1.8142	1.6253	1.7796	1.7620
Grazing biomass	2.0847	2.0876	2.0476	2.0239	1.9197	1.9072	1.9808	1.9799	1.9801	1.9738
Wood biomass	0.4781	0.5113	0.4381	0.5826	0.6078	0.6268	0.6473	0.6671	0.6618	0.5591
Capture fisheries	0.0150	0.0175	0.0160	0.0238	0.0196	0.0171	0.0169	0.0051	0.0139	0.0145
Total DE	8.3460	8.1889	7.9786	8.6249	8.0120	7.7015	7.9008	7.3075	7.7254	7.3536
TRADE										
IMPORTS										
Primary crop products	0.5789	0.5054	0.5484	0.4456	0.5837	0.6149	0.6515	0.7476	0.7538	0.7465
Wood	0.4761	0.3593	0.2851	0.2515	0.2335	0.3307	0.3452	0.3020	0.2632	0.2585
Livestock Products	0.0847	0.0660	0.0714	0.0949	0.1023	0.0936	0.0945	0.0774	0.1052	0.0722
Feed	0.0182	0.0206	0.0594	0.0565	0.0561	0.0815	0.0669	0.0763	0.0699	0.0831
Fish	0.0155	0.0155	0.0176	0.0179	0.0210	0.0226	0.0239	0.0234	0.0277	0.0284
Others	0.0030	0.0039	0.0028	0.0038	0.0035	0.0025	0.0048	0.0031	0.0040	0.0044
Total Imports	1.1764	0.9708	0.9847	0.8703	1.0000	1.1459	1.1868	1.2297	1.2238	1.1931
EXPORTS										
Primary crop products	0.2890	0.2616	0.2915	0.3292	0.3185	0.2851	0.2929	0.2783	0.2697	0.2521
Wood	0.0086	0.0166	0.0171	0.0140	0.0121	0.0081	0.0069	0.0079	0.0070	0.0041
Livestock Products	0.0070	0.0068	0.0111	0.0059	0.0056	0.0041	0.0070	0.0047	0.0107	0.0051
Feed	0.0111	0.0135	0.0108	0.0151	0.0055	0.0012	0.0017	0.0029	0.0079	0.0100
Fish	0.0027	0.0004	0.0029	0.0039	0.0031	0.0024	0.0019	0.0008	0.0014	0.0005
Others	0.0003	0.0003	0.0005	0.0004	0.0008	0.0006	0.0004	0.0003	0.0009	0.0005
Total Exports	0.3188	0.2992	0.3339	0.3685	0.3455	0.3015	0.3108	0.2950	0.2977	0.2724

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
DOMESTIC EXTRACTION											
Primary crop harvest	2.9385	3.0615	2.3430	2.8412	3.0262	2.6438	2.3907	2.4699	2.6745	2.6787	2.5778
Used crop residues	1.6491	1.7802	1.3921	1.7172	1.8569	1.6875	1.3760	1.4628	1.5554	1.5733	1.5212
Grazing biomass	2.0894	1.8069	1.9430	1.1200	1.0983	1.2609	1.2116	1.1348	0.9974	1.1741	1.0859
Wood biomass	0.5536	0.5489	0.5441	0.5415	0.5386	0.5361	0.5331	0.5331	0.5279	0.5251	0.5224
Capture fisheries	0.0121	0.0131	0.0127	0.0173	0.0160	0.0126	0.0161	0.0153	0.0030	0.0041	0.0202
Total DE	7.2427	7.2107	6.2349	6.2371	6.5359	6.1410	5.5275	5.6159	5.7583	5.9553	5.7275
TRADE											
IMPORTS											
Primary crop products	0.7437	0.7860	0.8178	0.8805	0.8390	0.7136	0.7194	0.7294	0.8075	0.7208	0.7978
Wood	0.2396	0.2158	0.2064	0.2228	0.2172	0.2204	0.2119	0.2273	0.2170	0.2162	0.3151
Livestock Products	0.0765	0.1056	0.1138	0.0707	0.1047	0.0978	0.0888	0.1275	0.0921	0.1075	0.1035
Feed	0.0903	0.1368	0.0403	0.0893	0.0816	0.0602	0.0623	0.0613	0.1113	0.0712	0.0882
Fish	0.0289	0.0285	0.0307	0.0324	0.0356	0.0309	0.0274	0.0265	0.0281	0.0277	0.0278
Others	0.0029	0.0045	0.0040	0.0047	0.0049	0.0045	0.0030	0.0013	0.0011	0.0016	0.0014
Total Imports	1.1819	1.2772	1.2130	1.3004	1.2830	1.1275	1.1128	1.1733	1.2571	1.1450	1.3339
EXPORTS											
Primary crop products	0.2577	0.2614	0.1992	0.2599	0.2634	0.2291	0.2306	0.2102	0.1999	0.2160	0.1543
Wood	0.0047	0.0034	0.0027	0.0054	0.0021	0.0029	0.0086	0.0090	0.0109	0.0124	0.0102
Livestock Products	0.0044	0.0089	0.0065	0.0060	0.0063	0.0075	0.0068	0.0076	0.0053	0.0080	0.0083
Feed	0.0061	0.0032	0.0024	0.0113	0.0050	0.0088	0.0147	0.0123	0.0084	0.0202	0.0227
Fish	0.0009	0.0012	0.0015	0.0016	0.0011	0.0012	0.0007	0.0009	0.0011	0.0008	0.0008
Others	0.0002	0.0007	0.0007	0.0005	0.0014	0.0011	0.0007	0.0007	0.0003	0.0008	0.0008
Total Exports	0.2741	0.2789	0.2130	0.2847	0.2793	0.2507	0.2622	0.2407	0.2259	0.2583	0.1972

Appendix B

Crop Domestic extraction, Import and Export Data by Crop Categories

(Units: Megatonnes (1000000 tonnes)

	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973
Domestic Extraction													
Cereals	0.008	0.009	0.010	0.007	0.006	0.006	0.004	0.004	0.005	0.005	0.006	0.004	0.004
Roots, tubers	0.077	0.082	0.087	0.098	0.110	0.126	0.126	0.105	0.109	0.143	0.200	0.215	0.193
Sugar crops	4.438	4.172	4.603	4.720	4.775	4.963	4.563	4.519	4.068	4.121	4.106	4.133	3.648
Pulses	0.002	0.002	0.002	0.002	0.002	0.004	0.005	0.006	0.005	0.005	0.005	0.007	0.004
Oil bearing crops	0.151	0.148	0.134	0.154	0.163	0.159	0.166	0.160	0.138	0.143	0.172	0.140	0.117
Vegetables	0.028	0.026	0.031	0.035	0.040	0.044	0.044	0.039	0.036	0.051	0.068	0.067	0.063
Fruits	0.407	0.439	0.467	0.484	0.513	0.498	0.472	0.409	0.393	0.397	0.419	0.425	0.346
Fibers	0.001	0.001	0.001	0.001	0.001	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000
Other crops (spices, stimulants, tobba	0.009	0.010	0.010	0.010	0.010	0.010	0.011	0.011	0.009	0.008	0.008	0.009	0.008
Imports													
Cereals and derived products	0.131	0.141	0.142	0.165	0.171	0.191	0.202	0.219	0.223	0.268	0.307	0.321	0.301
Roots, tubers and derived products	0.005	0.005	0.005	0.003	0.002	0.005	0.003	0.003	0.005	0.005	0.003	0.003	0.003
Sugar crops and derived products	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.019	0.015	0.004	0.013	0.005
Pulses and derived products	0.002	0.003	0.003	0.004	0.003	0.001	0.002	0.002	0.004	0.003	0.002	0.002	0.002
Oil crops and derived products	0.001	0.000	0.000	0.002	0.004	0.003	0.005	0.009	0.011	0.016	0.019	0.025	0.007
Vegetables and derived products	0.005	0.005	0.005	0.006	0.005	0.006	0.006	0.007	0.006	0.007	0.007	0.011	0.007
Fruits and derived products	0.003	0.003	0.003	0.004	0.004	0.003	0.003	0.003	0.003	0.004	0.004	0.006	0.005
Other crops (spices, stimulants, tobba	0.003	0.003	0.003	0.003	0.003	0.004	0.004	0.004	0.006	0.008	0.011	0.011	0.009
Exports													
Cereals and derived products	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
Roots, tubers and derived products	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.006	0.004
Sugar crops and derived products	0.539	0.499	0.499	0.521	0.541	0.560	0.481	0.537	0.435	0.428	0.412	0.353	0.340
Pulses and derived products	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Oil crops and derived products	0.002	0.009	0.001	0.000	0.002	0.002	0.000	0.000	0.000	0.000	0.001	0.001	0.001
Vegetables and derived products	0.000	0.001	0.001	0.001	0.001	0.003	0.004	0.005	0.006	0.011	0.006	0.005	0.002
Fruits and derived products	0.147	0.154	0.180	0.184	0.215	0.210	0.201	0.165	0.167	0.164	0.150	0.152	0.122
Other crops (spices, stimulants, tobba	0.013	0.013	0.013	0.015	0.013	0.016	0.016	0.011	0.014	0.018	0.017	0.020	0.019

	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
Domestic Extraction													
Cereals	0.0101	0.0138	0.0131	0.0106	0.0103	0.0073	0.0068	0.0064	0.0046	0.0070	0.0090	0.0082	0.0070
Roots, tubers	0.2091	0.2139	0.1946	0.2116	2.6354	0.2528	0.2136	0.2231	0.1832	0.2045	0.2480	0.2518	0.2462
Sugar crops	3.8468	3.5795	3.6283	3.2524	3.6406	2.9882	2.8104	2.4924	2.5493	2.3501	2.4497	2.2963	2.2394
Pulses	0.0047	0.0052	0.0042	0.0055	0.0091	0.0082	0.0074	0.0080	0.0066	0.0070	0.0079	0.0076	0.0079
Oil bearing crops	0.1222	0.1066	0.1022	0.1406	0.1446	0.1659	0.1948	0.1630	0.1181	0.1143	0.1259	0.1335	0.1804
Vegetables	0.0690	0.0714	0.0878	0.0925	0.1006	0.1088	0.1134	0.1247	0.1069	0.1261	0.1546	0.1381	0.1260
Fruits	0.3255	0.3141	0.3244	0.3367	0.3474	0.3353	0.3323	0.3280	0.3487	0.3377	0.3318	0.3467	0.3486
Fibers	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Other crops (spices, stimulants, tobbacc	0.0086	0.0085	0.0108	0.0075	0.0088	0.0067	0.0076	0.0099	0.0091	0.0107	0.0138	0.0112	0.0119
Imports													
Cereals and derived products	0.3309	0.3193	0.3570	0.2913	0.4073	0.1960	0.4506	0.4374	0.3513	0.3736	0.4255	0.3868	0.3641
Roots, tubers and derived products	0.0059	0.0032	0.0033	0.0035	0.0016	0.0009	0.0030	0.0013	0.0018	0.0026	0.0000	0.0000	0.0013
Sugar crops and derived products	0.0123	0.0064	0.0074	0.0119	0.0270	0.0016	0.0059	0.0080	0.0469	0.0487	0.0775	0.0383	0.0731
Pulses and derived products	0.0019	0.0024	0.0016	0.0007	0.0006	0.0002	0.0004	0.0005	0.0005	0.0005	0.0004	0.0003	0.0005
Oil crops and derived products	0.0044	0.0119	0.0346	0.0389	0.0535	0.0754	0.0707	0.0608	0.0608	0.1013	0.0623	0.0554	0.0569
Vegetables and derived products	0.0062	0.0062	0.0041	0.0019	0.0022	0.0010	0.0011	0.0016	0.0027	0.0018	0.0012	0.0009	0.0010
Fruits and derived products	0.0035	0.0037	0.0026	0.0013	0.0017	0.0008	0.0009	0.0012	0.0013	0.0020	0.0012	0.0011	0.0009
Other crops (spices, stimulants, tobbacc	0.0042	0.0043	0.0038	0.0015	0.0024	0.0020	0.0017	0.0027	0.0054	0.0034	0.0014	0.0017	0.0037
Exports													
Cereals and derived products	0.0008	0.0004	0.0006	0.0013	0.0016	0.0015	0.0009	0.0014	0.0012	0.0018	0.0007	0.0013	0.0013
Roots, tubers and derived products	0.0032	0.0032	0.0017	0.0022	0.0029	0.0034	0.0024	0.0040	0.0030	0.0029	0.0037	0.0032	0.0028
Sugar crops and derived products	0.3236	0.2547	0.2685	0.2475	0.2383	0.2147	0.1390	0.1213	0.1390	0.1445	0.1610	0.1516	0.1433
Pulses and derived products	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oil crops and derived products	0.0007	0.0003	0.0001	0.0000	0.0001	0.0002	0.0002	0.0002	0.0001	0.0052	0.0001	0.0002	0.0001
Vegetables and derived products	0.0021	0.0019	0.0012	0.0016	0.0017	0.0016	0.0019	0.0020	0.0024	0.0032	0.0057	0.0099	0.0109
Fruits and derived products	0.0871	0.0832	0.0878	0.0837	0.0851	0.0735	0.0436	0.0276	0.0322	0.0320	0.0212	0.0288	0.0390
Other crops (spices, stimulants, tobbacc	0.0253	0.0224	0.0144	0.0181	0.0163	0.0194	0.0175	0.0179	0.0181	0.0171	0.0231	0.0213	0.0280

	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Domestic Extraction														
Cereals	0.0062	0.0038	0.0034	0.0024	0.0035	0.0043	0.0036	0.0041	0.0039	0.0041	0.0032	0.0022	0.0022	0.0018
Roots, tubers	0.2532	0.2360	0.1982	0.2323	0.2454	0.2871	0.3132	0.3303	0.3462	0.3653	0.2944	0.2766	0.2760	0.2106
Sugar crops	2.0138	2.6031	2.2932	2.4910	2.7320	2.5250	2.6610	2.4500	2.3720	2.6239	2.4134	2.2600	2.3130	2.0250
Pulses	0.0075	0.0061	0.0055	0.0060	0.0060	0.0072	0.0068	0.0073	0.0063	0.0061	0.0051	0.0041	0.0041	0.0030
Oil bearing crops	0.1944	0.2070	0.0892	0.0796	0.0987	0.1390	0.1663	0.1742	0.1681	0.1867	0.1802	0.1704	0.1734	0.1728
Vegetables	0.1290	0.1003	0.1172	0.1268	0.1177	0.1506	0.1783	0.2152	0.2264	0.2381	0.1858	0.1938	0.2073	0.1803
Fruits	0.3781	0.3629	0.3672	0.3600	0.3428	0.3802	0.3983	0.4614	0.4800	0.5011	0.4756	0.4538	0.4519	0.4250
Fibers	0.0005	0.0005	0.0005	0.0004	0.0005	0.0005	0.0004	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0004
Other crops (spices, stimulants, tobbac	0.0127	0.0108	0.0114	0.0110	0.0113	0.0129	0.0139	0.0170	0.0173	0.0178	0.0144	0.0130	0.0134	0.0113
Imports														
Cereals and derived products	0.4214	0.4341	0.3578	0.3316	0.4463	0.4471	0.4473	0.3603	0.4254	0.3033	0.4543	0.4542	0.4434	0.5014
Roots, tubers and derived products	0.0005	0.0015	0.0026	0.0020	0.0005	0.0014	0.0017	0.0036	0.0066	0.0080	0.0099	0.0121	0.0116	0.0155
Sugar crops and derived products	0.0547	0.0494	0.0590	0.0665	0.0469	0.0508	0.0356	0.0462	0.0707	0.0845	0.0640	0.0940	0.0824	0.0958
Pulses and derived products	0.0017	0.0014	0.0021	0.0017	0.0011	0.0010	0.0018	0.0014	0.0017	0.0013	0.0021	0.0008	0.0034	0.0027
Oil crops and derived products	0.0808	0.0464	0.0665	0.0713	0.0605	0.1064	0.0753	0.0739	0.0227	0.0232	0.0212	0.0267	0.0294	0.0286
Vegetables and derived products	0.0012	0.0021	0.0028	0.0025	0.0022	0.0024	0.0047	0.0044	0.0069	0.0110	0.0153	0.0078	0.0130	0.0139
Fruits and derived products	0.0011	0.0026	0.0038	0.0045	0.0019	0.0019	0.0027	0.0025	0.0036	0.0047	0.0058	0.0067	0.0106	0.0183
Other crops (spices, stimulants, tobbac	0.0057	0.0100	0.0184	0.0107	0.0085	0.0049	0.0097	0.0130	0.0105	0.0095	0.0108	0.0125	0.0574	0.0713

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Domestic Extraction													
Cereals	0.0021	0.0018	0.0021	0.0016	0.0019	0.0019	0.0017	0.0020	0.0025	0.0026	0.0030	0.0031	0.0030
Roots, tubers	0.2243	0.2067	0.2181	0.1937	0.1678	0.1947	0.1825	0.1649	0.2024	0.2247	0.2405	0.2483	0.2432
Sugar crops	2.2310	1.9655	1.7757	1.9931	1.3687	1.7453	1.9680	1.6520	1.3346	1.3901	1.5183	1.4752	1.4026
Pulses	0.0031	0.0026	0.0025	0.0022	0.0019	0.0022	0.0020	0.0018	0.0023	0.0019	0.0024	0.0026	0.0027
Oil bearing crops	0.1844	0.2686	0.2687	0.2682	0.2688	0.3139	0.3147	0.3326	0.2666	0.2918	0.2926	0.3277	0.3128
Vegetables	0.2043	0.1634	0.2095	0.1668	0.1774	0.2040	0.1828	0.1795	0.2106	0.2027	0.2677	0.2735	0.2872
Fruits	0.4276	0.4235	0.4480	0.4240	0.3364	0.3545	0.3455	0.2912	0.3428	0.3305	0.3242	0.3207	0.2972
Fibers	0.0003	0.0003	0.0003	0.0004	0.0005	0.0005	0.0006	0.0006	0.0007	0.0007	0.0008	0.0007	0.0007
Other crops (spices, stimulants, tobbacco	0.0127	0.0117	0.0136	0.0114	0.0196	0.0241	0.0283	0.0194	0.0281	0.0249	0.0249	0.0269	0.0284
Imports													
Cereals and derived products	0.4833	0.4849	0.4655	0.4898	0.5403	0.5768	0.5406	0.4479	0.4234	0.4841	0.5771	0.4428	0.4870
Roots, tubers and derived products	0.0200	0.0177	0.0162	0.0205	0.0200	0.0190	0.0183	0.0167	0.0164	0.0130	0.0156	0.0134	0.0127
Sugar crops and derived products	0.1243	0.0947	0.1412	0.1358	0.1326	0.1369	0.1458	0.1266	0.1705	0.1248	0.1110	0.1269	0.1517
Pulses and derived products	0.0059	0.0036	0.0022	0.0083	0.0063	0.0087	0.0087	0.0075	0.0074	0.0070	0.0099	0.0070	0.0071
Oil crops and derived products	0.0238	0.0368	0.0259	0.0289	0.0262	0.0334	0.0199	0.0102	0.0044	0.0151	0.0333	0.0426	0.0525
Vegetables and derived products	0.0225	0.0150	0.0168	0.0213	0.0220	0.0187	0.0206	0.0208	0.0189	0.0181	0.0231	0.0183	0.0187
Fruits and derived products	0.0187	0.0150	0.0112	0.0174	0.0182	0.0214	0.0189	0.0176	0.0125	0.0112	0.0110	0.0130	0.0146
Other crops (spices, stimulants, tobbacco	0.0547	0.0786	0.0644	0.0633	0.0513	0.0650	0.0651	0.0650	0.0646	0.0548	0.0260	0.0554	0.0520
Exports													
Cereals and derived products	0.0071	0.0055	0.0054	0.0131	0.0085	0.0057	0.0083	0.0134	0.0122	0.0130	0.0112	0.0166	0.0170
Roots, tubers and derived products	0.0024	0.0055	0.0047	0.0018	0.0013	0.0026	0.0025	0.0020	0.0020	0.0019	0.0037	0.0124	0.0121
Sugar crops and derived products	0.1572	0.1387	0.1287	0.1572	0.1129	0.1404	0.1534	0.1362	0.1213	0.0941	0.1120	0.1037	0.0622
Pulses and derived products	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oil crops and derived products	0.0013	0.0002	0.0008	0.0008	0.0005	0.0006	0.0003	0.0001	0.0001	0.0002	0.0001	0.0002	0.0002
Vegetables and derived products	0.0023	0.0033	0.0041	0.0022	0.0014	0.0041	0.0024	0.0018	0.0018	0.0015	0.0032	0.0021	0.0026
Fruits and derived products	0.0602	0.0540	0.0517	0.0419	0.0227	0.0403	0.0320	0.0132	0.0160	0.0202	0.0189	0.0183	0.0173
Other crops (spices, stimulants, tobbacco	0.0386	0.0447	0.0621	0.0442	0.0516	0.0661	0.0641	0.0619	0.0767	0.0790	0.0504	0.0623	0.0425