Can the Caribbean localize its food system?

Exploring strategies to promote circular food systems in the Caribbean islands

by

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Author's Declaration

This thesis consists of material all of which I authored or co-authored: see Statement of Contributions included in the thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners. I understand that my thesis may be made electronically available to the public.

Statement of contributions

Chapters 1, 2, 3 and 5 have been written by Shupa Rahman under the supervision of Dr. Simron Singh and Dr. Cameron Mccordic for the sole purpose of this thesis. Chapter 4 presents research from an article published in the Journal of Industrial Ecology entitled “Can the Caribbean localize its food system? Evidence from biomass flow accounting”.

Brief overview of contribution:

- Shupa Rahman - Data curation, methodology, writing (original draft).
- Simron Jit Singh – Supervision, conceptualization, methodology, writing (review and editing)
- Cameron Mccordic – Supervision, conceptualization, methodology, writing (review and editing).

Abstract

Food security is a global concern and will remain so in the foreseeable future as the global food system experiences pressures on both the production and demand sides. Modern agriculture has given rise to a linear food production and consumption system. Such a food system is deemed inherently unsustainable and damaging to the health of populations. The key challenge in the near future will be to produce adequate, safe, and nutritious food for the population without exhausting resources and damaging the earth's ecosystem beyond repair. The circular economy model is surfacing as an alternative paradigm to the current linear food production and consumption system.

This research focuses on food security and sustainable food systems of island ecosystems, specifically in the Caribbean region. Small island developing states (SIDS) are at the forefront of sustainable development efforts as they require much more immediate action to find solutions to their sustainability challenges compared to the continental context. SIDS are faced with inherent challenges of size, insularity, remoteness, etc. that limit their resource availability, create heavy dependence on crucial resources and provide little resilience to the high frequency of natural disasters that take place in the region. These limitations prevent SIDS from achieving economies of scale and make their economies vulnerable to short run exploitations.

These processes and transitions have become prominent drivers of food (in)security and the evolution of food systems of SIDS. A diminishing domestic agricultural sector and rising import dependence puts the Caribbean SIDS in a disadvantageous position. These islands are also disproportionately impacted by climate change, extreme weather events and price/supply shocks. Conditions such as undernourishment, micronutrient deficiency and overnutrition, tend to coexist in the Caribbean food system.

Given the challenges and limitations the Caribbean SIDS would need to move away from the current food system to a multifunctional and diversified system in accordance with circular economy principles. The Caribbean SIDS require a complex systems approach and context specific research that will enable the respective domestic island systems to effectively respond to topical challenges. In order to trace the development or sustainability pathway of a socio-ecological system (SES) its biophysical flows need to be accounted for along with an understanding of the social processes that they are manifested from. This study takes a social metabolism approach to conceptualize the biophysical aspect of the SES of an island ecosystem. Social metabolism reveals the material and/or energy flows needed to maintain socio-ecological systems at different scales. The transition observed in social metabolism may act as an indicator of change in biophysical growth or de-growth of a society.

The objective of this research is to take stock of localization as a potential strategy of circular economy for island food systems. This study traces the socio-metabolic transition of island food systems over time for four Caribbean nations: Barbados, Dominica, Grenada, and Jamaica. The result is the respective metabolic profiles of the chosen island cases demonstrating what the Caribbean food system looks like and how they have changed over time. Material flow analysis, an operational tool of socio-metabolic research has been utilized. Derived indicators from a diachronic biomass flow accounting from 1961-2019 suggest a declining trend in local food production for all cases. While in Barbados and Jamaica this decline already began in the 1960s, for Dominica and Grenada this did not start until late 1970-80s. The physical trade balance of biomass is similar across all cases: from net exporters at the start of the study period to net importers as countries developed, albeit at different time periods.

Unfortunately, key stages in development of Caribbean SIDS have subsequently weakened the self-provisioning systems of food and given rise to a homogenous agricultural sector in a globalized market. The sustainability of SIDS is often associated with becoming self-reliant through such alternative local food networks. One of the suggested ways to enhance circularity in the food system is by diversifying production and consumption through localized food systems. Therefore, this study further disaggregates biomass flows to crop level to assess the extent of localization in the four islands and discuss their overall feasibility. Barbados and Jamaica indicate a trend that is moving away from food localization, while Dominica and Grenada appear to be modestly moving towards localization in recent years.

The trajectory of high import dependence and the diminishing export sector in these islands warrant the exploration of localization of the food system as a potential path towards self-sufficiency in the Caribbean SIDS. Considering the potential benefits of localization seems that it could be one of the strategies worth exploring to promote circular food systems in the Caribbean islands.

Key words:
Island industrial ecology; socio-metabolic research; circular economy; circular food systems; food localization; food security; biomass metabolism; Sustainable Development Goal 2

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SDG: Sustainable Development Goals
ICSU: International Council for Science
UN: United Nations
UNGA: United Nations General Assembly
SIDS: Small Island Developing States
SAMOA: SIDS Accelerated Modalities of Action
UN-OHRLLS: United Nations Office of the High Representative for the Least Developed Countries, Landlocked Developing Countries and Small Island Developing States
FAO: Food and Agricultural Organization
AIS: The Atlantic, Indian Ocean and South China Sea
SES: Socioecological systems
MFA: Material Flow Analysis
IE: Industrial Ecology
NGO: Non-governmental organization
CARICOM: Caribbean Community
EU: European Union
WTO: World Trade Organization
UNFCCC: United Nations Framework Convention on Climate Change
CARIFORUM: The Caribbean Forum
UNESCO: The United Nations Educational, Scientific and Cultural Organization
EW-MFA: Economy Wide Material Flow Accounting
UN-FAOSTAT: United Nations - Food and Agriculture Organization Corporate Statistical Database
FishStatJ: Software for Fishery and Aquaculture Statistical Time Series

Chapter 1 Introduction

1.1 Background

Unsustainable trajectories of the so-called Anthropocene have created major challenges for humanity. Climate change, food security, resource depletion and pollution are some of the significant issues that negatively impact social and ecological systems of the earth ecosystem (Capone et al., 2014; Ostrom, 2009). Scholars and policy makers alike approach sustainability from their respective vantage point. However, the overarching goal for humanity, is to ensure human rights of all people (which entails high quality of life that is equitably shared and sustainable) within the Earth's capacity to support life: "Humanity's sweet spot", endearingly coined by Kate Raworth. In that pursuit, 17 sustainable development goals (SDGs) were adopted (ICSU, 2015; Raworth, 2014). The right of every person in this planet to food, shelter, health, education, security, and equity encompass the 17 SDGs and their associated targets (Charlton, 2016).

The provision of food is one of the key ecosystem services that contribute to the achievement of targets across several SDGs (Wood et al., 2018), particularly SDG 2 that calls for food security and sustainable agriculture (FAO; 2016; UN, 2015). SDG 2 is believed to be key to the success of the whole SDG agenda as it inherently relates to all the spheres of sustainability: society, economy and the environment (Gil et al., 2019). Five out of the eight SDG 2 targets are directly related to food security and sustainable agriculture while the remaining three are related to improvement of the agricultural market through increasing investment and reducing distortions, volatility, etc. (Gil et al., 2019).

1.2 Food security and food systems

Food security is a fundamental human requirement and strongly related to health and sustainable development (Pérez-Escamilla, 2017; Capone et al., 2014). It is defined as a condition where "… all people at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO, 2002, p. 49). However, food security has become a global concern (especially after the global food crisis due to price spike in 2007-2008) (Porter et al., 2014) and will remain so in the foreseeable future as the global food system experiences pressures on both the production and demand sides (Rockström et al., 2020; Rosegrant and Cline, 2003).

Food and sustainability are deeply interconnected, and acknowledgment of their relationship began surfacing in the global policy environment during the 1980s when sustainable development was prioritized as a policy objective for all countries (Aiking & De Boer, 2004). Historically, food provisioning has shifted from hunting and gathering to agriculture and now agricultural expansion and intensification. The current system of food provision is deemed inherently unsustainable (Helms, 2004). Given the current trends of food consumption and food waste the world will require a 60% increase in food production by 2050 (Leunufna and Evans, 2014; Porter et al., 2014). The future era of globalization will expose the global food system to unparalleled pressures from a rising global population, creating competition for land, water and other resources. (Capone et al., 2014).

A food system can be defined as all processes and infrastructure dedicated to contributing towards food security within a population (Borman et al., 2022; Goodman, 1997): harvesting-storageprocessing-packaging-transportation-marketing-consumption-disposal (Porter et al., 2014). Agricultural systems include processes of production of both food and non-food products (Capone et al., 2014). Often the term agro-food system is used to refer to food and agricultural systems as one. Drivers of food system dictates food security outcomes (Porter et al., 2014). While earlier definitions of food security focused primarily on food production, later definitions gave attention to access (Porter et al., 2014). The issue of food security is increasingly being viewed as complex systems comprising of coupled physical, social, and ecological sub-systems (Jagustović et al., 2019; Van Berkum et al., 2018). Food security of a country is not merely the physical availability of food in the market or the ability of consumers to purchase that food. Food security is a multidimensional and multi-faceted issue and even though there is still quite some debate on the definition of food security, most scientific articles, government policy reports and leading NGO reports would agree, that the concept of food security or achieving thereof, comprises of four main dimensions or pillars: food availability, food stability, access to food and nutritional adequacy (FAO, 2008; Beckford, 2012; Ministry of Agriculture and Fisheries and Ministry of Health, 2013; Gross et al., 2000).

Food availability refers to the physical supply of food in the market either through domestic production or import of selected items. *Access to food* refers to the ability of households and individuals to afford sufficient and nutritious food. *Food stability* means that the supply of food has to be resilient to shocks. Domestic production has to be resilient to natural shocks such as extreme weather events and supply through imports has to be resilient to socioeconomic/ trade shocks such as policy changes, price hikes, trade embargos, etc. Finally, the fourth dimension of food security that is often overlooked is *Nutritional Adequacy*, which states that food should meet dietary needs of all demographics and contain sufficient nutrients to prevent non-communicable diseases such as cardiovascular diseases, blood pressure, obesity, etc. (Ministry of Agriculture and Fisheries and Ministry of Health, 2013; Beckford, 2012; Gross et al., 2000). Consumption of food is variably dependent on availability, accessibility and choice of consumers based on geography, socioeconomic status, culture, marketing and consumer attitude among others (Capone et al., 2014).

At the core of all these dimensions, is the concept of food sovereignty that goes beyond the concept of food security and states that human beings have the inherent right to adequate, safe, healthy and sustainable supply of food that fares with their respective cultural practices and religious sensitivities (Thompson 2019; Patel, 2009).

There is also a temporal aspect of food security in that it can be chronic, transitory or seasonal. Chronic food insecurity refers to the inability to meet minimum food demands for a long period of time usually due to persistent poverty. Transitory food insecurity usually results from sudden inability to produce and access food due to issues with food production, supply, changes in price and income. Finally, seasonal insecurity is a pattern of food insecurity that takes place as a result of seasonal climatic changes and cropping patterns acting as impeding factors to supply (Beckford, 2012). Out of the three types of food insecurity this can usually be predicted as it occurs in a cyclical manner.

Another important aspect of food security is vulnerability (Beckford, 2012). Borrowing from climate change literature, vulnerability can be defined as "a function of a system's exposure and sensitivity to stimuli and its capacity to adapt to the effects" (Shah et al., 2019, p. 220). In the context of food security, vulnerability is defined in relation to a negative outcome such as food insecurity or famine (Dilley and Boudreau, 2001). Therefore, a food system or a population can be deemed "vulnerable" based on a combination of factors including risk of exposure to a threat; the extent to which the food system or population would be impacted; and the ability of the food system or population to recover, in other words, its resilience (Dickinson et al., 2021; Moseley and Battersby, 2020). "Vulnerability" that refers to the potential future threats to food security in a place where the present situation may seem to be fine, demonstrates the dynamic nature of food security and its high susceptibility to external risk factors (Beckford, 2012).

Modern or conventional agriculture has given rise to a linear food production and consumption system. Generally, a linear model of production and consumption comprises of "take-make-use dispose" practices (Stahel, 2016; Korhonen et al., 2018). A food system generating from such a model is open-ended, deemed wasteful, disruptive to nutrient flows and damaging to the environment and the health of populations (Ellen Macarthur Foundation, 2018). There are increasing concerns about issues around ecosystem integrity, loss of social systems, land degradation, etc. (Waldron et al., 2017). However, the key challenge in the near future will be to produce adequate, safe, and nutritious food for the population without exhausting resources and damaging the earth's ecosystem beyond repair (Capone et al., 2014). Therefore, alternative strategies to development such as the circular economy model is often explored to address these challenges in the food system (Esposito et al., 2020; Jurgilevich et al., 2016).

This research focuses on food security and sustainable food systems of island ecosystems. Small island developing states (SIDS) are at the forefront of sustainable development efforts as they require much more immediate action to find solutions to their sustainability challenges compared to the continental context (Baldacchino and Kelman, 2014; Deschenes and Chertow, 2004).

1.3 Sustainability in island food systems

SIDS are a diverse group of nations that found common ground due to their ecological uniqueness and vulnerabilities (Saint Ville et al., 2015; Connell et al., 2020). From its inception in 1992 as a political category (UN, 1992) several seminal events have followed to urge the rapid and efficacious implementation and review of emerging sustainable development priorities of SIDS and reaffirmed SIDS as “a special case for sustainable development” (UN, 2015). These events include the 1994 Barbados Programme of Action for the Sustainable Development of Small Island Developing States (UNGA, 1994), the Mauritius Declaration in 2005 and the SIDS Accelerated Modalities of Action (SAMOA) Pathway in 2015 (Sindico, 2021).

SIDS are faced with some unique challenges such as small size, insularity, boundedness, and remoteness that limits their resource availability, carrying capacity and assimilative capacity (Petridis et al., 2017; Saint Ville et al., 2015; Garfield, 2004; Kane, 2004). SIDS generally have a narrow resource base, heavy dependence on crucial resources from remote markets, lack of space and little resilience to natural disasters. Therefore, essential processes such as resource extraction, manufacturing and waste disposal are more difficult in island ecosystems compared to land ecosystems (UN-OHRLLS, 2020). These limitations in turn hamper their achievement of economies of scale and make their economies vulnerable to short-run exploitations and intrusive technologies that disregard their inherent characteristics and indigenous practices (Deschenes and Chertow, 2004). These processes and transitions have become prominent drivers of food (in)security and the evolution of food systems of SIDS (Connell et al., 2020).

A total of 52 countries and territories are classified as SIDS by the UN. They are mostly located in three geographical regions: the Caribbean, the Pacific and the Atlantic, Indian Ocean and South China Sea (AIS) region (UN-OHRLLS, 2021). SIDS specifically in the Caribbean region are faced with complex issues in their food systems. The historical significance of plantation agriculture, high frequency of natural disasters and even their small population sizes and diversity within the region create challenges in their food systems. Research point towards systemic issues such as heavy dependence on the mainland (Beckford, 2016), lack of access to finance, markets and knowledge networks as some of the limitations for small-scale farming in the region (Lowitt, et al., 2020).

Deschenes and Chertow (2004) highlighted the importance of addressing self-reliance in islands through alternative localization strategies since resource security is a major concern. Such a strategy might be relevant for Caribbean SIDS considering their domestic food systems lack self-reliance or self-sufficiency making them more vulnerable to challenges of food (in)security than the mainland.

As mentioned before, the Caribbean SIDS are inherently similar with respect to their challenges, limitations and historical and cultural backgrounds. However, they are also diverse in demography, size, land and resource availability and vulnerability, among other features (Beckford and Rhiney, 2016). Naturally, potential opportunities and solutions for agricultural development and efforts towards food security in these islands will differ (Saint Ville et al., 2015). Moving away from the current food system of the Caribbean SIDS will require a multifunctional agriculture system that takes into account broad societal and environmental goals (Waldron et al., 2017). Instead of myopic and reactive measures, the Caribbean SIDS require a complex systems approach and context specific research that will enable the respective domestic island systems to effectively respond to topical challenges (Lowitt et al., 2015; Saint Ville et al., 2015).

1.4 Research objectives

Petridis and colleagues (2017) pose the question, "Can scientific research facilitate the sustainability transition of an island?" and discuss how transformative science has the ability to initiate and catalyze societal transformation which can be applied to island research. From an academic point of view, sustainability management of SIDS is gaining attention in the scientific community because sustainable practices are known to find their way in these island ecosystems as a natural response to these very limitations, as scarcity and vulnerabilities are known stimulus of innovation (Deschenes and Chertow, 2004; Singh et al. 2020). Not to mention due to their limited size (which is usually cited as a disadvantage) these island ecosystems are manageable units of study, with a potential for replicability of outcomes. Therefore, this type of research holds value in island scholarship and island sustainability transitions (Garfield, 2004).

To that end, this research inquires:

(1) *What does the Caribbean food system look like and how has it changed over time?*

(2) *What is the extent of localization that has taken place in the Caribbean?*

(3) *Could localization be a critical strategy for islands to move towards circular food systems?*

1.5 Thesis structure

This is an article-based thesis divided into four chapters. Chapter 2 covers a review of current literature of the topics of inquiry narrowing down to the focal point of the research. Chapter 3 explains the concept of social metabolism and its operational tool “material flow analysis” utilized in this study. That is followed by description of the chosen island cases. Chapter 3 then focuses on detailing the steps taken for data curation and methodological framework used for the empirical analysis.

Chapter 4 consists of an article published in the Journal of Industrial Ecology. It highlights the empirical analysis of this thesis and is presented without changes, (i.e., identical to the submitted version). This chapter presents a concise version of the research:

⇒ with a brief background,
⇒ a succinct state-of-the art review of current literature with analysis of gap in research,
⇒ description of the data curation and methodology,
⇒ followed by presentation of key results and discussions. This is done to open the discussion of how the current metabolic profile emerged and how certain biogeographic and socioeconomic factors may have shaped them.
⇒ the article ends with a discourse on the feasibility aspect of localization and whether the Caribbean SIDS can localize their food system.

Chapter 5 provides discussions and conclusions on the trade dynamics of the island cases and localization as a potential solution for the Caribbean SIDS. The efficacy of MFA indicators for this type of research is also discussed. This chapter concludes this thesis with post-analysis reflections on food system localization in the Caribbean SIDS along with future direction for research.

Chapter 2 Reviewing Island literature: food systems, food security and agricultural policies

2.1 Characterization of island food systems: through drivers and challenges of food security

Food production and consumption is a fundamental part of every economy albeit to varying extents based on socioeconomic factors. Developing countries are generally more reliant on their agricultural sector/ food production activities (Gil et al., 2019). However, islands, particularly SIDS have a distinctly different food production system compared to other developing countries of similar socio-economic conditions. Historically, small islands across the Caribbean have gone through major economic shifts over the years. During the era of colonization, agriculture and manufacturing industries took precedence. This changed when tourism was highlighted as a means to diversify and develop the economies and stimulate foreign exchange. The growth of tourism along with loss of preferential access to markets and high frequency of extreme weather events all led to a major decline in the agricultural sector. Meanwhile, rise of cheaper food imports further disrupted the domestic food production system of the islands (Thomas et al., 2018).

In this section some of the significant drivers of food (in)security in the Caribbean SIDS are described followed by the food security challenges that have emerged as a result:

The enduring impact of colonialism

The colonization of Caribbean islands drastically changed their local food systems over time. Traditional practices of food production were replaced with intensive export economies. Small-scale cultivation of root crops and fruits, etc. for domestic consumption were displaced by large scale monoculture of cash crops (Marrero and Mattei, 2022). Agricultural production was decoupled from local ecogeographical conditions which led to the genetic decline of traditional crops and significant ecological degradation (Marrero and Mattei, 2022; Wallman, 2018). Plantation economies were fueled by labour of enslaved and indentured people to meet the demands of the expanding consumer market of primarily the European mainland. Crops such as sugar, coffee, etc. have played a major role in the rise of industrial capitalism and the diffusion of the global market in the region (Mintz, 1986).

In the post-colonial period, land re-distribution led to an inequitable and inefficient land tenure system (Griffith-Charles, 2010). The Caribbean's present-day challenges such as dependence on coercive international aid/policies (Black, 2001) and the exploitative tourism sector (Wong, 2015) reflect the region's colonial legacy.

Lack of resources and infrastructure

Locally occurring natural resources are often scarce in island ecosystems putting them at constant risk of supply and price fluctuations (Saint Ville et al., 2015; Deschenes and Chertow, 2004). There is a tight competition for resources such as fresh water and high-quality land that are crucial to enhancing food security of SIDS. It is difficult for resources such as freshwater to be prioritized amidst other needs such as increasing demands for higher quality drinking water and sanitation for the rising local and tourist populations. The tradition of harvesting cash crops through monoculture occupies much of the land suitable for producing fresh and diverse produce (Sonneveld et al., 2021). Lack of infrastructure leads to high transportation and communication costs which ultimately effects the prices of local food (Kane, 2004).

Income disparity and prevalence of poverty

Seven of the Caribbean countries have more than 30% of the population falling below national poverty levels. In case of Haiti, the number is estimated to as high as 59%. There is also a high level of income inequality in almost all the Caribbean countries. As a result, purchasing power is seen to be 16.4 times more among higher income earners (FAO, 2015a). Composition of agricultural produce markets are dictated by purchasing power (Helms, 2004). Here it is relevant to note that even though staples have occupied the highest share in the food import expenditure of the Caribbean quite steadily over the last decades, it is now gradually declining with a simultaneous increase of expenditure of the other food groups. This may suggest that the Caribbean consumers are expanding and diversifying the range of food groups they consume. However, it is not characteristic of the entire population and may just be an indication of the purchasing habits of the higher income group (Walters and Jones, 2012).

Changes in landscape and land-use pattern

Small landmass along with low population density leads to limited opportunities to achieve economies of scale and diversification (Lenderking et al., 2021; Felician, 2012). The problem is further compounded due to narrow resource base, especially arable land. Per capita available arable land in the Caribbean countries is about half that of the least developed countries (LDCs) and developing countries (The World Bank, 2018c). Caribbean lands also tend to be ecologically fragile and susceptible to soil erosion. Within available land there is the added issue of an unequal land tenure system that includes issues of informal tenure, prolonged bureaucratic procedures for land ownership, land distribution inequities within marginalized communities, occupation of environmentally sensitive land and other conflicts (Griffith-Charles, 2010). Land tenure inequities affect land-use pattern and act as a barrier to the small-scale domestic food production system of the Caribbean (Marrero and Mattei, 2022). As a result, these countries have to rely on external land use through the global food supply chain to meet consumption needs (Nakamura et al., 2021).

Socio-agronomic issues

There is a significant disproportional gender participation in agricultural activities in the Caribbean SIDS. For instance, Tandon (2012) found that participation of rural women in several Caribbean SIDS was not equitable due to wage gaps, unequal inheritance rights to land, etc. Women farmers tend to be left out of decision making and strategies around agricultural activities and food security. (Tandon, 2012). Researchers argue that gender sensitivity in agriculture, such as in agricultural extension services, can catalyze efforts towards enhancing food security (Barry and Gahman, 2021). In recent times however, there is a general aversion towards agriculture as a profession, especially among younger populations of the Caribbean (Kendall and Petracco, 2009).

Climate change and extreme weather events

Evidence points towards change in climate and increase in sea level temperature in the Caribbean Sea. Significant changes in regional climate (temperature and rainfall) can affect the Caribbean agricultural sector causing even further decline of the domestic small-holder food production sector (Rhiney et al., 2018). Climate-related hazards affect the vulnerable and poor people's lives directly through impacts on livelihoods, reductions in crop yields or destruction of homes and indirectly through food prices (UN-OHRLLS, 2015). Over the years 1990-2014 there have been 182 major natural disasters in the region, affecting 11.5 million people. This has caused 241,550 deaths and US$16.6 billion in damages. This has caused significant issues in the domestic agriculture and food sector due to damage of immovable assets, disruption of flow of goods and services causing vulnerability to the supply chains. Future impacts of climate change are believed to put pressure on island food production systems especially in coastal areas while simultaneously increasing import costs (Nunn, 2016).

As seen so far in this section SIDS are faced with certain vulnerabilities that are innate and not dependent on the conditions of the outside world and at the same time, they are faced with other vulnerabilities that emerge due to their external dependences on resources (Nunn and Kumar, 2018; Petridis et al., 2017). This parallels with island scholarship that conceptualizes islands as simultaneously both open and closed systems. Islands are also considered both insular and embedded within complex systems (Petridis et al., 2017). These contrasting dual nature of islands are a result of globalization 's compounding effects that have also defined the current food security challenges.

A disadvantageous trade and production nexus

Agriculture has historically been the backbone of the Caribbean economy and the small-scale domestic food sector has always been the driver of food security in the region. Domestic food farming in countries like Jamaica is still dominated by traditional farming techniques (Beckford, 2012). Despite the importance of agriculture and the prevalence of smallholder farmers, most of the Caribbean SIDS have experienced a significant reduction in food output and has eventually become a net food importer over the last decades, their domestic agricultural structure changing to accommodate export related food products (Beckford, 2012). Caribbean SIDS have a deeply entrenched export oriented agricultural system (Lowitt et al., 2015).

In SIDS countries, imports are by far the largest source of food, far outcompeting domestic food production. In the Caribbean at least 7 countries import more than 80% of their food. Breaking down by food groups, the largest import expenditure of the Caribbean has been on staples while all other food groups such as animal products, dairy, fruits and vegetables, etc. occupy 10-20% of the expenditure share (Walters and Jones, 2012). Domestic production of SIDS has become increasingly less diverse and focused on non-subsistence export-oriented markets (Nunn, 2016).

The import dependence of all SIDS is generally quite precarious for the producers, consumers and the overall economy (Petridis et al., 2017). To put it in a global context, while the ratio of food imports relative to exports has remained at a steady 7% even during the food price spikes of 2008, that number for SIDS was around 40- 42% at the same time period (UN-OHRLLS, 2015). Smallscale food producers face significant challenges to have a competitive edge with cheaper foreign imports and as a result the Caribbean and other islands as well have become more export oriented to access affordable food. Caribbean SIDS experience diseconomies of scale in all aspects of the food system as they are generally unable to achieve high multiplier effect in investment, production or consumption (Petridis et al., 2017).

While agriculture’s contribution to GDP keeps decreasing in the Caribbean SIDS their import bill has been estimated to increase up to US $10 billion in 2020 (Campbell et al., 2021). Small-holder farmers, responsible for less than two hectares of land comprise of almost 90% of farms in many Caribbean SIDS accounting for about 55% of total agricultural land. These types of informal agricultural systems face systemic challenges such as lack of technology and information, barriers to market entry, exposure to extreme weather events all of which make small-scale farming less competitive against the highly saturated imported food market (Saint Ville et al., 2015).

“Proportional vulnerability” of the Caribbean SIDS

Due to their innate characteristics the Caribbean SIDS face disproportionate and inequitable share of impacts of climate change and intensification of extreme weather events (Lenderking et al., 2021; Lowitt et al., 2015). The Caribbean countries are known to have fragile ecologies and higher frequency of natural disasters (Khaira and Ford, 2007). All aspects of food security are potentially affected by climate change, including food access, utilization, and price stability. In this regard, food security of SIDS is most vulnerable to persistent drought, sea-level rise, coastal erosion, ocean acidification and other extreme weather events. It seems that the relatively poor food performance, especially with regard to reducing malnutrition is facing challenges due to these climate change impacts (Lenderking et al., 2021; UN-OHRLLS, 2015).

With oil prices suddenly declining during the pandemic countries with heavy dependence on food imports had to face challenges (Ganpat and Ramdwar, 2021). A recent Caribbean COVID-19 regional survey revealed an overview of the impacts caused due to disruptions on markets, livelihoods, and food security. The majority of respondents stated that their livelihoods were impacted in a moderate to severe way, the main reason being movement restrictions (Caribbean COVID-19 Food Security & Livelihoods Impact Survey, 2020). According to the respondents, the implications for food security due to this disruption will be mainly due to loss of purchasing power and inability to access markets. The aftermath of the global pandemic has once again demonstrated the fragility of island food systems and the precariousness of their external dependence (Sindico, 2021).

Reliance on food imports means that the Caribbean SIDS are also exposed to volatile food prices. Income inequality and high frequency of disasters further exacerbate the situation as populations below the poverty line cannot afford accessibility to food (Thomas et al., 2018). As for exported food, the food price crises of 2007 and 2008 has effectively demonstrated the disproportionately larger impact that global price shocks can have on food and commodity supply of island states compared to the rest of the world (FAO, 2015a).

Triple burden of malnutrition

According to FAO, the world produces enough food to meet the daily nutritional requirements of all its inhabitants. Still, a billion people can be characterised as hungry. This paradoxical situation points to the fact that food insecurity is not merely a problem that occurs due to lack of food but more due to impeding factors in availability, access and utilization (Porter et al., 2014; Beckford, 2012) that prevents the available food from meeting the minimum requirements. For instance, undernourishment, micronutrient deficiency and overnutrition, can all coexist in the food system referred to as “The triple burden of malnutrition” (Gil et al., 2019).

Caribbean Island states house pockets of severe food insecurity that can be seen by the percentage of undernourished populations (Trotman et al., 2009). A recent study indicates that most people residing in Caribbean SIDS cannot sufficiently avail most of the food groups required for a healthy diet (Sonneveld et al., 2021). The issues in the food production system and the high dependence on imports have resulted in a nutrition transition in SIDS. For majority of the population the only source of affordable food is imported, which is highly processed and very low in nutritional value. Consumption of these foods have given rise to malnutrition in both of its forms; undernutrition due to micronutrient (essential vitamins and minerals) deficiencies and overnutrition due to overconsumption of macronutrients (refined carbohydrates and trans fats). This has resulted in the prevalence of many non-communicable diseases in these island states, which also impacts their economies as the health expenditure increases (Campbell et al., 2021).

On the opposite end of the spectrum, the problem of hunger and undernourishment still exists in SIDS due to a portion of the population living in poverty (FAO, 2014; FAO 2016). Among the Caribbean SIDS, Jamaica's progress towards the Sustainable Development Goal (SDG) 2, for achieving food security is faced with major challenges. Undernourishment is still reported to be significant, while the prevalence of obesity is on the rise, currently affecting 8.4% and 25% of the population respectively (Sustainable Development Report, 2019). The nutrition transition in the Caribbean region due to sole consumption of cheap, low nutrition imported food has caused the health expenditure to double in the last decade (FAO, 2016a).

2.2 Co-evolution of agricultural trade and sustainable development policy in the Caribbean SIDS

In the Caribbean, agricultural trade and trade policies have proven to be critical to food security and human development in general (Beckford, 2012).. The policy environment has also evolved alongside sustainable development efforts towards SIDS. Therefore, this section provides a policy review of major agricultural trade and sustainable development policies that have influenced the trajectory of agriculture and food security in the Caribbean SIDS.

In regards to policy, Saint Ville and colleagues (2015) divided the agricultural system of the Caribbean Community (CARICOM) into four phases that can provide insights for Caribbean SIDS as many of them fall into the same category: i) rise of plantation (1700 – 1800s) with protected export markets in Europe, subsistence production, monoculture by exploitative labour; ii) decline of plantation (1838 – mid 1900s) as a result of the emancipation of slavery and the emergence of various social institutions created by formerly enslaved people that led to sharing of land, produce and labour; iii) post- independence (1950 -1990) was a period of political independence and smallholder farmers vertically integrating into export markets with the support of subsidies and preferential market access; iv) post globalization (1990 – present) is the period of major decline in domestic agriculture due to loss of protected markets, more frequent natural disasters, increased cost of production and increase of imports among others.

In the 1960s and 1970s agricultural policy in the Caribbean tried to shift towards food self-sufficiency in which domestic food production and eating local grown food were prioritized (Beckford, 2012). This is because agricultural policy framework of Caribbean SIDS had heavy focus on export-oriented agriculture to the point that limited their ability to support small-scale domestic production even after the collapse of traditional export markets (Lowitt et al., 2015). This was the result of the preferential access to trade in the European Union (EU) that allowed the export sector to thrive.

The trade policy environment gradually started to change though after the trade liberalization of the 1980s, which was part of a conditional package of policies to receive structural adjustment program loans from the World Bank. In 1994, the Caribbean committed themselves to a multilateral trade policy focused on lowering agricultural product tariffs. After more than 10 years, the impact of that decision can be seen in the form of steady increase in imports and decrease in exports, the gap between the two widening each year. These types of neoliberal trade policies greatly disadvantaged local small-holder farmers by flooding the market with cheap imports (Saint Ville et al., 2015; Black, 2001) as well as lowering preferential margins for export. This in turn negatively impacted countries in the region where significant percentages of the populations living in rural areas depended on livelihoods related to agricultural activities (Ford and Rawlins, 2007). Moreover, negative impacts were seen in the form of consumption behaviour, prevalence of noncommunicable diseases and increase of health expenditure (FAO, 2014; FAO 2016).

The underlying policy assumption was that lowering agricultural product tariff would create alternative areas of production and trade that would be more competitive and economically sustainable. Policy reforms focused on import substitution, ensuring prices for isolated remote areas and creating marketing boards to promote exports of non-traditional products. These policy mechanisms were enacted to provide the domestic Caribbean market space and time to achieve competitiveness (Ford and Rawlins, 2007). However, trade policies do not work in isolation and requires complementary and compensatory policies for a smooth transition, which was not allowed. Although the Caribbean already had a long history of plantations agriculture, deeply rooted to its colonization, these changes revived the export oriented agricultural sector that even though has some short-run economic benefits, mostly hampered the domestic food production sector (Kendall and Petracco, 2009). As a counteractive measure, the government in collaboration with various regional organizations introduced national policies such as the Regional Transformation Programme for Agriculture, to increase competitiveness of the domestic market. However, due to lack of adequate technical and financial resources, dissimilar levels of priorities and awareness across stakeholders and lack of integration within national, regional, and international levels made it difficult to achieve any significant success.

The aftermath of the trade liberalization policies created realization among SIDS countries that they require preferential access to export markets and relief from the impact of trade liberalization in their economies. However, World Trade Organization (WTO) did not recognize the trade issues of SIDS to be unique to them and this was reflected in subsequent policy decisions (Linsay, 2019). "……under the World Trade Organisation (WTO) rules, terms are imposed on Caribbean small states as if each of them is equal in physical space, market size and resources to the US, China, India or Japan. Small Caribbean countries enjoy no special and differential treatment despite their small land space, their small populations, their limited human capital and their susceptibility to shocks that originate from outside their borders." (Sanders, 2017).

Coincidentally, 1994 was also the year a global conference on the sustainable development of SIDS adopted Barbados Programme of Action (BPoA). This conference devised a specific action plan for SIDS under the guidelines of Agenda 21 that comprised of nation, regional and international measures to support sustainable development of SIDS (Kane, 2004). Caribbean SIDS are parties to Agenda 21, a comprehensive action plan to support sustainable development in the 21st century. As such they are responsible for monitoring national scale progress towards sustainable development (Momtaz and Kabir, 2013; Garfield, 2004).

Since the inception of CARICOM in 1973, governments of the region have recognized the need for regional integration. CARICOM is a group of 15 countries (most of which are also SIDS) that share a common historical background rooted in colonization (Lowitt et al., 2016). Their Regional Food and Nutrition Security Policy have been established to develop a harmonized and holistic approach to food and nutrition security. However, the success of this policy is unclear, as it seems that behind agreed upon goals there are many differences in how food security is framed and approached at the national and regional level. There have been some strides though in the form of integrating technical and conceptual social learning among stakeholders to promote community participation and collective action that may help towards regional integration for food security issues in the long run (Lowitt et al., 2016; Saint Ville et al., 2015).

In 2002, the World Summit on Sustainable Development (WSSD) reaffirmed SIDS as a "special case for sustainable development" and highlighted challenges and concerns that were specific to this group of countries (Kane, 2004). In 2005, the Mauritius Declaration, a 10-year comprehensive review of Barbados Programme of Action (BPoA) was conducted by the United Nations General Assembly (Kane, 2004) where specifically financial and resource constraints of SIDS to implementing BPoA was highlighted (Felician, 2012). Unfortunately, progress reports towards BPoA does not measure whether an individual island state is actually moving towards sustainability or not (Garfield, 2004). In 2012 at the Rio+20 summit member states renewed their political commitment towards SIDS (Felician, 2012).

Also, in 2002 the World Food Summit +5 (a follow up event to the first World Food Summit in 1996) set a goal for reducing global hunger by half by 2015, for which FAO established a Trust Fund for Food Security and Food Safety (Beckford, 2012). As concerns of food security increased in the Caribbean, the Caribbean Forum (CARIFORUM) asked FAO to step in. Together they collaborated and launched a US$26 Million food security project. What followed were several such joint initiatives in subsequent years to tackle issues of food security, poverty and health (Beckford, 2012).

Food security was identified as a priority concern for SIDS in 2014 at the third international conference on SIDS leading to the SAMOA pathway in 2015. This led to resolutions affirming international cooperation and multi-stakeholder partnerships for research and development on agriculture and food security in SIDS (Lowitt et al., 2015). The 2015 Paris agreement of the United Nations framework convention on climate change (UNFCCC) had significant implications for food security of SIDS since they are among the most vulnerable to global climate change.

As this review demonstrates food (in)security is driven by multitude of factors (social, political, economic, environmental) that result in complex and interconnected challenges. The position of the Caribbean SIDS has often been unfavorable due to their historical contexts, misdirected policies, global pressures, and innate vulnerabilities. However, the positive outlook is that the urgency of their challenges is being globally recognized and creating impetus for change. This research takes a step in that direction to assess the problem of food (in)security in the Caribbean SIDS through the emerging concept of social metabolism.

Chapter 3 Methodology

3.1 Taking a social metabolism approach to study island food systems

Sustainability is a systems-based concept and therefore any and all sustainability challenges that have emerged (such as food security) requires a systems thinking perspective. Systems thinking helps to understand change across scales and takes into consideration the dynamic interconnectedness between subsystems and between actors in the system (Williams et al., 2017). Systems analysis of islands dates back to the 1970s with UNESCO's Man and the Biosphere program that investigated the dynamics of coupled human-nature systems (Deschenes and Chertow, 2004). Coupled human-nature systems (Jianguo Liu, 2007) or social-ecological systems (SES) (Petridis et al., 2017) (that create sustainability challenges) are complex, and their dynamics are influenced by multitude of contextual factors such as biophysical processes, government policies and market and trade interventions. In these systems larger scale processes shape local ones, meaning that a government decision made in one place can impact a SES elsewhere (Jianguo Liu, 2007). Ecological economists lament that the way humans and natural systems organize lead to failures in feedback where "benefits accrue at one scale, but costs are carried by another" (Robin and Steffen, 2007, p. 1698). This leads to intragenerational (socio-economic groups) and intergenerational (across generations) inequity (Losee, 2017). This holds true for SES of SIDS since policies and events taking place at the global arena have made immense negative impact on their domestic food systems.

An analysis of coupled human-nature systems takes place under a socioecological systems research approach (Petridis et al., 2017). This approach challenges the dichotomous way human and ecological systems are viewed (Lowitt et al., 2015). This kind of approach also intends to enhance interdisciplinarity within the field of sustainability science. In order to trace the development or sustainability pathway of an SES its biophysical flows need to be accounted for along with an understanding of the social processes that they are manifested from (Petridis et al., 2017). The concept of "social metabolism" can make this possible as it can be used to conceptualize the biophysical aspect of nature-society relations from a stock-flow perspective by evaluating the economy in terms of biophysical stocks and flows of matter and/or energy needed to generate new stocks or maintain and regenerate current stocks (Bogadóttir, 2020; Eisenhut, 2009). Social metabolism reveals the material and energy flows needed to maintain socioecological systems at different scales. It can monitor material/resource use in a physical economy by lending tools and indicators for measuring its sustainability. The transition observed in social metabolism may act as an indicator of change in biophysical growth or de-growth of a society (Bogadóttir, 2020).

Conceptually, the understanding of society's metabolism has been laid out by Fischer-Kowalski (1997); Fischer-Kowalski (1998); Fischer-Kowalski and Hüttler (1998a); Fischer-Kowalski and Hüttler (1998b). Sociometabolic research (SMR) is increasingly being used for studying food systems (Fraňková et al., 2017) as understanding interconnections and interdependence between human and ecological systems will aid in development of food security policy that is both efficacious and adaptive (Lowitt et al., 2015). Islands are interesting cases for social metabolism research as they are bounded systems with limited resource availability that also appear to be open economies with dependence on external resources (Krausmann et al., 2014; Deschenes and Chertow, 2004). Section 4.2 (as part of the article) focuses specifically on the state-of-the-art and research gap of SMR in general and those pertaining to islands and/or food systems (See Table 2 of Chapter 4).

An operational tool of SMR is material flow analysis (MFA) that can be utilized to monitor and/or forecast the physical economy or assess alternative strategies for material/resource management (Cullen and Brazell, 2018; Villalba et al., 2018; Mulalic, 2005). MFA elaborates to "material flow accounting" and often to "material flow analysis". Both the descriptive and analytical terms respectively are used interchangeably by scholars (Fischer-Kowalski et al., 2011). MFA originated from the fields of natural sciences and engineering (Kytzia et al., 2004) and has evolved into an operational tool to assess social systems. It is a structured framework that requires a systemic organization of data into an accounting system that can perceive the physical economy as a metabolism where materials enter, exit, and are processed but never completely disappear (Hendriks et al., 2000; Mulalic, 2005). MFA has already been used in fields such as medicine, social and economic systems (Villalba et al., 2018) and is increasingly becoming a method of choice to analyze socioeconomic metabolism (Chertow et al., 2020; Allesch and Rechberger, 2018; Fischer-Kowalski 1998b).

The historical transition of material flows can be traced on account of the diachronic availability of data (Kosai and Yamasue, 2021). The objective of following a material system over time is to either focus on past developments or future predictions (Villalba et al., 2018). Evaluating the metabolic transition over time provides understanding of how the food system evolves with changes in population, GDP, land use patterns, market shocks, extreme weather events, etc. (Cullen and Brazell, 2018). This can be useful in the island context (Deschenes and Chertow, 2004). Even though islands are perceived as bounded systems from an MFA perspective they appear to be open economies as they extract few key resources for export purposes and rely on imports to meet domestic needs and consumptions (Krausmann et al., 2014).

As per the law of conservation of matter MFA follows a mass balance principle to book-keep the inputs, outputs, and throughputs in the defined material system. This makes it a great decision support tool in environmental or resource management and policy assessment as it can indicate the extent and source of environmental loading (Allesch and Rechberger, 2018; Femia and Vignani, 2005). But the ultimate goal of this type of research is to support policy formulation or assessment (Bringezu, 1997). Material flow analysis, as a tool, for understanding the metabolic system (Hendriks et al., 2000), can reduce complexity of the system for assessment purposes while still laying a robust base for policy development (Villalba and Émbil, 2018; Brunner and Ruchberger, 2016).

A standard MFA considers the flows of solid materials that can be broadly categorized into three groups: minerals, fossil and biomass (Hinterberger et al., 2003). MFA usually excludes flows pertaining to air and water (Villalba et al., 2018). Biomass is a fundamental material flow that is indispensable in provisioning of food (Eisenhut, 2009; Weisz et. al., 2007). Globally, around a third of the material consumption is comprised of plant biomass alone and in developing nations the ratio is even more (Krausmann et al., 2008). Tracking the input and output of biomass within the food system can provide important information. The material balance will reveal the composition of biomass metabolism of an economy revealing the domestic extraction of biomass and the importation and exportation of biomass commodities in physical units (tonnes) (Hinterberger et al., 2003).

Overall, standardization of MFA methodology has initially been overseen by EUROSTAT (Eurostat, 2013, Eurostat, 2011; Eurostat, 2009) and Organization for Economic Co-operation and Development (OECD) work program on material flows (OECD 2008). A state of the art of MFA methodology and indicators has been presented in Fischer-Kowalski et al., 2011. Krausmann et al., 2018, has adapted the guidelines to enable analysis of historical time periods and different world regions such as the Caribbean. To meet the needs of more localized analysis Singh et al (2010) provided a framework to analyze social metabolism of local rural systems.

3.2 Description of the chosen island cases

Table 3 of Chapter 4 provides a side-by-side overview of the four island cases with regard to demography, economy, and land use features. The following section lays out the locational, geographical, topographical, and climatic characteristics of the four island cases along with notable events.

Fig 1: A map of the Caribbean region highlighting the small island developing states (SIDS) chosen as cases for this study: Barbados, Dominica, Grenada, and Jamaica.

Barbados

Barbados is the most easterly of the Caribbean islands, situated in between the Southeastern Caribbean Sea and the Atlantic Ocean at latitude 13.2° N and longitude 59.5° W (Mohan et al., 2020; Mesolella et al., 1969). Barbados is 90 miles east of the archipelago of the Lesser Antilles (Mesolella et al., 1969) but often grouped with the island chain (Britannica, 2021). The island has a relatively flat terrain with a notable high point 336 m above sea level, giving it a somewhat triangular shape (Mohan et al., 2020; Mesolella et al., 1969). It has a tropical maritime climate with two main seasons, dry (December to May) and wet (June to November) with temperatures ranging from 21 to 30 °C (Britannica, 2021; Mohan et al., 2020). Barbaodos is a non-volcanic island (Mesolella et al., 1969) with lesser mountainous terrain (Britannica, 2021) compared to other Caribbean islands which provided opportunities for tourism. Barbadian economy is highly dependent on its tourism sector (Mycoo, 2006) accounting for 13% of the GDP directly and 40% of employment (Kemp-Benedict, 2020). However, from 2019 to 2020 there has been a marked 53.5% decrease in total contribution of travel and tourism to GDP in the country, most likely due to the global pandemic (WTTC, 2021), actualizing the vulnerability of SIDS to external shocks very recently. The island lies in the southern edge of the Caribbean hurricane belt (Kemp-Benedict, 2020). Barbados is a founding member of CARICOM playing an important role in regional integration of the Caribbean (Kemp-Benedict, 2020).

Dominica

The commonwealth of Dominica is the largest and most northerly of the Windward Islands (Benson et al., 2001), situated at the centre of the arc of the Lesser Antilles chain (Alfaro-Pelico, 2013) at 15.4° N latitude and 61.4° W longitude. It is part of the West Indies region of the Caribbean (Schnitter et al., 2019). The country mostly consists of rugged and steep mountainous terrain of volcanic origins (Weaver, 1991) with slopes of 30° or more, rising to its highest point of 1,447 m. Much of the country's topography can be characterized as dense tropical forest vegetation with high elevation and large number of deeply incised narrow, river valleys and steep ridges. Dominica has a warm tropical climate consisting of a dry season from January to April and a rainy season from July to October (Alfaro-Pelico, 2013). The island receives heavy annual rainfall which results in diverse vegetation but also makes it prone to frequent localized flooding and landslides. But most significantly Dominica is affected by tropical storms and hurricanes (Weis, 2018; Benson et al., 2001). As the country is completely volcanic in nature and geologically primitive it is highly prone to natural hazards such as landslides and earthquakes. Also, since most of the island's settlements and infrastructure are located near the coast, Dominica is particularly vulnerable to extreme weather conditions (Benson et al., 2001). Dominica is a member of OECS (Alfaro-Pelico, 2013), the wider CARICOM and the Eastern Caribbean Central Bank (ECCB) that issues a common currency for the eastern Caribbean countries (Benson et al., 2001).

Grenada

Grenada (12.1° N, 61.7° W) is the smallest and southernmost of the Windward Islands (Felician, 2012; Steele, 1974) part of the Lesser Antilles chain (Fritz et al., 2011) OECS. It is a tri-island state consisting of Mainland Grenada, Carriacou and Petite Martinique and few smaller uninhabited islands. Grenada accounts for 89% of the area (FAO, 2015b). The island has an ovate shape with mostly mountainous terrain originating from volcanic activity (Steele, 1974) encircled by expansive coral reefs (Felician, 2012). The centre of the island has higher elevation areas comprising of tropical rainforests (Fritz et al., 2011). The country is endowed with streams and spring of fresh water (Steele, 1974). The climate is humid tropical with most of the precipitation taking place seasonally between June and November (Fritz et al., 2011).

A marked dry season takes place the rest of the year (FAO, 2015b). Grenada lies south of the hurricane belt but is highly prone to hurricanes such as the devastating impacts of Hurricane Ivan in 2004 (Fritz et al., 2011).

Jamaica

Jamaica, the largest British West Indies Island (Asprey and Robbins, 1953) lies in the northwestern Caribbean Sea (considered almost at the centre) with a latitude of 18.1° N and a longitude of 77.3° W (Evelyn and Camirand, 2003). Together with Cuba, Dominican Republic, Haiti and Puerto Rico, Jamaica comes together as the natural group of islands called the Greater Antilles (Asprey and Robbins, 1953). Jamaica is a tropical island with varied climatic conditions as it has a rainy windward coast, a drier leeward coast and central montane region that is on the cooler side (Asprey and Robbins, 1953). The island is volcanic in origin with some limestone regions. It can be divided topographically into mountains, valleys, and coastal plains (UNCTAD, 2017). Also present are a number of streams with steep gradients falling through narrow valleys and some major faults that may potentially be seismically active (Carby, 2018). These combinations of features put Jamaica at risk of hazards such as flooding, landslides and drought. The island lies within the North Atlantic Hurricane Belt making it prone to tropical cyclones between June and November (UNCTAD, 2017). Greater than half of Jamaica is stands above 1000 ft. in elevation (Asprey and Robbins, 1953). Most of the land area comprises of agricultural and forest cover (UNCTAD, 2017).

3.3 Study approach and system definition

The methodological framework utilized in this study is material flow analysis which is a systems level analysis that can track the boundary of a material system defined in space and time (Cullen and Brazell, 2018; Villalba et al., 2018) by connecting the source, pathways and final sinks of the material in question (Allesch and Rechberger, 2018). An economy wide material flow analysis (EW-MFA) is quantification of physical exchange of material stocks and flows among a national economy, connected foreign economies and the environment (Kovanda and Weinzettel, 2017; Brunner and Rechberger, 2016; Femia and Vignani, 2005).

The spatial boundary of this study is the political boundary of the Caribbean Island states of Barbados, Dominica, Grenada and Jamaica. The temporal boundary of this study ranges from the year 1961 to 2019. EW-MFA, as a framework of analysis aggregates all flows of the system into three main categories: input, throughput, and output. For the system in question, input flows comprise of domestic extraction of biomass and imports of biomass commodities from foreign economies; output flows comprise of exports of biomass commodities to foreign economies and emissions and wastes that leave the system. For this study, the output flows only consist of exports since emissions dedicated to the food production and consumption system are difficult to isolate for quantitative purposes and falls outside the scope of the study. Any and all flows in between are considered throughput and placed under the so called "black box". Opening it would entail investigating intra-system or intra-economy flows which are known as "indirect flows", "embodied flows" or "hidden flows" (these flows having respective distinctions based on the type of analysis) under the current framework (Fischer-Kowalski et al., 2011; Krausmann et al., 2014). EW-MFA does, however, derive indicators that can analyze the important processes and relationships between material flows, as will be discussed in the subsequent sections. As for stocks, EW-MFA distinguishes them into three major types: artefacts, animal livestock and humans (EUROSTAT, 2013). However, since this study focuses on biomass flows pertaining to the food system, it has only considered animal livestock as the socio-economic material stock of these islands.

3.4 Data source and acquisition

Data of all biomass flows pertaining to agriculture and livestock commodities have been obtained from the open access source FAOSTAT of Food and Agricultural Organization (FAO) of United Nations (FAO, 2021a; FAO, 2020a). Biomass production and trade data of the flow "capture fisheries" and fish commodities respectively has been obtained from FishStatJ (FishStatJ, 2020), a software created by the Fisheries Division of FAO dedicated for only fishery and aquaculture time series data. Lastly population data for per capita calculations was obtained from World Bank Group (The World Bank, 2021; The World Bank, 2019). Data for all biomass flows were collected in tonnes and were later converted to megatonnes (Mt) for absolute values of indicators. All biomass flows per capita were calculated in tonnes/capita.

3.5 Chosen indicators of biomass metabolism and their method of quantification

EW-MFA generates several aggregate indicators that can either serve as summarized account (benchmarking between similar material systems, monitoring change over time, etc.) of materials or in a broader sense, reveal the metabolic performance/transition of the national economy or its aspects (Villalba et al., 2018; Fischer-Kowalski et al., 2011). For this study, EW-MFA indicators have been selected based on its relevance to the defined system and context of the issue at hand, which is island food security. Existing MFA studies compile aggregate summary indicators into two broad categories: direct indicators such as domestic extraction, imports and exports, and derived indicators such as domestic material input, domestic material consumption and physical trade balance (EUROSTAT, 2013; Bringezu et al., 2003). Both categories of indicators can also be analyzed in combination with other socio-economic indicators (Shah et al., 2020).

3.5.1 Domestic Extraction of biomass

Domestic extraction, in this study, is the extraction or harvest of biomass from the local environment that is then put to further economic use. Biomass extracted locally serves the purpose of human food, livestock feed, fish capture and biomass of animals that are hunted. These are represented as flows of primary crop harvest, used crop residue, grazed biomass by livestock and capture fisheries. Biomass from hunted animals have not been considered in this study as it is not a significant form of food production in the region. Domestic extraction can be categorized into used and unused extraction. Used extraction consists of primary crop harvest, used crop residue, biomass from fodder crops and grazing livestock and capture fisheries (Krausmann et al., 2008). Biomass harvested from wood is generally also part of the used extraction. However, it has been excluded from calculation in this study as it does not pertain to the food production and consumption system.

$$\textit{Total domestic extraction} = \textit{primary crop harvest} + \textit{used crop residue} + \textit{grazed biomass} + \textit{capture fisheries} \quad (i)$$

$$\textit{Total domestic extraction/ per capita} = \textit{total domestic extraction/ total population} \quad (ii)$$

Domestic extraction is also known as used extraction, as it leads to subsequent economic production. Unused extraction is biomass that has no further economic purpose after the harvesting process such as unrecovered crop residues, belowground biomass of harvested crops, biomass destroyed in fires caused by humans, etc. (Krausmann et al., 2008). Unused or indirect extraction is “killed” during the harvest process and does not hold any further economic value. It usually comprises of unused or unrecovered crop residues (which will be discussed below) and belowground biomass of primary crop harvests (Krausmann et al., 2008).

Primary crop harvest

Primary crop harvest denotes the total aboveground plant biomass or all primary crops originating from agricultural activity. The production of primary crops is accounted for in fresh weight at harvest time, its moisture content ranging from 15 to 95% depending on the species.

Data for primary crop harvest has been obtained from the production domain of FAOSTAT (as is weight of crops at the time of harvest). Primary crop categories have been selected based on the

EUROSTAT guide for EW-MFA (2013) and are as follows: cereals, roots and tubers, sugar crops, pulses, oil bearing crops, vegetables, fruits, fibers, and other crops. The category "other crops" comprise of various stimulant crops, beverage crops, spice crops and tobacco. Refer to Appendix A for the complete list. There was no data available for fiber crops of Dominica and Barbados at the time of collection. FAOSTAT also did not have harvest data for "other crops" of Barbados. The aggregate values of primary crop harvest have been calculated excluding these crop types, in case of Dominica and Barbados. Fresh weight of crop biomass was converted to air-dry weight by utilizing crop-specific water content data (Krausmann et al., 2008).

Used crop residue

FAO does not provide data on crop resides. Therefore, it was calculated by using crop specific and region-specific harvest factors taken from literature (Krausmann et al., 2008). Used crop residue, a fraction of the harvested cultivar subjected to further socio-economic use, comprises of a relatively large biomass flow. In general, crop residues serve a myriad of purposes, such as in construction, energy production, fertilizer, livestock bedding and feed, etc. (EUROSTAT, 2013; Eisenhut, 2009).

EUROSTAT provides a list of crops that most likely provide residues for further economic use, but it is most relevant to European studies. They include wheat, barley, oats, rye, maize, rice, all other cereals, rape seed, soybean, sugar beet and sugar cane. In most cases, used crop residues come from all types of cereal crops, sugar crops, and oil-bearing crops. Any other type of crops is considered only when there is a specific context present. For instance, a 2016 study on the socioeconomic metabolism of biomass in Jamaica conducted field surveys to reveal that the main types of crops or "cultivars" that generate significant residue for further use in the country are: maize, rice paddy, sugar cane, cassava, potatoes, sweet potatoes, groundnut shells and coconut. For the purpose of this study this crop list has been followed to calculate used crop residues of all four islands studied, as field data collection was out of the scope. However, during data collection it was observed that apart from Jamaica, FAOSTAT did not have production data of three of the cultivars, namely, rice paddy potatoes and groundnut shells for Barbados, Dominica and Grenada. Therefore, it was assumed that these three islands do not produce significant crop residues for usage from these cultivars.

After acquiring the production quantity of these crops (from the production domain of FAOSTAT), their available crop residue was calculated using the corresponding harvest factors for each crop, based on the Caribbean region, derived from Krausmann, 2018, Krausmann et al. 2013 and Wirsenius 2000. The regional recovery rate of each crop, also derived from Krausmann, 2018, Krausmann et al. 2013 and Wirsenius 2000, helped to calculate the actual amount of used residue from the available crop residue.

*Available crop residues [t (as is weight)] = primary crop harvest [t (as is weight)] * harvest factor*

(iii)

*Used crop-residues [t (as is weight)] = available crop-residues [t (as is weight)] * recovery rate*

(iv)

Fodder crops and grazed biomass

Biomass from fodder crops was not calculated. Biomass uptake from grazing animals is not reported in FAOSTAT and hence was calculated in multiple stages. The demand-driven approach was taken (Krausmann et al., 2018) where the grazing gap is identified based on the demand driven feed balance. To start the process, data of stock of grazing animals (per head) was collected from the production domain of FAOSTAT. Species of grazing animals were based on Krausmann et al. (2008). Next, the annual feed requirements of the selected species were calculated based on their corresponding standard annual feed intake values (tonnes/head/year) calculated for the Latin America and Caribbean region (Krausmann et al., 2018; Krausmann et al., 2008) at 15% moisture content.

Total annual feed requirement = Stock(Annual feed intake at 15% mc for L&C region)*

(v)

After calculating the feed requirement, data for marketed feed was obtained from the commodity balance domain of FAOSTAT from the year 1961 to 2013. Please refer to Appendix A for the complete list of market feed commodities that have been taken into account for calculating total market feed per annum. Market feed data was not available for the years 2014 to 2019 and hence grazed biomass for these six years have been calculated using a different method described in subsequent steps.

The last component for calculating the demand for grazed biomass is non-market feed which in this case is essentially the air-dry weight of used crop residues at 15% moisture content. For this step of the calculation, first the species of cultivars were selected based on certain assumptions. Based on field surveys/interviews conducted by Okoli (2016), it was revealed that out of the eight cultivars mentioned in the previous section, cereal and coconut crops are not known to serve feeding purpose in Jamaica. Apart from that, sugarcane, cassava, potato, sweet potato and groundnut in shell are known to serve as livestock feed. As for sugarcane, it was revealed that only 30% of its residue is utilized as feed. For the purpose of this research, these assumptions from Okoli (2016), regarding the crop residues of Jamaica have been considered the same for this case in Jamaica and the other three islands as well.

In order to convert the fresh weight of used crop residues to its air-dry weight, the global average water content of each crop type was calculated, following the manual published in 2010 by Singh and colleagues. From there, the factor of moisture content (15%) for each crop type were obtained. Lastly, the air-dry weight (at 15% mc) was obtained for each crop as a product of their fresh weight and corresponding factor of moisture content.

$$Factor_{mc} = (1\text{-}mcfresh) / (1\text{-}mcair\ dry) \quad (vi)$$

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

Finally demand for grazed biomass for the period 1961-2013 were obtained as the difference between total feed requirement and total feed available (containing both marketed and nonmarketed feed).

$$Demand\ for\ grazed\ biomass = Total\ feed\ requirement - (marketed\ feed + non\ marketed\ feed) \quad (viii)$$

Grazed biomass for the period 2014-2019 was calculated utilizing large animal units (LAU) of each livestock species, for the Caribbean region. Firstly, the stock of livestock (per head), the data for which was already in place, was converted into LAU using specific livestock unit coefficients for each species provided by FAO for the Caribbean region (FAO, 2005).

$$Large\ animal\ units\ (LAU) = stock\ of\ livestock * Livestock\ unit\ coefficient \quad (ix)$$

Next, the grazed biomass for the period 1961-2013 that had already been calculated and the aggregate LAU of all species per annum, were both utilized to obtain a ratio for the period 19612013 (grazed biomass/LAU). The grazed biomass to LAU ratio for the period 2014-2019 was assumed to be an average of the last eight years (2006-2013). Finally, this ratio was used to calculate the grazed biomass of the period 2014-2019 (F. Krausmann, personal communication, November 13, 2020).

Capture fisheries

The data for capture fisheries was collected from FishStatJ, under the domain “capture fisheries”. Data was available from the year 1961 to 2018. Since there was no data available for the year 2019, at the time of collection, an average of past years was calculated to fill this gap. Refer to Appendix A for further details such as the complete list of fish species considered and specifics on handling missing data for 2019.

3.5.2 Foreign trade of commodities and the physical trade balance

Biomass commodities to be considered under these flows have been based on the EUROSTAT (2013) classification of biomass trade flows and FAO’s commodity groups (FAO, 2020a; FAO, 2021a). Broadly, trade commodities for both imports and exports have been classified into crops (which contain aggregate values of major crop types), livestock (which contain aggregate values of primary and secondary livestock products as well as honey and other miscellaneous products), feed (which contains aggregate value of marketed crop residues such as meal, cake, pulp and tow waste of various crops as well as forage products such as pellets of tow waste and straw husk) and fish.

Crop, livestock, and feed commodity data have been collected from the trade domain of FAOSTAT. Only fish trade data has been collected from FishStatJ, for which data was available up to the year 2017. Average of past years were estimated as values for the years 2018 and 2019. See Appendix A for the complete list of commodities and specifics on calculation of missing data.

Physical trade balance of biomass is simply the difference between the value of import and export commodities of biomass. It measures the physical trade surplus or deficit in an economy, to indicate the extent to which domestic material consumption is based on domestic extraction as opposed to foreign imports. In other words, to what extent a certain material (or all materials) will weigh down the domestic environment in the form of accumulated goods or waste, or to the extent to which it is dependent on said foreign imports.

$$\textit{Physical trade balance (PTB) = Imports – Exports} \quad (x)$$

3.5.3 Domestic material consumption

For this research, domestic material consumption refers to the absolute consumption of biomass within the food system of the selected Caribbean islands. Domestic biomass consumption (or domestic material consumption of biomass) can be calculated from the domestic material input of biomass excluding the export of biomass commodities. Domestic material input of biomass entails all inflows of biomass into the food system that have further use or economic value. DMC can also be calculated for each individual flow of used domestic extraction.

$$\textit{Domestic material consumption (DMC) = Used domestic extraction + Imports – Exports} \quad (xi)$$

3.5.4 Import dependency ratio

A better understanding of the drivers of biomass consumption can be achieved through linking trade statistics with domestic production (Cullen and Brazell, 2018). Import dependency of crop biomass shows the level of external dependence on trade and was calculated as a ratio of imports of crop commodities to DMC per capita. The ratio has been presented as a percentage.

$$\textit{Import dependence ratio (IDR) = (Imports/DMC per capita)*100} \quad (xii)$$

3.5.5 Data limitations

FAO was chosen over other databases such as UN Comtrade since it is generally deemed a reliable source for agricultural data (Krausmann et al., 2008). While the coverage of data in FAOSTAT is relatively comprehensive the availability of data was an issue in some instances. In these cases, the missing data was supplemented using available quantification methods as has been explained in the methodology and Appendix A where applicable (Also see section 4.3.2).

3.6 Expert interviews

Local experts from the Caribbean SIDS were consulted via interviews to validate key findings from the empirical analysis of this research and to gain additional insights. These interviews were part of a larger project entitled "Policy pathways towards achieving sustainable food security in an island state" supported by the Social Sciences and Humanities Research Council of Canada (SSHRC). An ethics clearance was obtained from the University of Waterloo's Office of Research Ethics to conduct the interviews. These were remote interviews conducted on an online platform. Participation was entirely voluntary, and the duration of each interview was approximately 45-60 minutes. The interviews were recorded with the permission of the interviewees and later transcribed. Interviewees were chosen based on a preselected list of occupation categories relevant to the main objective of the study (island food security, island agriculture, etc.) and their respective expertise on the four chosen island cases (see Table 1).

Interviewee occupation	**Island expertise**			
	Barbados	**Dominica**	**Grenada**	**Jamaica**
Policy makers	2		1	
Employees of ministries			1	1
Employees of international associations	1	1		2
Farmers associations		1		

Table 1: Distribution of interviewees based on occupation category and island expertise.

Three major questions were posed to interviewees focusing on domestic production, major crop types and utilization of crop residues:

- If local production of food has increased/decreased in (island case) do any specific policies or intervention come to mind that may have led this change?
- Is there any evidence that would suggest greater utilization of crop residue for livestock/cattle feed instead of using traditional market feed?
- Speaking with some field experts in Jamaica in a previous study (Okoli, 2016), it was revealed that only a few types of crops are utilized further for livestock feed (such as: maize, rice paddy, sugar cane, cassava). Is this the case for (the Caribbean) Grenada, Dominica, and Barbados as well? Is there any other type of crops that have significant value as livestock feed or fodder?

The expert opinion obtained through these interviews supplemented the analysis of agricultural trends and patterns in the four island cases studied. The insights were incorporated in Chapter 5 to discuss the domestic production of crops and utilization of crop residues from the perspective of local experts.

Chapter 4 "Can the Caribbean localize its food system? Evidence from biomass flow accounting"[1]

4.1 Introduction

The second UN Sustainable Development Goal (SDG 2) calls for zero hunger for all. The Food and Agricultural Organization (FAO) defines food security as a condition where "… all people at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO, 2002). Achieving SDG 2 requires a transformation in food systems through sustainable agriculture and changes in dietary patterns (Sachs et al., 2019). Despite its importance (Yang et al., 2020), SDG 2 is not on track for the 2030 agenda (FAO, 2020b; SDG report, 2021) as there are barriers to sustained food supply and appropriate nutrition, the COVID-19 pandemic being a significant one (UN Economic and Social Council, 2021).

The problem of food security is even more acute in Small Island Developing States (SIDS), a political category since the 1992 UN Conference on Environment and Development, as they share unique characteristics such as, "small size, limited resources, geographic dispersion and isolation from markets" (UN, 1992). On average, SIDS import 60% of their food requirements (FAO 2019). The Caribbean SIDS, home to 41 million inhabitants with 19+ million tourists every year, produces on an average less than half of its food requirements (The World Bank, 2021; UNWTO, 2021; FAO, 2017). Small-holder farmers face significant challenges, competing with cheaper imports of food from the mainland that have the advantage of economies of scale (FAO, 2016a; Beckford, 2012). The problem is further compounded by the increasing frequency of extreme weather events (OCHA, 2020; Acevedo et al., 2013) and the region's narrow resource base; per capita arable land in the Caribbean small states (0.1 ha/capita) is about half that of the LDCs and developing countries (The World Bank, 2018c).

As islands are heavily dependent on food imports, self-sufficiency and resource security through localization is often advocated by scholars (Béné, C., 2020; Tello and de Molina, 2017; GizickiNeundlinger et al., 2017; Dorodnykh, 2017; Feagan, 2007). While there is no widely agreed upon definition for localization, in the context of food security, localization may be understood as food production and consumption that occur in a defined geographical area to support a self-reliant and sustainable agri-food system (Bellows and Hamm, 2001) by shortening supply chains (Fraňková et al., 2017) and stimulating localness (e.g., local ownership, satisfaction of local needs, and local capital flow).

[1] This chapter contains an article published in the Journal of Industrial Ecology (JIE) highlighting the empirical analysis of this thesis and is presented verbatim. This chapter presents a concise version of the research.

This study is motivated by a fundamental question: Can the Caribbean localize its food system? We conduct a diachronic Material Flow Accounting (MFA) of biomass from 1961 to 2019 for four Caribbean nations: Barbados, Dominica, Grenada, and Jamaica. We adopt a social metabolism approach (Haberl et. al. 2016; Tello and de Molina, 2017), systematically quantifying the biomass flows over time, and analyzing the trends to uncover the transitions of island food systems and their responses to food insecurity. Using standard headline indicators of MFA, we assess the extent of food localization and its future prospects in the region.

The following section provides a brief overview of socio-metabolic research, highlighting some of the relevant studies and gaps in existing literature on biomass flows. Section 3 details the approach, indicators, and methodological steps taken to conduct a biomass MFA for the four cases. In section 4, we present the findings for each case and indicator, followed by a discussion in section 5 based on cross-case comparison of indicators, drivers, and trends of localization. The final section offers some concluding thoughts on Caribbean's potential to localize its food production.

4.2 Marking the contours of socio-metabolic research (SMR) with respect to biomass flows

Islands, like living organisms, depend on metabolic flows to sustain, consuming resources and producing waste. Socio-metabolic research (SMR) monitors resource use from entry to exit, develops strategies to become more resource efficient, and to improve quality of life (FischerKowalski and Weisz 1999, Molina and Toledo, 2014; Haberl et al. 2016, 2019). Material Flow Accounting (MFA) is one of the core accounting frameworks for conducting socio-metabolic research. An MFA quantifies the throughput of resources in a socio-economic system (Brunner and Rechberger, 2016).

MFA follows a mass balance principle that characterizes the size of the physical economy, also referred to as its characteristic metabolic profile (Fischer-Kowalski & Weisz, 1999). The focus could be on specific materials of interest (e.g., fossil fuels, biomass, metals, and minerals), but an economy-wide MFA (EW-MFA) will consider all material categories. At its core, MFA asks what quantity and quality of materials and energy are domestically extracted, imported, transformed, stocked, used, and discarded. A number of standard headline indicators of MFA allows researchers to compare patterns of resource-use of socio-economic systems and find ways to efficiently use resources and reduce environmental impact. As such, MFA compares the environmental performance of socio-economic systems in space and time for a sustainability analysis. Quantifying the natural resource requirements of socio-economic systems and their uses provides insights into the related environmental pressure generated by various sectors at multiple scales. MFA also offers critical information on system vulnerabilities inherent in specific combinations of resource use and dependencies that may be aggravated during shocks.

In an island context, MFA indicators offer useful interpretation on the proliferation of "metabolic risk" (Singh et al. 2020), either through increased resource dependency from outside, or diminishing health of the limited resource base on which social and economic wellbeing depends. Quantifying biomass flows, from harvest to end uses, the various by-products and trade, offers insights into the efficiency and sustainability of the food and the land-use system, and highlights the relative economic importance of biomass in relation to other material categories (e.g. metals, minerals, and fossil fuels) (Wirsenius, 2003; Wirsenius, 2000; Fischer-Kowalski and Haberl, 1998). MFA studies focusing on biomass alone, specifically in the context of food security, are very limited. Biomass accounts are generally included in the EW-MFA studies but not the focus, such as in Dong et al. (2017); Kovanda (2017); Infante-Amate et al. (2015); Schaffartzik et al. (2014); West et al. (2014); Kovanda and Weinzettel, (2013); West and Schandl (2013); Vellejo et al. (2011); Steinberger et al. (2010); Krausmann et al. (2008); Schandl and Eisenmenger (2006), Weisz et al. (2007). These studies seek to unravel trends, demonstrate metabolic transitions over time and identify regional differences with regard to society's use, turnover, and appropriation of biomass among a host of other materials. EW-MFA on islands that have considered biomass flows have been conducted for Trinket (Singh et al. 2001), Cuba (Eisenhut 2009), Trinidad and Tobago and Iceland (Krausmann et al. 2014).

Studies with an explicit focus on biomass metabolism to understand food systems and land-use are still very rare. Moreover, Okoli (2016) conducted the only known MFAbiomass for an island, that is Jamaica for the period 1961 to 2013. Table 2 summarizes the research objectives of select seminal studies and the gaps as identified by the respective authors. According to scholars issues arise when it comes to utilizing the MFA framework and analyses for niche contexts (e.g. localization of food systems) or highly dynamic and responsive systems (e.g. food security on islands) (Tello and de Molina, 2017; Krausmann et al., 2008).

Study	Scale	Research objective	Gaps in biomass studies as identified by authors
Wirsenius (2003)	Global and regional	Describing the main characteristics of the biomass metabolism of the food system.	Lack of focus on assessment of non-edible crops in the food system, efficiency of food systems, link between consumption pattern and resource requirement and utilization of by-products.
Risku-Norja and Mäenpää (2007)	National	Conducting an MFA to analyze the Finnish food flux, while simultaneously analyzing their environmental and economic consequences.	The focus is mostly on environmental consequences, not so much in analyzing the agriculture or food sector or the economics of it.
Krausmann et al. (2008)	Global	Introducing a methodological framework to comprehensively account for global socioeconomic biomass flows at the national level, considering regional characteristics and consumption patterns.	Biomass usually part of EW-MFA and not the focus. Biomass flow estimations highly aggregated and lacks further analysis of biomass use (such as food).
Soto et al. (2016)	National	Understanding the historical evolution of biomass flows of the Spanish agricultural system by utilizing standard headline MFA indicators.	Studies lack assessment of contribution of biomass in the metabolic transition. SMR studies are mostly at global scale and lack specific analysis of agriculture.
(Okoli, 2016)	National	Biomass flows for Jamaica and establishing their link with national food security of the country.	Empirical analysis of biomass metabolism cases (in this case Jamaica) in relation to food import dependence and national food security.

Table 2: Gap analysis based on key biomass metabolism studies in current literature.

Current studies suggest the need for comprehensive biomass metabolism studies focusing on the food production and consumption system along with subsequent analysis of socioeconomic and biogeographical factors. This study attempts to address some of the gaps identified in earlier works on biomass metabolism.

4.3 Methodology

An MFA of biomass (MFAbiomass) was conducted for the period 1961-2019 for four Caribbean Island states: Grenada, Barbados, Dominica, and Jamaica. These cases represent the region in terms of their variability in size, geographical spread across the Caribbean Sea, demographics, socio-economic and agricultural conditions (see Table 3).

	Barbados	Dominica	Grenada	Jamaica
Population (per head)	287,025	71,808	112,003	2,948,279
Population density (people/sq. km)	667	96	328	271
Sovereign status (Year)	1966	1978	1974	1962
GDP (million US$)	5,209	582	1,210	16,458
GDP per capita (US$/capita)	18,148	8,111	10,809	5,582
Land area (sq. km)	430	750	340	10,830
Agricultural area (sq. km)	100	250	80	4,440
Arable land (% of land area)	16.30	8.00	8.80	11.10
Arable land (ha/capita)	0.02	0.08	0.03	0.04

Table 3: The island cases at a glance for the year 2019 (land data is for 2018). Source: The World Bank (2018a, 2018b, 2018c, 2018d, 2019); FAOSTAT (2019).

4.3.1 MFA indicators used in this study

As a national MFA study, the system boundaries are the same as the political boundary of each respective island state. Given that our focus is food security and its localization, we considered only biomass flows related to food, that includes flows related to meat and dairy production. For the most part, we adopted standards and conventions of MFA as prescribed by EUROSTAT (2018). However, certain aspects of the methodology have been tailored to fit the island context drawing on research and manuals that specifically focus on biomass metabolism and/or nonindustrialized regions (Okoli, 2016; Krausmann et al., 2018; Singh et al., 2010). We focus on five standard headline indicators to define the biomass metabolism and extent of food localization in the island cases. Their annual values are reported in Megatonnes (Mt) in absolute terms, as well as tonnes/capita in per capita terms.

- *Domestic Extraction of biomass* ($DE_{biomass}$), also known as used extraction, is the extraction of biomass from the natural environment within the food production system to be further processed in the economy.
- *Imports* are biomass commodities that enter the national economy for domestic consumption.
- *Exports* are biomass commodities that exit the national economy to enter foreign markets.

- *Physical Trade Balance* of biomass ($PTB_{biomass}$) measures the physical trade surplus or deficit in an economy, indicating the extent to which domestic material consumption is based on DE as opposed to foreign imports.
- *Domestic Material Consumption* of biomass ($DMC_{biomass}$) refers to the absolute consumption of biomass within the food system.
- *Import dependency ratio* of biomass ($IDR_{biomass}$) indicates the extent to which imports meet domestic consumption.

4.3.2 Data sources and methodological steps

The UN-FAOSTAT (FAO, 2021a; FAO, 2020a) and FishStatJ (FishStatJ, 2020) were the two main databases used for this research, complemented by expert interviews in the region.

DE was calculated as the sum of flows of primary crop harvest, used crop residue, grazed biomass by livestock and capture fisheries. Primary crop harvest denotes the total aboveground plant biomass or all primary crops originating from agricultural activity. The production of primary crops is accounted for in fresh weight at harvest time, its moisture content ranging from 15 to 95% depending on the species. Used crop residue, a fraction of the harvested cultivar subjected to further socio-economic use, comprises of a relatively large biomass flow. After acquiring the production quantity of these crops (from the production domain of FAOSTAT), their available crop residue was calculated using the corresponding harvest factors for each crop, based on the Caribbean region, derived from Krausmann et al., 2018 and Wirsenius 2000 (See Appendix B).

*Available crop residues [t (as is weight)] = primary crop harvest [t (as is weight)] * harvest factor*

(1)

The regional recovery rate of each crop, also derived from Krausmann et al., 2018 and Wirsenius 2000, helped to calculate the actual amount of used residue from the available crop residue (See Appendix B).

*Used crop-residues [t (as is weight)] = available crop-residues [t (as is weight)] * recovery rate*

(2)

As grazed biomass is not reported by FAOSTAT the demand-side approach was taken, following (Krausmann et al., 2008), where the grazing gap is identified based on the demand driven feed balance.

$$\textit{Demand for grazed biomass} = \textit{Total feed requirement} - (\textit{marketed feed} + \textit{non marketed feed}) \quad (3)$$

As a first step, data on the number of grazing animals (per head) was collected from the production domain of FAOSTAT. Species of grazing animals were based on Krausmann et al. (2008). Next, the annual feed requirements of the selected species were calculated based on their corresponding standard annual feed intake values (tonnes/head/year) calculated for the Latin America and Caribbean region by Krausmann et al. (2008) at 15% moisture content (See Appendix B).

$$\textit{Total annual feed requirement} = \textit{Stock}*(\textit{Annual feed intake at 15\% mc for L\&C region}) \quad (4)$$

After calculating the feed requirement, data for marketed feed was obtained from the commodity balance domain of FAOSTAT from the year 1961 to 2013 (See Appendix A). Marketed feed data was not available for the years 2014 to 2019 and hence grazed biomass for these six years was calculated using an alternative method at the end since it requires the average value of grazed biomass from previous years.

The last component for calculating the demand for grazed biomass (1961-2013) is non-market feed which in this case is essentially the air-dry weight of used crop residues (calculated above) at 15% moisture content. For this step of the calculation, the species of common cultivars used as livestock feed were selected based on field interviews conducted by Okoli (2016). The assumptions from that study regarding livestock feed of Jamaica have been considered the same for the four island cases in this research (See Appendix A for details).

In order to convert the fresh weight of used crop residues to 15% moisture content, the global average water content of each crop type was calculated, following the manual published by Singh et al. (2010). Lastly, the air-dry weight (at 15% mc) was obtained for each crop.

$$Factor_{mc} = (1\text{-}mcfresh) / (1\text{-}mcair\ dry) \tag{5}$$

$$Air\ dry\ weight\ (at\ 15\%\ mc) = fresh\ weight\ (at\ 80\%\ mc) * Factor_{mc} \tag{6}$$

Finally demand for grazed biomass for the period 1961-2013 were obtained as the difference between total feed requirement and total feed available, containing both marketed and nonmarketed feed (See equation 3).

Going back to the grazed biomass for the period 2014-2019 was calculated utilizing large animal units (LAU) of each livestock species, for the Caribbean region. Firstly, the number of livestock (per head) was converted into LAU using specific livestock unit coefficients for each species provided by FAO for the Caribbean region (FAO, 2011).

$$Large\ animal\ units\ (LAU) = stock\ of\ livestock * Livestock\ unit\ coefficient \tag{7}$$

Next, the grazed biomass for the period 1961-2013 that had already been calculated and the aggregate LAU of all species per annum, were both utilized to obtain a ratio for the period 19612013 (grazed biomass/LAU). The grazed biomass to LAU ratio for the period 2014-2019 was assumed to be an average of the last eight years (2006-2013). Finally, this ratio was used to calculate the grazed biomass of the period 2014-2019 (F. Krausmann, personal communication, November 13, 2020).

The data for capture fisheries was collected from FishStatJ, under the domain "capture fisheries". Data was available from the year 1961 to 2018. Since there was no data available for the year 2019, at the time of collection, an average of past years was calculated to fill this gap.

PTB is simply the difference between the value of import and export commodities of biomass.

$$PTB_{biomass} = Imports - Exports \tag{8}$$

DMC is the domestic biomass flows of DE and imports excluding exports.

$$DMC_{biomass} = DE_{biomass} + Imports - Exports \tag{9}$$

Import Dependency Ratio is the ratio of imports of crop commodities to DMC per capita.

$$Import\ dependence\ ratio\ (IDR) = (Imports/DMC\ per\ capita)*100 \tag{10}$$

After the empirical analysis, several local experts of selected islands were consulted (as part of a larger project), in order to validate key findings. Insights from these interviews have aided in the interpretation of results (See section 3.6 for details of interviews).

Since national MFA primarily depends on secondary data, our findings are premised on the accuracy of FAOSTAT as a reliable source for agricultural statistics (Krausmann et al., 2008). Unintentional overlaps/ double counting or exclusions were carefully examined and addressed to the extent possible. Some categories of biomass flows are not considered either because they are outside the scope of the study (e.g., wood/timber as it is not part of the food system), or were insignificant in volume (e.g., biomass from hunted animals). Unused or indirect extraction that is “killed” during the harvest process and does not hold any further economic value is excluded from this study as this usually comprises of unused or unrecovered crop residues and belowground biomass of primary crop harvests (Krausmann et al., 2008).

4.4 Results

We now present the results of the four island cases across three MFA indicators: Domestic Extraction (DE), Domestic Material Consumption (DMC), and Physical Trade Balance (PTB) for all edible biomass categories to investigate the dynamics of the food system for the period 1961 and 2019.

4.4.1 Barbados

Figure 2 is an overview of Barbados's biomass metabolism from 1961 to 2019. Domestic extraction of biomass grew at a rate of 30% when it peaked in 1967 with 2.99 tonnes/capita. Thereafter, a declining trend set in that continued until 2019, dropping to 1.05 tonnes/capita, a drop by 87%. The first 30 years of the study period, show magnitude of grazed biomass to be minute, compared to primary crop harvest and used residues (Fig 2), but it has been consistently increasing on its own right till 1989. Since then, the flow of grazed biomass has met and surpassed, not only the flow of used crop residues but even that of primary crop harvest. This has happened despite magnitude of grazed biomass falling after the peak in 1989. Capture fisheries is not a significant flow in Barbados in comparison to other biomass flows. It has been relatively steady over this period, aside from a rapid spike and drop during 1987-1989. Barbados has been in a trade deficit for biomass commodities, during the first 20 years of the study period (Fig 2). However, consistent increase in imports, especially crop commodities, has led the country to become a net importer around 1981. Crop and livestock commodity imports have both increased at similar rates quite significantly over the span of 59 years, at 259% and 230% respectively. While crop and livestock commodity exports, show a varied picture, declining at very different rates, 90% and 568% respectively. In Barbados, DMC of crops has declined more than three times, from its peak during the 60s, averaging 1.40 Mt, to its lowest, averaging 0.40 Mt during 2010-2019 (Fig 2).

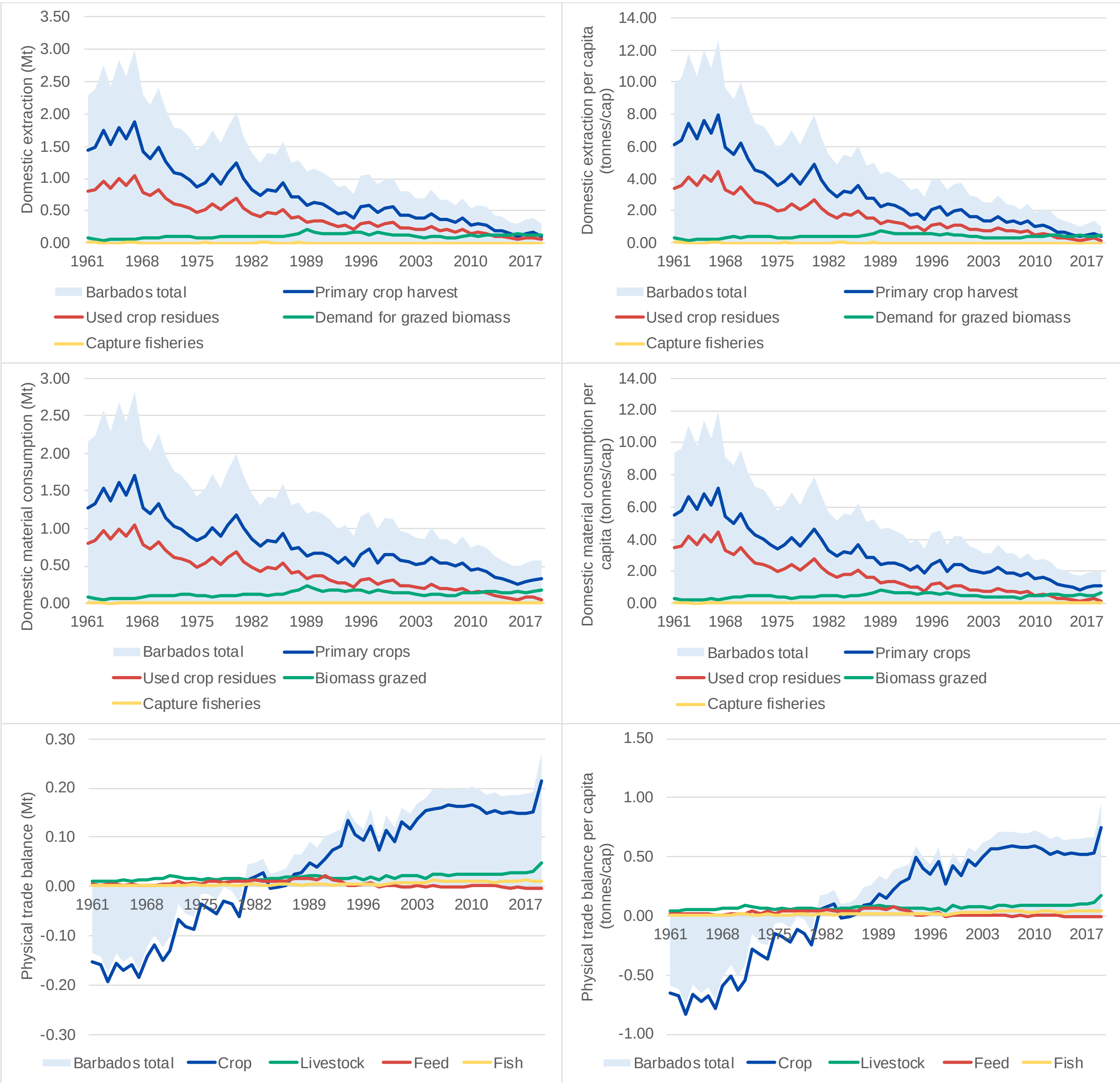

Fig 2: Annual aggregate flows of domestic extraction, domestic material consumption and physical trade balance of Barbados in absolute values in Megatonnes (left) and per capita values in tonnes/capita (right) over a span of 59 years. Underlying data for Figure 2 are available in Appendix D.

4.4.2 Dominica

DE and DMC of biomass in Dominica shows a pattern of rise and fall over the last 59 years (Figure 3). Especially when it comes to DE of crop biomass, steady increases (such as from 1961-1978 and 1980-1988) have been followed by decline, often sharp or over a short span of time. However, the overall trend of 59 years does not point towards a decline since the country's profile demonstrates rebound from these falls. DE of crop biomass has been increasing over the last two decades after a particularly long fall from 1988 to 2003, during which time it fell from its peak (0.17 Mt), almost twofold. Demand for grazed biomass has grown almost 5 times from 1961 to 1987. Since then, change has been less dramatic in comparison, while growth continues. It should be noted that there was a rapid decline of demand for grazed biomass after 2005, which was then picked up after 5 years. Biomass from capture fisheries is quite negligible in Dominica compared to other flows. Nevertheless, it experienced some sharp ups and downs over the span of 59 years. DMC of biomass, on the other hand, shows a varied picture. DMC of crop biomass has been increasing (Figure 3) over the last 59 years at a much steadier pace than DE. And interestingly, DMC of grazed biomass has also been increasing alongside till 1996, reaching magnitudes close to that of DMC of crops, after which it starts to drop, even though DMC of crops continue to soar. Dominica very recently became a net importer, in the last decade (Figure 3), as per its physical trade balance since the drastic fall in export of crops. This transition can also be attributed to a steady increase in import of livestock commodities till 1996. In the last decade, import of both crop and livestock biomass has increased significantly in Dominica, leading to a trend of increasing trade surplus.

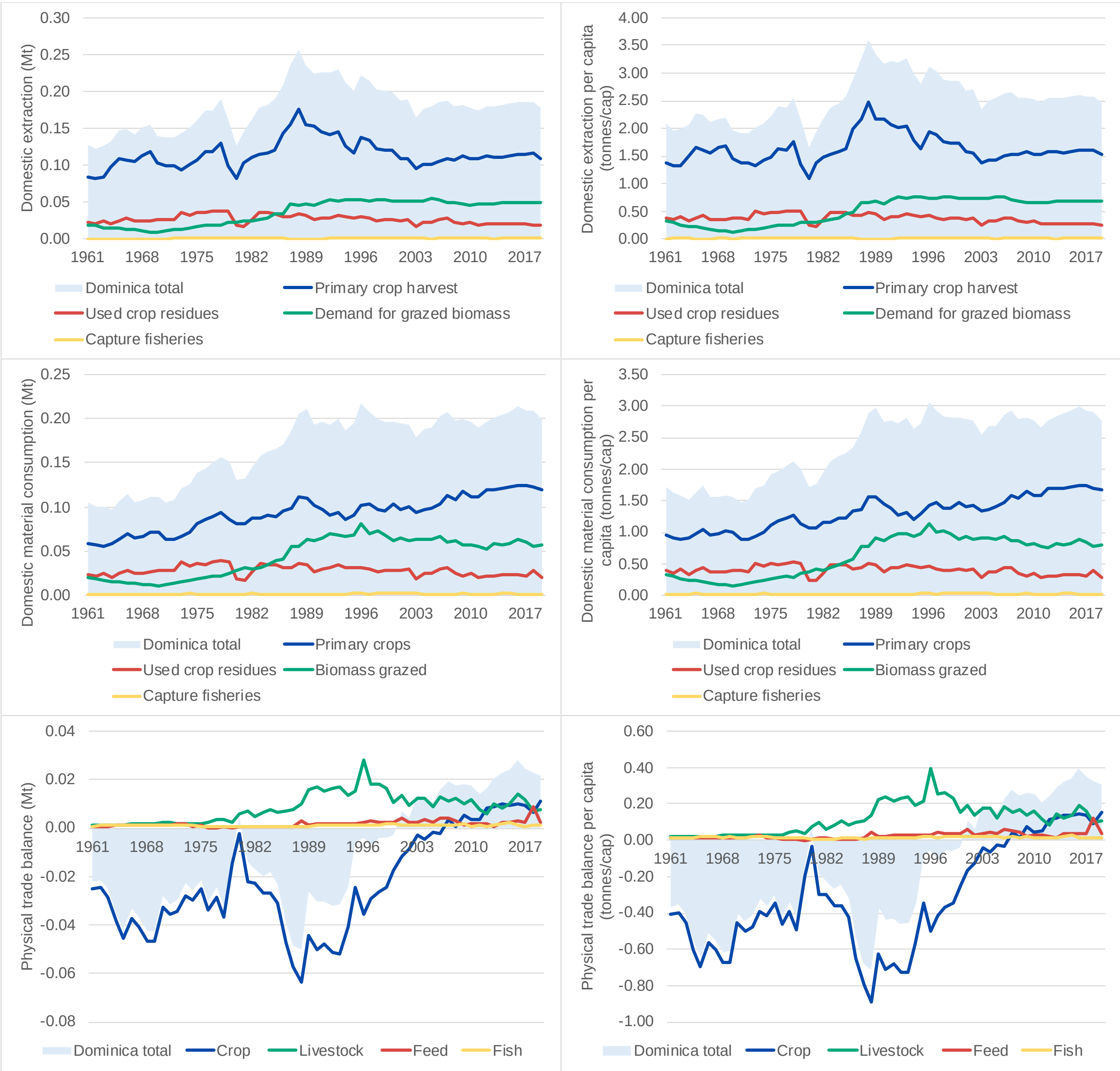

Fig 3: Annual aggregate flows of domestic extraction, domestic material consumption and physical trade balance of Dominica in absolute values in Megatonnes (left) and per capita values in tonnes/capita (right) over a span of 59 years. Underlying data for Figure 3 are available in Appendix D.

4.4.3 Grenada

Figure 4 shows that after a few initial peaks (1967, 1978), DE of biomass has been declining in Grenada for almost 3 decades. After this long slump however, a significant surge in DE can be witnessed, which continued till 2015. This change in trend is on account of DE of crop biomass, which observed its peak in 2016 at 0.14 Mt. To compare, the past average has been around 0.05 Mt across 5 decades. Grenada has transitioned from net exporter to net importer due to changes in their crop trading patterns. Crop imports increased almost fourfold since the beginning of the study period and only started declining in the last decade. Although much lower in magnitude, livestock and feed imports increased more drastically, about 14 times and 62 times respectively over the 59 years. Meanwhile, export of crops has consistently gone down since Grenada's peak during 1968 at 0.03 Mt. Exports have picked up only in the recent decade after continued fall to its lowest magnitude during 2009. While livestock export is not notable in Grenada, export of feed seems to hold significance especially since the late 2000s when magnitude matched close to that of crops, historically the most important commodity of foreign trade. This sudden increase in feed may likely be due to increase in primary crop harvest in that time. The country has observed a striking and consistent increase in DMC of crops especially in the two decades (2009-2016), reaching a peak of 0.18 Mt, while the past several decades maintained an average crop DMC about three times lower.

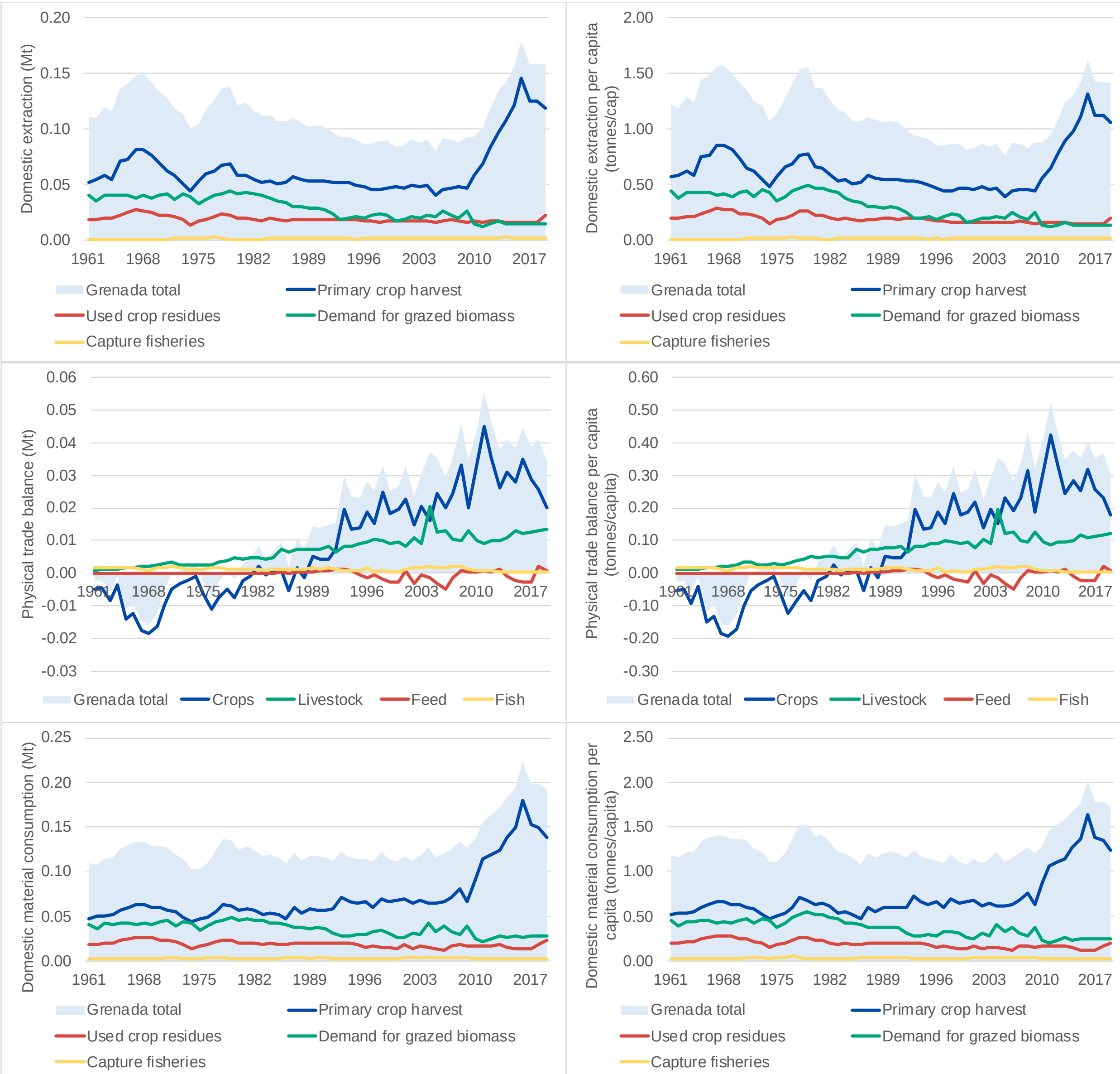

Fig 4: Annual aggregate flows of domestic extraction, domestic material consumption and physical trade balance of Grenada in absolute values in Megatonnes (left) and per capita values in tonnes/capita (right) over a span of 59 years. Underlying data for Figure 4 are available in Appendix D.

4.4.4 Jamaica

DE of biomass in Jamaica is on an overall decline, the trend being more dramatic in DE per capita (Figure 5). Since its early peak (5.81 Mt) in the late 1960s, DE of crop biomass has decreased twofold over the following 20 years. After a short-lived rise from 1989-1996, DE of crop biomass continues to plummet to its lowest magnitude in 59 years (1.82 Mt), now more than 3 times lower than the extraction levels of the peak year. Jamaica has transitioned into a net importer early on due to simultaneous rapid increase in crop imports and decrease in crop exports (Figure 5). However, livestock commodity export, even though lower in magnitude compared to crop commodities, has increased at a more dramatic rate, beginning from the late 1980s. Although not a significant flow, the trends in feed trade has also changed noticeably. Both feed imports and exports have dramatically increased since early 2000s. Imports grew at a fast pace in Jamaica mostly due to crop commodities which have increased by 450% over the span of 59 years. Imports have been increasing consistently over the last 59 years of study. On the other hand, export of biomass commodities in Jamaica have been consistently plummeting. The most drastic fall have been from 1966 to 1981, when it decreased by almost five times from 0.78 Mt to 0.16 Mt. Exports are at an all-time low in recent year at 0.099 Mt. DMC absolute and DMC per capita have overall declined by 45% and 69% respectively in Jamaica. The country is observing its lowest DMC in the last decade. Starting from 9 Mt and 5 tonnes/capita in the 60s and 70s when it was the highest in the study period, it steadily declined, in the last ten years, to its lowest, averaging around 6 Mt and 2 tonnes/capita.

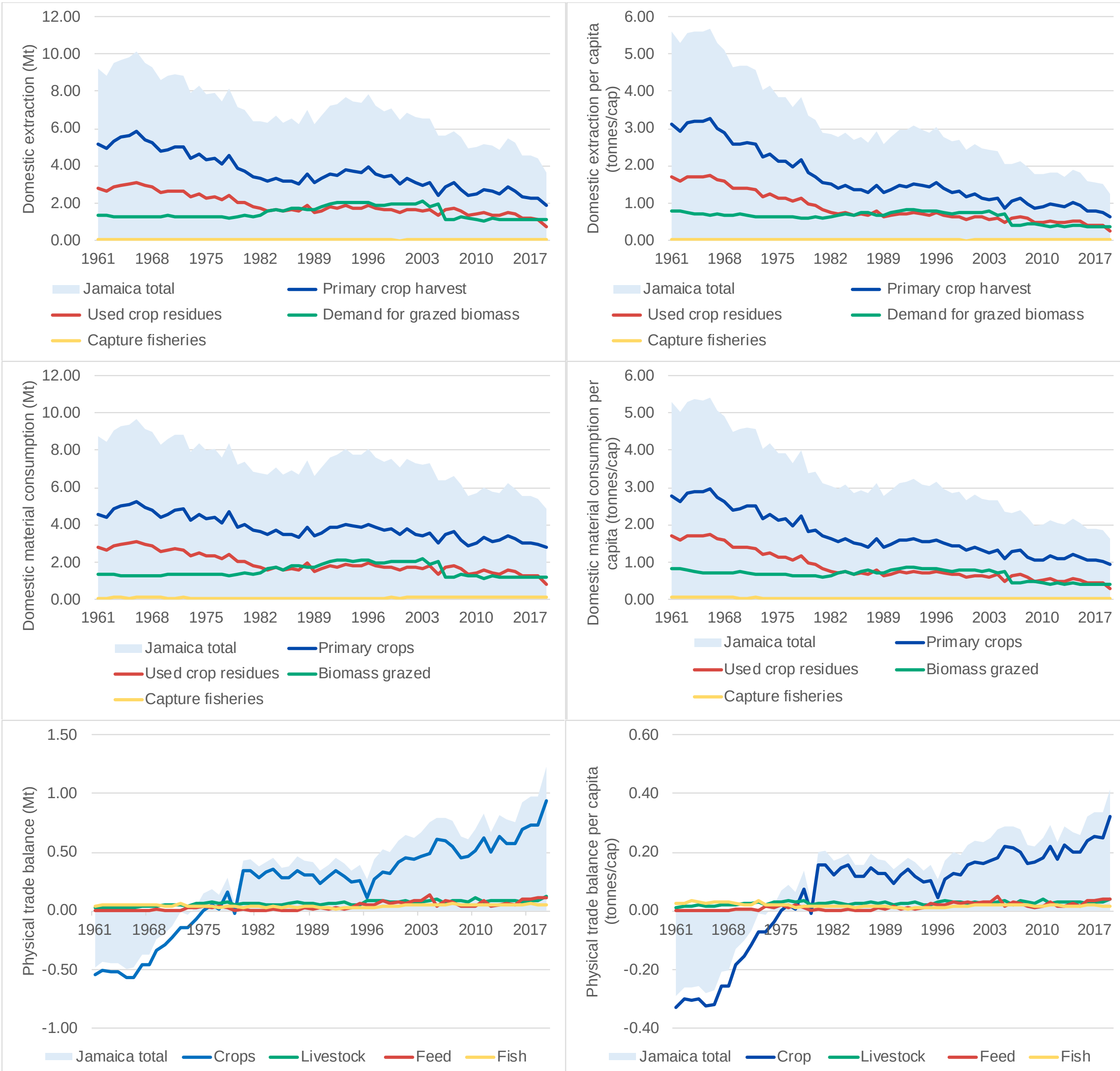

Fig 5: Annual aggregate flows of domestic extraction, domestic material consumption and physical trade balance of Jamaica in absolute values in Megatonnes (left) and per capita values in tonnes/capita (right) over a span of 59 years. Underlying data for Figure 5 are available in Appendix D.

4.5 Discussion

In this section, we will take on a wider regional lens, comparing and interpreting trends across the four island cases. The extent of localization will be addressed by drawing on indicators of production, consumption and trade and the way they relate to one another.

4.5.1 Comparing the island biomass systems

Table 4 provides an overview of the metabolic transition that has taken place between 1961 and 2019 in the biomass systems of Barbados, Dominica, Grenada, and Jamaica. The variability in the socio-economic context for the four islands may suggest some underlying reasons in the way the biomass system has evolved in the study period (refer to Table 3). At the outset, two groups seem to emerge that show similar trends: Barbados/Jamaica and Dominica/ Grenada.

		DE/capita			**PTB/capita**			**DMC/capita**		
Island case	**Biomass category**	1961	2019	Δ (%)	1961	2019	Δ (%)	1961	2019	Δ (%)
Barbados	**Aggregate**	9.94	1.05	-89%	-0.59	0.95	260%	9.35	1.99	-79%
	Crops	6.17	0.38	-94%	-0.65	0.75	214%	5.52	1.13	-80%
	Livestock	0.31	0.47	51%	0.04	0.17	304%	0.36	0.64	81%
Dominica	**Aggregate**	2.09	2.47	19%	-0.37	0.30	183%	1.72	2.78	61%
	Crops	1.38	1.52	10%	-0.41	0.15	137%	0.97	1.67	73%
	Livestock	0.32	0.69	115%	0.02	0.10	486%	0.34	0.79	134%
Grenada	**Aggregate**	1.22	1.41	16%	-0.03	0.31	1242%	1.19	1.72	44%
	Crops	0.57	1.06	85%	-0.05	0.18	434%	0.52	1.24	139%
	Livestock	0.44	0.13	-69%	0.01	0.12	1047%	0.45	0.25	-44%
Jamaica	**Aggregate**	5.59	1.22	-78%	-0.29	0.42	243%	5.30	1.64	-69%
	Crops	3.10	0.62	-80%	-0.33	0.32	197%	2.77	0.94	-66%
	Livestock	0.79	0.36	-54%	0.01	0.04	248%	0.80	0.40	-50%

Table 4: Comparing domestic extraction, domestic material consumption and physical trade balance per capita (tonnes/capita) of Barbados, Dominica, Grenada and Jamaica.

DE of biomass has decreased drastically in Barbados and Jamaica following their peak during the 60s, mainly due to the decline of their respective agricultural sectors. Dominica, and Grenada, however, are now on the rise, showing an overall increase in $DE_{biomass}$ of 42% and 39% respectively in the same period. Jamaica has the highest DE of biomass in absolute values, averaging 5 times higher than the other three islands combined. This is to be expected since Jamaica has 10 times more agricultural land than the other three islands combined (See Table 3). With respect to per capita values for overall DE of biomass, Barbados showed the most drastic change, with 9.94 tonnes/capita in 1961 that dropped to 1.05 tonnes/capita in 2019. Barbados' economic development was largely based on plantation agriculture during early British colonialism, specifically sugar plantation, supported by Barbadian labor (Brathwaite and YongGong, 2012). The other cases, especially Dominica and Grenada transitioned slower, but have meanwhile caught up, and are all converging at an average 1.5 tonnes/capita in 2019.

Cereal production was highest in Barbados until its decline in the 90s, from which point Grenada had the highest Cereal production among the sampled islands. That said, these staple crops are not significant in the domestic production of any of the four island's food systems. The harvest of sugar crops per capita has declined in all four islands. Sugar crop production in both Jamaica and Barbados had been many folds higher than any other crops produced in these two islands, indicating the significance of the crop in these countries. In Barbados, contribution of sugar to GDP has declined from 21% in 1960 to 1.4% in 2005 (Richardson-Ngwenya and Momsen, 2011).

The production of roots and tubers are on the rise with Dominica producing significantly higher than the other three islands. Grenada is also a leading producer of fruits among the four islands and has recently increased its vegetable production significantly in the last decade. Even though Jamaica is the leading producer of stimulant and spice crops among the four islands, Grenada too has a significant share of the same relative to its other crop harvests. Spices are an important export of Grenada as it is one of the biggest global producers of crops such as nutmeg (Wiley, 1999).

The evolution of $PTB_{biomass}$ is similar for the four islands in that, from net exporters at the start of the study period to net importers, albeit at different time periods. A combination of factors such as structural policy adjustments and high frequency of natural disasters were responsible for decline in small-scale crop production leading to heavy dependence of imports and downfall of exports (Labadie, 2009; Barker, 2012). On average, Caribbean SIDS spend 20% of their overall export earnings on food imports, compared to a global average of 5%. That proportion is even higher for islands such as Jamaica (48%), Barbados (67%) and Dominica (103%) (Hickey and Unwin, 2020). Jamaica became a net importer from 1974, on account of drastic decline of its export sector, especially sugar. This continued towards the 90s to early 2000s when the market was flooded with subsidized agricultural imports forcing farmers to buy the cheaper imports in order to resell instead of producing locally. During the same period, a number of natural disasters occurred in the country diminishing crop production for both local market and exports (Beckford et al., 2007). In the 1980s, Grenada and Barbados followed suit and became net importers of biomass. Dominica, however, joined the category latest in the year 2000.

This transition of $PTB_{biomass}$ was led by significant increase in the import of food crops where livestock, feed, and fish are only 10% of the PTB combined. The exception is Dominica, where livestock import is quite significantly higher in comparison with other cases, having increased more than two-fold in the same period. Dominica's Ministry of Agriculture had collaborated with

FAO to develop their livestock sector. Focus was placed on the small ruminants since they are able to graze marginal lands not suited for human food production and because of their ability to withstand unfavorable weather conditions (FAO, 2017). More recently, Dominica shows a trend of importing more feed for local livestock production instead of importing livestock itself.

4.5.2 Extent of localization of food production

To understand the extent of localization, we analyzed DMC in relation to imports, exports, and the import dependency ratio (IDR) defined as the "part of the domestic food supply that has been produced in the country itself" (FAO, 2011). Biomass flows are further disaggregated to identify the primary food crops of each island case and reveal their respective contribution in the trend towards localization.

Barbados seems to be moving away from the localization of food production. DMC of crop commodities has declined by 75% over the span of 59 years. Barbados did implement an Agricultural Diversification Program (1964) and a national development plan (1965-68) that laid out strategies to increase yield of sugar and other food crops to meet local needs and to reduce dependency of the economy on the single commodity export sector (Francis, 1973). However, focus was placed on overall economic diversification which meant two things: decline of the sugar industry and rise of the tourism sector. This is why the spike in vegetable production in the 60s and 70s (for details, see Appendix C) has been attributed to tourist consumption (Francis, 1973). Sugar was at its peak from 1961 to 1970, averaging, 1.34 Mt but now move in the range of 0.19 Mt. Barbados' trend of DMC of crops has been driven by DE (of mostly sugar crops), their values very close to each other. This changed when imports started increasing (See Figure 2). In particular, DE and imports are converging over time and in 2019 their values are almost identical (around 0.27 Mt).

Dominica seems to be trending towards localization. DMC has been more consistently increasing due to increase in imports, particularly fruit beverages which seems to be a significant import commodity in the country. However, the local production of fruits, roots and tuber crops are starting to rise and now account for almost 75% of the total DMC of crops since the last decade (averaging 0.05 Mt and 0.04 Mt respectively). A major export of Dominica is bananas grown mostly by small-holder farmers (FAO, 2008), and so changes in regulations easily threaten this kind of peasant-oriented production system as they are less competitive in comparison to Latin America's more industrialized production system (Wiley, 1999). Another risk to Dominica's agricultural system is the constant threat of flash floods, droughts, and destructive hurricanes (CIA, 2021).

While Dominica produces sufficient roots and tubers, they also import a different variety, indicating diversified commodity demand of root and tuber crops. Overall, lower exports and the steady increase of DE over the study period suggest a trend of increasing localization of food production.

Grenada also seems to be trending towards food localization, especially in the case of vegetable and fruit crops. In previous years, the domestic food demand was met largely by imports. Local crop production and export fell between 1976-1986, perhaps due to major disasters around that period. Grenada is at the edge of the hurricane belt, making it vulnerable to extreme weather events. During the 2004 Hurricane Ivan, 100% of the banana and 90% of the nutmeg industry was destroyed. During this time farmers lost 90% of their average annual revenue (FAO, 2015c). These devastating changes are not as visible in the metabolic profile of Grenada in the case of spice crops for instance which are low volume but have great economic value for the country. A significant spike in DE and hence DMC occurred from 2009 to 2016. IDR of fruit and vegetable crops plummeted during the same time period. With negligible export of these crops over this period, it may be an indication of increased localization taking place.

In Jamaica, we see a marginal shift towards localization for some foods. Jamaica's major crops are cereal, sugar, and fruits. The downfall of the sugar export industry caused a consistent decline in DMC. Interestingly, IDR started to increase after 1980s. Further analysis suggests that as sugarcane production declined, importation of refined sugar increased in the country. As for cereal crops, DMC is consistently increasing over the years with a steady import dependence. Local production of fruits increased in the last decade primarily for domestic consumption. With no significant export sector for fruit crops in Jamaica it seems that the country is becoming more self-sufficient in this regard.

4.6 Can the Caribbean localize its food system?

Given the Caribbean's precarious dependence on high food imports, self-sufficiency through localization is often seen as a panacea. Whether food localization is inherently beneficial or viable for a small island state needs to be further investigated. Localization can be challenging already in a non-island context where the viability of localization is contingent on the availability of arable land, water, and soil nutrients (Frankova et al. 2017) along with a viable workforce (Kendall and Petracco, 2009). One of the reasons why DE and DMC increased in smaller islands like Dominica and Grenada may potentially have been due to the increase in arable land in the last two decades. Dominica increased twofold (0.04 ha/capita to 0.08 ha/capita) from 1998 to 2009, while Grenada increased threefold between 2000-2009 from 0.01 to 0.028 ha/capita (The World Bank, 2018c). On the other hand, the arable acreage per capita on Barbados and Jamaica decreased steadily over the last five decades around 3 times and 2.5 times respectively (The World Bank, 2018c).

In case of larger islands, land productivity and labour intensity seem to have an inverse relationship with farm size (Weis, 2004), as has been shown for Jamaica during the 70s and 80s (Rao, 1990). Jamaica's agricultural land area is about 9 times larger than that of the other 3 islands combined. It's arable land, on average, 6 times larger. However, its arable land as a percentage of total land area and arable land per capita, are both on the lower end, when compared to the other three islands (The World Bank, 2018b; 2018c). Decline in arable land may also be a result of soil erosion due to steepness of slopes and years of monoculture.

Soil fertility is a known factor of harvest which can be measured by a proxy indicator such as soil nutrient budget (FAO, 2021b; Scoones and Toulmin, 1999). We observe that Dominica and Grenada have declining soil nutrient budgets which may be indicative of increasing crop yield. On the other hand, Barbados and Jamaica have increasing soil nutrient budget. In fact, Barbados was among the top 10 countries for soil nutrient budget of 180 kg/ha in the last decade. Although the reason for this could be limited crop land availability more than low baseline soil quality (FAO, 2021b). It is important to note that increasing food production through conventional farming in an already space constrained island context could compromise terrestrial, coastal and marine ecosystem health through deforestation, nutrient and fertilizer run-off, eventually offsetting other critical ecosystem services vital for the island's economy.

Thus, a paradigm shift towards localization in small islands would require an approach that is intersectional (to include nutrition, public health, and climate), as well as flexible and adaptive (considering intraregional trading as part of the localization framework) (Brookfield, 1992; Friel, 2009). Although MFA may alone not be an appropriate framework as a management tool, it offers valuable macro-level perspectives into trends of biomass use and food localization that traditional economic analysis may not. The ability to analyze dynamics among indicators for specific crops, their unequal trade and resource requirements (such as land-use) positions MFA as an appropriate tool for such studies. This study is an important contribution to Caribbean's food security debate and serves as a point of departure for local institutions to conduct context specific studies to develop strategies for achieving SDG 2.

Chapter 5 Discussion and Conclusion

5. 1 Insights from local experts in the Caribbean SIDS

As mentioned in section 3.6, local experts from four Caribbean SIDS were consulted on two major themes: extent of domestic production and utilization of crop residues. This section provides a summarized account of information collected from those expert interviews to supplement the empirical analysis.

With regard to domestic production

Biomass flow analysis of Grenada and Dominica's food system highlights an increase in production in the last two decades. Interviews with local experts provided mixed insights. When inquired about this change in domestic production, some experts from both islands, suggested that increase may not have been as dramatic and/or may not have been due to specific policy interventions. However, one expert from Dominica stated that local production has indeed increased due to prioritizing diversification of both the agricultural sector and the economy and increasing local consumption. Attention was brought towards hurricane Ivan in 2004 and hurricane Maria in 2017 after which agricultural production had plummeted in Grenada and Dominica respectively and so it should be noted that any increase in production had taken place after a major decline. In terms of increase in production of fruits and vegetable crops in Grenada, people's desire for healthy living and consuming local produce, increase in tourism creating additional demand and favorable soil conditions, may have been bigger driving factors compared to government intervention. Local experts highlighted a long term government intervention that may have had some influence. It was the promotion of and advocating for growing and eating local produce. In Dominica, due to frequency of extreme weather events, greater emphasis was placed on root crops since they hold up better in extreme weather conditions and diversification of tree crops since they are vulnerable. Interest in agriculture has been maintained and as a result large quantities of root crops and vegetables have been produced over the years. With the assistance of the FAO, CARDI and other regional and international organization, production of major crops has been expanded. State of the art abattoir establishment has helped in expansion of livestock production in Dominica.

Backyard gardening program came up quite often when discussing increasing trends in domestic production in recent years (in Grenada and Dominica), however it is still unclear whether it contributed to significant increase. Soursop was highlighted as an important crop in Grenada that may have significantly contributed to increase in domestic crop harvest in recent times. Even though backyard gardening is a tradition in the Caribbean it found new motivation during the pandemic in islands like Grenada and Dominica, when risk of import dependence was further realized upon borders closing.

Even though banana industry in Dominica and sugar industry in Barbados has declined, these crops still hold significance and are produced at significant magnitude in the respective countries. However, the decline of the banana sector has enabled Dominica to increase diversification of the agricultural sector. Decline of the sugar industry is not a reflection of Barbados' lack of interest but rather can be attributed to drought and worker related issues (salaries, unions, delay in starting process of planting which impacts yield, etc.).

With regard to utilization of crop residues

It is estimated that around 30% to 50% of food intended for human consumption is inevitably wasted as it moves along the food system. Current efficiency levels point towards loss of natural resources, energy, and productivity (Jurgilevich et al., 2016). For an island, that means not only putting a strain on an already narrow resource base (UN-OHRLLS, 2020) but also neglecting the physical waste of food in a place where undernourishment levels are still significant (FAO, 2016b).

Utilizing crop residue for livestock feed is a recognized tradition in many Caribbean islands. Small-scale farmers have been known to collect their crop wastes to feed their animals. However, in a larger or commercial scale this is not viable and so market feed is the preferred option in islands such as Grenada, Dominica, Barbados and Jamaica. Utilization of crop residue for animal feed has to be comparable to the convenience of using market feed in order for it to have any significant impact. Lack of organization, additional cost of transportation and collection, uncertainty of supply and certain nutritional requirements for feed have been identified as some of the constraints of not utilizing crop residue, even though the concept was generally perceived positively among the experts.

5.2 Evolution of trade dynamics in the four Caribbean islands

The figure below demonstrates the evolution of trade dynamics that took place in Barbados, Dominica, Grenada and Jamaica during the last five decades. As discussed in section 4.5.1, these islands have all transitioned from net exporter to net importer status. Jamaica went through the most drastic change in PTB in the early years and had the highest PTB in absolute terms over the years compared to the other islands. This is possibly due to its larger economy and population size (See Table 4). Meanwhile, physical trade balance per capita is led by Barbados surpassing even Jamaica. This trajectory of high import dependence and the diminishing export sector shown here for these islands warrant the exploration of localization of the food system as a potential path towards self-sufficiency in the Caribbean SIDS.

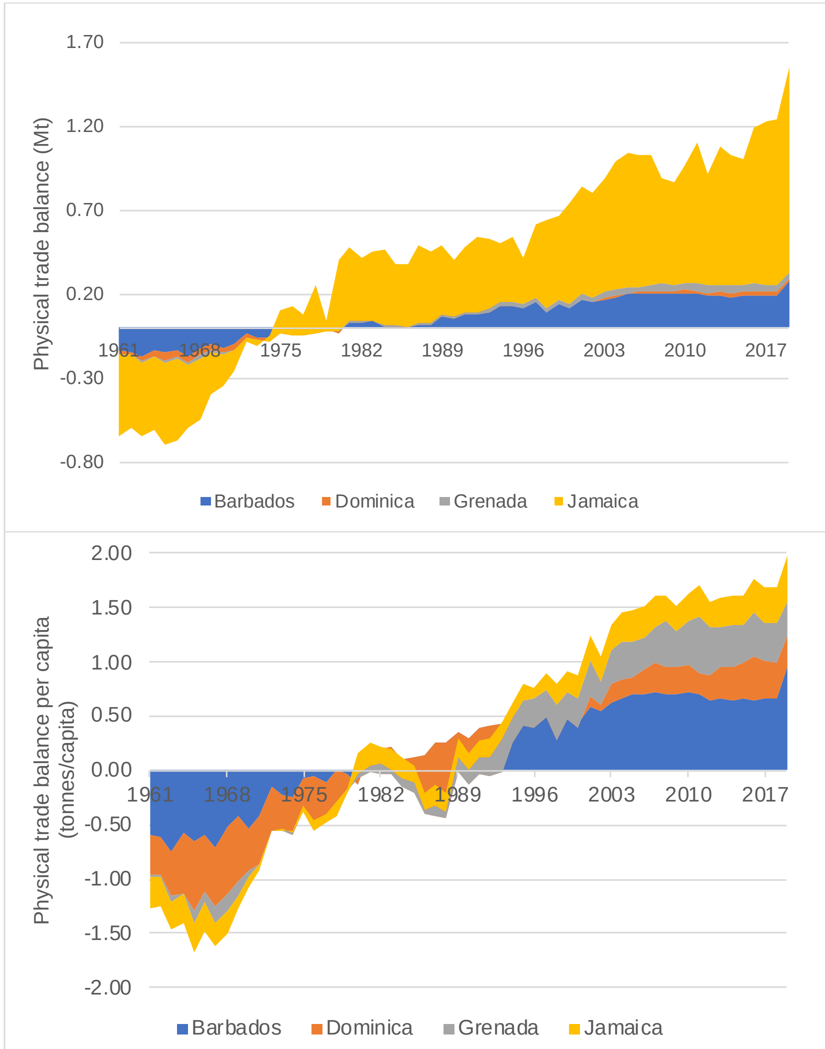

Fig 6: An overview of the physical trade balance in Mt (top) and physical trade balance per capita in tonnes/capita (bottom) of the four island cases studied between 1961 to 2019.

5.3 Localization: a potential path towards circular food systems in the Caribbean SIDS

The circular economy model is surfacing as an alternative paradigm to the current linear food production and consumption system (Esposito et al., 2020). Circular economy lends theories and principles from industrial ecology, a field that aims to close the loop of materials and substances in order to decouple resource consumption and environmental impacts from economic activities (Saavedra et al., 2018). Circular economy is restorative by design (Geissdoerfer et al., 2017). A circular design applies the principles of systems thinking, use of renewable resources, material and energy cascading and resilience through diversity, among others. Applied to the food system, that implies reducing the amount of waste generated from the food system, reuse of food, management and utilization of by-products and waste during food manufacturing, nutrient recycling and recovery, and changing into more diverse and efficient dietary patterns (Jurgilevich et al., 2016).

One of the suggested ways to enhance circularity in the food system is by diversifying production and consumption through localized food systems (Jeffries, 2018; Jurgilevich et al., 2016). Social movements towards alternative food provisioning networks often turn to localization as a reactionary measure when globalized institutions are ineffective at solving issues present in the current food system (Allen, 2010). While there is no widely agreed upon definition for localization, in the context of sustainability in food systems, localization may be understood as food production and consumption that occur in a defined geographical area to support a self-reliant and sustainable agri-food system (Bellows and Hamm, 2001) by shortening supply chains (Fraňková et al., 2017) and stimulating localness (e.g., local ownership, satisfaction of local needs, and local capital flow). Agricultural movements particularly in developing nations suggest that farmers may seek more local control of food production (Waldron et al., 2017).

The sustainability of SIDS is often associated with becoming self-reliant (Baldacchino, 2014). Particularly, self-sufficiency of food is considered paramount for island states due to their isolated nature (Kim et al., 2015). Unfortunately, key stages in development of Caribbean SIDS have subsequently weakened the self-provisioning systems of food (Lowitt et al., 2015) and given rise to a homogenous agricultural sector in a globalized market (Watts et al., 2005). “Alternative food networks” are believed to be the antidote (Watts et al., 2005). Alternative agro-food social movements striving for sustainable agriculture and food security are known to encourage localization (Allen, 2010). Newer definitions of food security also bring focus on enhancing capacity of the local food production systems through concepts of community food security originating from principles of social justice, equity in access and availability of food, quality, and reliability of food supply (Feagan, 2007). The specific combination of food security challenges outlined in section 2.1 also suggests that lack or absence of self-reliance in the provisioning of food is a major risk factor for the Caribbean SIDS. Therefore, localization seems to be a potential path forward that is worth investigating.

The discourse on localization or re-localization can be traced back to earlier calls for sustainability through self-sufficiency, democracy, decentralization, etc. all of which are spatially referenced concepts and opposing to the “agro-food distanciation” caused by the globalized food system (Feagan, 2007). “Alternative food networks”, “alternative food provision system”, “re-spatilization” and “localization” are terms that are often used interchangeably or within the same context in literature. Advocates and or scholars of local food view locality as a closed system where food is produced, processed, and retailed in a geographically bounded area defined in various ways as local. So local food can mean locally produced food or food with a clear regional provenance. This requires changes in mechanisms that are alternative to the conventional channels such as large food processing companies and dealing with multiple retailers or intermediaries, etc. (Morris and Buller, 2003).

Various benefits are cited for localization of food production or a localized food system. One of the most understood benefits of local food systems is support for community and the local economy by “keeping food dollars close to home” (Allen, 2010). Local food is considered opportunity for farmers to obtain a bigger share of retail prices (Morris and Buller, 2003). Localization can increase equity in the food system in term of resource distribution, democratic participation, etc. (Allen, 2010). Such initiatives can also create jobs for locals in the areas of food distribution, sales, etc. as an alternative food system can also result in an alternative economic system through diversification (Watts et al., 2005). According to Sindico (2021) an improved local food system should not only be comprised of increasing domestic production but also have the ability to diversify the economy for islands that heavily rely on a single sector such as tourism (Sindico, 2021). An important aspect of localization paradigm is the rediscovery of traditional foods in local diets that can bear various health and economic co-benefits (Campbell et al., 2021).

Localization is believed to stimulate horizontal instead of vertical networks for endogenous economic development. This would not only minimize the influence of larger multi-national food producers and retailers but also incorporate the knowledge and innovation of small-scale producers through short food supply chains (Watts et al., 2005). Shortening of food chains is one of the more well-known strategies for localization. Shortened food chains reconfigure relations between food production and locale through changing agricultural practices. This can be through reducing food miles (distance food has to travel from place of production to final sales) by removing powerful intermediaries and small-holder farmers directly selling to consumers which can ultimately reduce overall cost of production and help farmers keep a bigger share of the revenue (Feagan, 2007; Watts et al., 2005). Shortened food supply chains can also serve so-called “food deserts” where fresh food is either prohibitively expensive or not at all available or both (Watts et al., 2005). Agrotourism, an alternative form of tourism is often proposed as a means to catalyze local food production to improve food security all the while capitalizing on the existing tourism sector (Thomas et al., 2018). This can be relevant for the Caribbean SIDS as countries such as Dominica already has an existing agrotourism sector.

Localness in the food system can also be stimulated through concepts of foodsheds, label of origin, terroirs, etc. Food sheds are spatially bound systems of food production having variables specific to the delineated space such as micro-weather patterns, types of soil, terrain, etc. Food sheds can re-orient social and political decisions on food to the place in question (Feagan, 2007). “Label of origin” branding of food products is another way to stimulate local production of food as the transaction becomes more meaningful. This type of marketing refers to specific area whose micro-climate patterns, soil type, etc. imparts a distinctive quality to the food that it produces (Feagan, 2007).

Winter (2003) points out that many aspects of food production still remain at the local level due to the spatial unevenness of globalization (Winter, 2003). This is because global food corporations have to adapt to local variations in purchasing behavior, cuisine, etc. (Winter, 2003). Then there are the Caribbean SIDS who faced a drastic transition in consumption pattern due to circumstances beyond local control such as unfavorable shifts in global policy, distortion of markets by flooding of cheaper imports, high frequency of extreme weather events, etc.

Notably, there is a disconnect in current localization literature and island food security challenges. The need for localization for sustainable agriculture and food security, especially for island food systems has been highlighted in several studies (Sampedro et al., 2020; Béné, C., 2020; Tello and de Molina, 2017; Gizicki-Neundlinger et al., 2017; Feagan, 2007). However, it was interesting to note that the literature pool for localization is contextually dominated by developed or industrial countries (Wilson, 2011; Allen, 2010; Feagan, 2007; Hinrichs, 2003; Morris and Buller, 2003; Winter, 2003). "Localization" research on or for developing countries or island states was difficult to find. For instance, research based on North American or European countries have explained the importance of localization in terms of reducing environmental impacts of conventional food systems, the ability to buy food from where it is produced to improve traceability of the food chain or prevent "commodity fetishization", etc. (Watts et al., 2005). Even with discussion on the "quality turn"/ "turn to quality" (a prominent concept in alternative food system literature) (Watts et al., 2005; Winter, 2003), focus is placed on organic foods, specialty local food products, etc.

While these are all important features of localization in their own right, they are somewhat distanced from the imminent food security frame of thinking that is required for SIDS. For instance, quality turn for islands would perhaps mean moving away from ultra-processed food that comprises of most imports and more towards fresh produce that meets nutritional adequacy. Equally important is the ability of people to purchase that quality of food and the stability of supply. Also, backyard gardens or kitchen gardens have traditionally been a major part of the local food provisioning system of the Caribbean SIDS (Campbell et al., 2021) and can perhaps be supported to enhance localization. A perspective that western/ industrialized case studies on localization often lack is that strengthening local food systems can strengthen rural communities. There are mentions of "family farms" as a farm structure. However, family farm structures differ in Caribbean SIDS. These themes of discussion more relevant to the island context are somewhat lacking from the current localization literature.

A more specific literature search for "self-sufficiency for food security" yielded relatively greater results for developing nations all over the world (Lombardozzi and Djanibekov, 2021; Soltani et al., 2020; Baer-Nawrocka and Sadowski, 2019; Clapp, 2017; Ghose, 2014; Luan et al., 2013; Simelton, 2011; Barkin, 1987; Mears, 1984; O'Hagan,1976). Kim et al. (2015) was one of the very few island food self-sufficiency studies available. This is not to say that differences in literature are rigidly dichotomous. But it does reflect the differences in food security/ food system challenges and nuances in the contexts thereof in different regions.

Localization is often considered to be inherently socially just and ecologically sustainable (Wilson, 2011; Morris and Buller, 2003). Much of the idea of localization remains only at the level of advocacy instead of empirical research into the extent and impact of local food initiatives, analysis of evidence or critique of localization. For islands it is even less. Nonetheless the CARICOM secretariat does recognize the merit of improving the resilience of domestic agricultural sector to address regional challenges of food security by enhancing diversity and quality of diets (Saint Ville et al., 2015). However, this has not been fully actualized as it requires a fundamental overhaul of current institutional practices (Saint Ville et al., 2015). The lack of evidence means that localization cannot be portrayed as a panacea (Morris and Buller, 2003). "Local-scale food systems are equally likely to be just or unjust, sustainable or unsustainable, secure or insecure." – thus context matters, and objectivity and critical analysis are imperetive (Wilson, 2011).

Scholars suggest a systems-based approach to studying food and agriculture (Hinrichs, 2003) and that applying concepts of localization can be beneficial to food systems research (Feagan, 2007). In order to remove the strictly dichotomous way in which global-local relationships are viewed a systems-based approach to studying food and agriculture can be useful to demonstrate the interconnectedness and interrelatedness that exists within the overall system (Hinrichs, 2003). Academic interest in alternative food provisioning systems is rising and to that end Watts and colleagues (2005) recommend that for alternative food provisioning it is important to discuss the extent to which they are present in the food system and the viability thereof (Watts et al., 2005). Emphasis on extent of localiation has been the focus of sections 4.5.2 and 4.6 of this research.

Studying the current state of food system localization from a social metabolism perspective has provided the opportunity to both critically and objectively assess localization as a potential solution instead of assuming its inherent benefits for islands. Understanding the social metabolism of a socio-ecological system through material and energy stocks and flows provides understanding of the ways in which a society has organized over time. The material and energy flows are simply the material manifestation of ideologies upheld by the society. Uncovering these flows aid in greater understanding of the ways in which the complex socio-ecological system comes into being in relation to its social, political and economic trajectories (Bogadóttir, 2020).

5.4 Efficacy of MFA for food security research

Indicators can be leverage points, their presence or absence and level of accuracy changing the behaviour of a system for better or worse. Changing indicators is one of the easiest ways to make system changes without altering physical structures, introducing new technology or enforcing regulations, which can be especially beneficial for developing countries (Meadows, 1998). Therefore, research and discourse towards improving indicators to keep up with the dynamic complex systems can be beneficial.

Interesting insights can be drawn from the interpretation of biomass flow indicators in relation to production and consumption dynamics. From a food security standpoint, the efficacy of DMC as an indicator seeks further analysis. As an example, the value of DMC of sugar crops in Barbados (Figure C), is not really the "apparent consumption" of the local population of Barbados but rather mostly constitutes the remnants of what was or is being exported outside the country (cf. Krausmann et al., 2014). Some studies have focused on Raw Material Equivalent or Raw Material Consumption (RMC) for this reason. However, the methodology is still not as standardized as it is for DMC (Kovanda, 2019).

MFA is known for its ability to provide macro-level assessment through its aggregate indicators. However, it also has the scope to provide more directed/focused assessment as can be seen in our assessment of the extent of localization that has taken place in the Caribbean islands (see section 5.2). This type of flexibility in maneuvering the focal system is useful when analyzing dynamic and responsive systems such as food systems of small islands. On the other hand, it highlights some drawbacks of using aggregate indicators/ aggregate values for biomass analysis in the island context, as the food system of islands is often dictated by single crops. For instance, in Dominica, fruit crop is the significant crop harvest (Figure C). However, disaggregating the indicator values further it can be seen that fruit crop is the major harvest mostly on account of banana crops. So, whether DE dictated by a single crop alludes to the same interpretation as fruit harvest increasing (from a food security standpoint) is something to be considered. The same is the case for Grenada where Soursop is a dominant crop (personal communication, 2021).

5.5 Post analysis reflections and new nexus

Regardless of the intraregional differences all island states share the common "experiential identity" known as "islandness" (Petridis et al., 2017; Selwyn, 1980). Discourse around island sustainability echoes its elusory nature (Baldacchino and Kelman, 2014) and disadvantageous position (Connell, 2018) especially in the global context. Localization, commonly described as an antithesis to globalization (Hinrichs, 2003), can be an opportunity for island communities to identify inefficiencies in the current systems and focus on increasing local food production to reduce dependence on imports (Nunn, 2016). Activists champion localization as "something done by people, not something done to them". (Hinrichs, 2003). This is relevant to the discussions of food security challenges faced by the Caribbean SIDS most of which are consequences of external forces. This brings to light the necessity of localization that has been described in the literature as "discriminating in favor of the local" (Hinrichs, 2003).

Going back to the third research question of this thesis "Could localization be a critical strategy for islands to move towards circular food systems". Considering the potential benefits (refer to section 5.2) it seems that localization could be one of the strategies worth exploring to promote circular food systems in the Caribbean islands. An additional consideration is that small islands experience shocks differently. As mentioned before, small islands are simultaneously both open and closed systems (Petridis et al., 2017). Their openness exposes them to multitude of exogenous shocks (Encontre, 1999). While their boundedness, isolation and size make them less able to respond to shocks. As stated by Baldacchino, "There are no cushions, no robust economic differentiation, no economies of scale, no physical, economic or psychological hinterland, to absorb any such shocks." (Baldacchino, 2014, para 5). An island's vulnerability to shocks has implications for its local food system and food security (also see section 1.2, para 7) as can be seen in the state of the Caribbean's domestic agriculture and risky external dependence. It is believed that revalorizing local food systems can enhance food security of islands that are heavily dependent on imported supply chains, high frequency of extreme weather events, climate change, and so on. The capacity of island food systems to meet domestic dietary requirements through localization is increasingly becoming a relevant area of research. (Marrero and Mattei, 2022). Although island societies today exhibit globalized consumption patterns there is still insistence among groups to revive the traditional emphasis on self-sufficiency and traditional practices for sustainable food production. Despite the declining trends in domestic production, agriculture is still an integral part of the Caribbean's identity. For instance, Timmers (2020) finds that Jamaica's domestic food system is still relevant in current times and a source of income for small-holder farmers who still utilize place-based agricultural techniques (Timmers, 2020).

However, localization as a potential solution for island food security is not without contestation. While forced economic development is said to be inappropriate for islands, scholars also do not support a romanticized version of localization. Move towards localization can have divisive motivation or implications often through "defensive localism" (Feagan, 2007). In certain contexts, localization can become elitist and exclusionary (Frankova and Johanisova, 2012). This can be disadvantageous for islands not only due to the lack of context specific research on food security but also because revalorization of local markets in developed regions can be detrimental to island exports sectors that rely on their demands (Baldacchino, 2014). A path towards localization of island food systems has to be treated with caution. It is important to understand how localization can co-exist in a place that is highly dependent on external resources (Timmers, 2020). The definition of local in localization has to be customized to fit the island context as some islands do not have the option to produce food locally due to constraints in resource availability, soil conditions, weather patterns, proneness to disasters, etc. For instance, it is suggested that a future increase of 1.5 °C will negatively impact agricultural productivity in Jamaica making even fewer crops available to local farmers. A localization paradigm for the Caribbean SIDS will have to take these uncertainties into account (Rhiney et al., 2018).

In that case, the definition or criteria of localization of island food systems can benefit from including the concept of regionalism and other place-based strategies. Studies suggest that the issue of food security should be handled regionally as opposed to nationally since different island states within a region have varying levels of resources, capacities, challenges, and vulnerabilities, all the while facing the same overarching issue (FAO, 2014). Through collaboration, to reform regional trade and production policies, diffuse knowledge of practices and technological innovations and allocating resources equitably the entire region can be benefitted (UN, 2015). Countries that have higher agricultural capacity can be a focal point for achieving food security in the region (Kendall and Petracco, 2009) through increasing its food production efficiency and by forming symbiotic multilateral trade regimes with neighbouring islands.

To that end, this type of “transformative” or “emancipatory” island studies that assesses localization objectively can be beneficial as they hold the virtue of unveiling various alternative possibilities for islands. They inspire multiple pathways that are realistic, contextualises sustainability action plans, are open to scrutiny and implies the importance of democratic choice for solving local issues (Petridis et al., 2017).

This study traced the socio-metabolic transition of island food systems over time. The result is the respective metabolic profiles of the chosen island cases demonstrating what the Caribbean food system looks like and how they have changed over time. As much as IE concepts and tools (such as social metabolism and tracking material flows) are useful for island research, the island context can be useful for IE as a field, since implementation of solutions are believed to be more feasible given their manageable boundary (Deschenes and Chertow, 2004). MFA as a methodological framework allows for replicability provided that data is available or becomes available in the future. This study can aid future research/can act as a blueprint for future research on other SIDS cases. Increasing number of MFA studies on a national scale can help towards providing more refined estimates of regional aggregation. So, this kind of approach is buildable. It is expected that insights gained from this research will trigger interest and catalyze further research in the region.

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Appendices

- Appendix A: This appendix (Table A) contains an inventory of commodities considered for each biomass category to calculate the MFA indicators. It also contains their sources and information on missing data.

- Appendix B: This appendix (Tables B, C, D, E, F and G) provides additional information (such as harvest factor, recovery rate, factor of moisture content, etc.) required in the calculation of MFA indicators.

- Appendix C: This appendix (Figures A, B and C) provides some additional figures presenting the DE, PTB and DMC of biomass that are disaggregated to demonstrate specific crop types. Underlying data for these figures are provided in Appendix F.

- Appendix D: This appendix provides underlying data in tabular form for Figures 2, 3, 4, 5 in the main text and Figures A, B, C in the appendix.

Appendix A: Inventory and missing data

Biomass category	Aggregate of	Based on	Data source	Missing data
Primary crop harvest	Cereal, roots and tubers, sugar crops, pulses, oil bearing crops, vegetables, fruits, fibers, other crops	EUROSTAT, 2018	FAOSTAT, 2020 (Production domain)	No data available for fiber crops of Dominica and Barbados at the time of collection.
Primary crop harvest of "other crops" (stimulants, beverage crops, spice crops, tobacco)	Anise, badian, fennel, coriander Chillies and peppers, dry Cinnamon Cloves Cocoa, beans Coffee, green Ginger Mate` Nutmeg, mace and cardamoms Pepper (piper spp.) Spices nes Tea Tobacco, unmanufactured Vanilla	EUROSTAT, 2018	FAOSTAT, 2020 (Production domain)	FAOSTAT did not have harvest data for "other crops" of Barbados. The aggregate values of primary crop harvest have been calculated excluding these crop types, in case of Dominica and Barbados.
Cultivars considered for the flow "Used crop residue"	Maize Rice paddy Sugar cane Cassava Potatoes Sweet potatoes Groundnuts in shells Coconut	(Okoli, 2016)	FAOSTAT, 2020 Production domain	
Livestock species considered for the flow "Demand for grazed biomass"	Cattle Sheep Goats Horses Asses Mules Pigs		FAOSTAT, 2020	

	Chickens			
Marketed feed	Bananas Brans Cassava and products Cereals, others cake Groundnut cake Maize and products Molasses Oilcrops, other Oilseed cakes, other Potatoes and products Rice and products Rice (Paddy equivalent) Roots and tubers dry equiv Sorghum and products Soyabean cake Millets Oats Wheat		FAOSTAT, 2020	Data unavailable from 2014-2019
Non-marketed feed	Coconut and cereal do not serve feeding purpose. Sugarcane – 30% Cassava Potato Sweet potato Groundnut in shell	Okoli, 2016	FAOSTAT, 2020	
Capture fisheries	<u>Barbados:</u> Albacore Atlantic sailfish Atlantic white marlin Bigeye tuna Blue marlin Carangids nei Common dolphinfish Flyingfishes nei Freshwater fishes nei Marine crustaceans nei		FISHSTATJ, 2020	Data for 2019 not available, average of past years taken.

Marine fishes nei
Marine molluscs nei
Marlins,sailfishes,etc. nei
Seerfishes nei
Sharks, rays, skates, etc. nei
Skipjack tuna
Snappers, jobfishes nei
Stromboid conchs nei
Swordfish
Tuna-like fishes nei
Wahoo
Yellowfin tuna

<u>Dominica:</u>
Atlantic bonito
Atlantic sailfish
Bigeye tuna
Blackfin tuna
Blue marlin
Common dolphinfish
Freshwater fishes nei
King mackerel
Longbill spearfish
Marine fishes nei
Skipjack tuna
Swordfish
Tuna-like fishes nei
Wahoo
Yellowfin tuna

<u>Grenada:</u>
Albacore
Atlantic Spanish mackerel
Atlantic bonito
Atlantic moonfish
Atlantic sailfish
Atlantic thread herring
Atlantic white marlin
Barracudas nei
Bigeye scad
Bigeye tuna
Blackfin tuna

Blue marlin
Brazilian sardinella
Broad-striped anchovy
Carangids nei
Caribbean spiny lobster
Common dolphinfish
Coney
Flyingfishes nei
Freshwater fishes nei
Frigate and bullet tunas
Goatfishes, red mullets nei
Green turtle
Groupers, seabasses nei
Grunts, sweetlips nei
Halfbeaks nei
King mackerel
Little tunny(=Atl.black skipj)
Marine fishes nei
Needlefishes, etc. nei
Parrotfishes nei
Rainbow runner
Red hind
Sand tilefish
Scads nei
Scaled sardines
Sea urchins nei
Serra Spanish mackerel
Sharks, rays, skates, etc. nei
Skipjack tuna
Snappers, jobfishes nei
Snooks(=Robalos) nei
Squirrelfishes nei
Stromboid conchs nei
Surgeonfishes nei
Swordfish
Triggerfishes, durgons nei
Various squids nei
Wahoo
Yellowfin tuna

	<u>Jamaica:</u> Caribbean spiny lobster Freshwater fishes nei Marine crabs nei Marine fishes nei Nile tilapia Penaeus shrimps nei Stromboid conchs nei Tuna-like fishes nei	
Import Crop commodities	<u>Cereals:</u> Barley Beer of Barley Maize Bran Maize flour Wheat Bran Bread Buckwheat Canary Seed Cereal Prep nes Cereals, Breakfast Cereal, flour Mized grain flour Rice flour Wheat flour Food prep, flour, malt extract Fructose and syrup Glucose and dextrose Mixed grain Macaroni Maize Malt Millet Mixes and doughs Oats Oats rolled Maize oil Pastry Quinoa Rice, broken Rice, husked Rice, milled Rice, milled/husked Rice, paddy	FAOSTAT, 2020a; FAO, 2021a

Rye
Sorghum
Straw husks
Wafers
Wheat

Roots and tubers:
Cassava, dried
Cassava, starch
Potatoes
Potatoes flour
Potatoes, frozen
Roots and tubers nes, flour
Roots and tubers nes
Sweet potatoes

Sugar crops:
Beet pulp
Fructose and syrup
Glucose and dextrose
Honey, natural
Lactose
Maple sugar and syrups
Molasses
Sugar confectionery
Sugar raw centrifugal
Sugar refined

Pulses:
Beans, dry
Broad beans, horse beans, dry
Chickpeas
Pulses, flour
Lentils
Peas, dry

Oil crops:
Coconuts
Coconuts, desiccated
Copra
Cottonseed
Mustard, flour

Groundnuts, shelled
Groundnuts, prepared
Karite nuts (sheanuts)
Linseed
Margarine, liquid
Mustard seed
Oil, boiled etc
Castor bean, oil
Coconut, oil
Cottonseed, oil
Groundnut, oil
Linseed, oil
Olive, oil, virgin
Palm, oil
Palm kernel, oil
Rapeseed, oil
Sesame, oil
Soybean, oil
Sunflower, oil
Vegetable origin nes, oil
Oilseeds nes
Olives
Olives preserved
Peanut butter
Poppy seed
Sesame seed
Soya sauce
Soybeans
Sunflower seed

<u>Vegetables:</u>
Artichokes
Asparagus
Beans, green
Broad beans, horse beans, dry
Cabbages and other brassicas
Carrots and turnips
Cauliflowers and broccoli
Chillies and peppers, green
Cucumbers and gherkins
Eggplants

Garlic
Tomato, juice
Leeks, other alliaceous vegetables
Lettuce and chicory
Melons, other (inc. cantaloupes)
Mushrooms and truffles
Mushrooms, canned
Onions, dry
Onions, shallots, green
Peas, green
Pumpkins, squash and gourds
Spinach
Sweet corn frozen
Sweet cron prep and preserved
Tomatoes
Tomatoes, paste
Tomatoes, peeled
Vegetables in vinegar
Vegetables, dehydrated
Vegetables, fresh nes
Vegetables, frozen
Vegetables, homogenized
Vegetables, preserved, nes
Vegetables, preserved, frozen
Vegetables, temporarily preserved
Watermelons

Fruits:
Apples
Apricots
Apricots, dry
Avocados
Bananas
Blueberries
Cherries
Cherries, sour
Cider etc

Currants
Dates
Figs
Figs dried
Fruit, cooked,
homogenized
preparations
Fruit, dried nes
Fruit, fresh nes
Fruit, prepared nes
Fruit, tropical fresh nes
Grapes
Juice, apple, concentrated
Juice, apple, single
strength
Juice, citrus, concentrated
Juice, citrus, single
strength
Juice, fruit nes
Juice, grape
Juice, grapefruit
Juice, grapefruit,
concentrated
Juice, lemon,
concentrated
Juice, lemon, single
strength
Juice, orange,
concentrated
Juice, orange, single
strength
Juice, pineapple
Juice, pineapple,
concentrated
Kiwi fruit
Lemons and limes
Mangoes, mangosteens,
guavas
Oranges
Papayas
Peaches and nectarines
Pears
Persimmons
Pineapples

Pineapples canned
Plantains and others
Plums and sloes
Plums dried (prunes)
Raisins
Strawberries
Tangerines, mandarins, clementines, satsumas
Vermouths & similar

Nuts:

Almonds shelled
Almonds, with shell
Areca nuts
Brazil nuts, shelled
Cashew nuts, shelled
Cashew nuts, with shell
Chestnut
Hazelnuts, shelled
Hazelnuts, with shell
Kola nuts
Nuts, prepared (exc. Groundnuts)
Pistachios
Walnuts, shelled
Walnuts, with shell

Others:

Anise, badian, fennel, coriander
Chillies and peppers, dry
Cinnamon
Cloves
Cocoa, beans
Coffee, green
Ginger
Mate`
Nutmeg, mace and cardamoms
Pepper (piper spp.)
Spices nes
Tea
Tobacco, unmanufactured

	Vanilla	
Import livestock commodities	<u>Meat, meat products and offal:</u> Bacon and ham Meat nes Meat, beef and veal sausages Meat, beef, preparations Meat, cattle Meat, cattle, boneless (beef & veal) Meat, chicken Meat, chicken, canned Meat, dried nes Meat duck Meat, game Meat, goat Meat, goose and guinea fowl Meat, horse Meat, pig Meat, pig sausage Meat, pig, preparations Meat, pork Meat, sheep Meat, turkey Offals, edible, cattle Offals, liver duck Offal, liver geese Offals, pigs, edible Offals, sheep, edible <u>Animal fat:</u> Fat, cattle Fat, pig Lard Oils, fat of animals nes Tallow <u>Dairy:</u> Butter, cow milk Buttermilk, curdled, acidified milk	FAOSTAT, 2020a; FAO, 2021a

	Cheese, processed Cheese, whole cow milk Cream fresh Ice cream and edible ice Lactose Milk, products of natural constituents nes Milk, skimmed cow Milk, skimmed dried Milk, whole condensed Milk, whole dried Milk, whole evaporated Milk, whole fresh cow Whey, condensed Whey, dry Yogurt, concentrated or not <u>Eggs:</u> Eggs, dried Eggs, hen in shell Eggs, liquid Eggs, other birds in shell Honey and other livestock products: Beeswax Fatty substance residues Food prep nes Honey, natural	
Import feed commodities	Alfalfa meal and pellets Beet pulp Cake, groundnuts Cake, soybeans Feed and meal, gluten Feed, compound nes Feed, vegetable products nes Flax tow waste Food waste Forage products Meal, meat Olive resiudes, oil Straw husks	FAOSTAT, 2020a; FAO, 2021a

Import fish commodities	Aquatic animals nei Cephalopods Crustaceans Demersal fish Freshwater & diadromous fish Marine fish nei Molluscs excl. cephalopods Pelagic fish	FAOSTAT, 2020
Export Commodities	Same as import commodities	FAOSTAT, 2020a; FAO, 2021a

Table A: Commodities considered in calculation of each biomass category of MFA indicators

Appendix B: Additional information for calculation of biomass categories of MFA indicators

Item	Harvest factor
Maize	3
Rice paddy	1.2
Sugar cane	0.7
Cassava	0.8
Potatoes	1
Sweet potatoes	1
Groundnuts in shell	1.5
Coconut	2.3

Table B: Harvest factor of cultivar species. Source: Krausmann et al., 2018

Item	Recovery rate
Maize	0.8
Rice paddy	0.8
Sugar cane	0.8
Cassava	0.9
Potatoes	0.75
Sweet potatoes	0.75
Groundnuts in shell	0.75
Coconut	0.8

Table C: Recovery rate of cultivar species. Source: Krausmann et al., 2018

Item	Energy content of biomass (GJ/tonne)	Global average fresh weight factors	Global average water content	Global average water content (%)	Factor of moisture content (15%)
Cereal	18.3	15.8	0.139	14	1.013
Roots and tubers	16.3	4.2	0.740	74	0.306
Sugar crops	16.0	2.9	0.816	82	0.217
Pulses	20.0	17.9	0.107	11	1.051
Nuts	25.0	23.7	0.050	5	1.117
Oil bearing crops	25.0	18.1	0.277	28	0.851
Vegetables	18.5	1.5	0.916	92	0.098
Fruits	20.0	3.8	0.811	81	0.223
Fibers	19.5	17.5	0.101	10	1.057
Spices	19.0	8.0	0.580	58	0.494
Other crops	19.0	14.5	0.238	24	0.897
Fodder crops	18.5	3.6	0.805	81	0.229

Table D: Calculation of factor of moisture content (15%) of primary crop types. Source: Singh et al., 2010.

Air dry weight at 15% mc	Factor mc (15%)
Maize	1.013
Rice paddy	1.013
Sugar cane	0.217
Cassava	0.306
Potatoes	0.306
Sweet potatoes	0.306
Groundnuts in shell	1.117
Coconut	0.851

Table E: Factor of moisture content (15%) of cultivar species considered for the biomass category "used crop residue"

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

Table F: Annual feed intake at 15% moisture content (mc) of livestock species.
Source: Krausmann et al., 2008.

Livestock species	LU cofficients for the Caribbean region
Cattle	0.6
Sheep	0.1
Goats	0.1
Horses	0.65
Asses	0.5
Mules	0.6
Pigs	0.2
Chickens	0.01

Table G: Livestock unit coefficients for calculation of Large Animal Unit (LAU). Source: FAO, 2011.

Appendix C: Additional figures

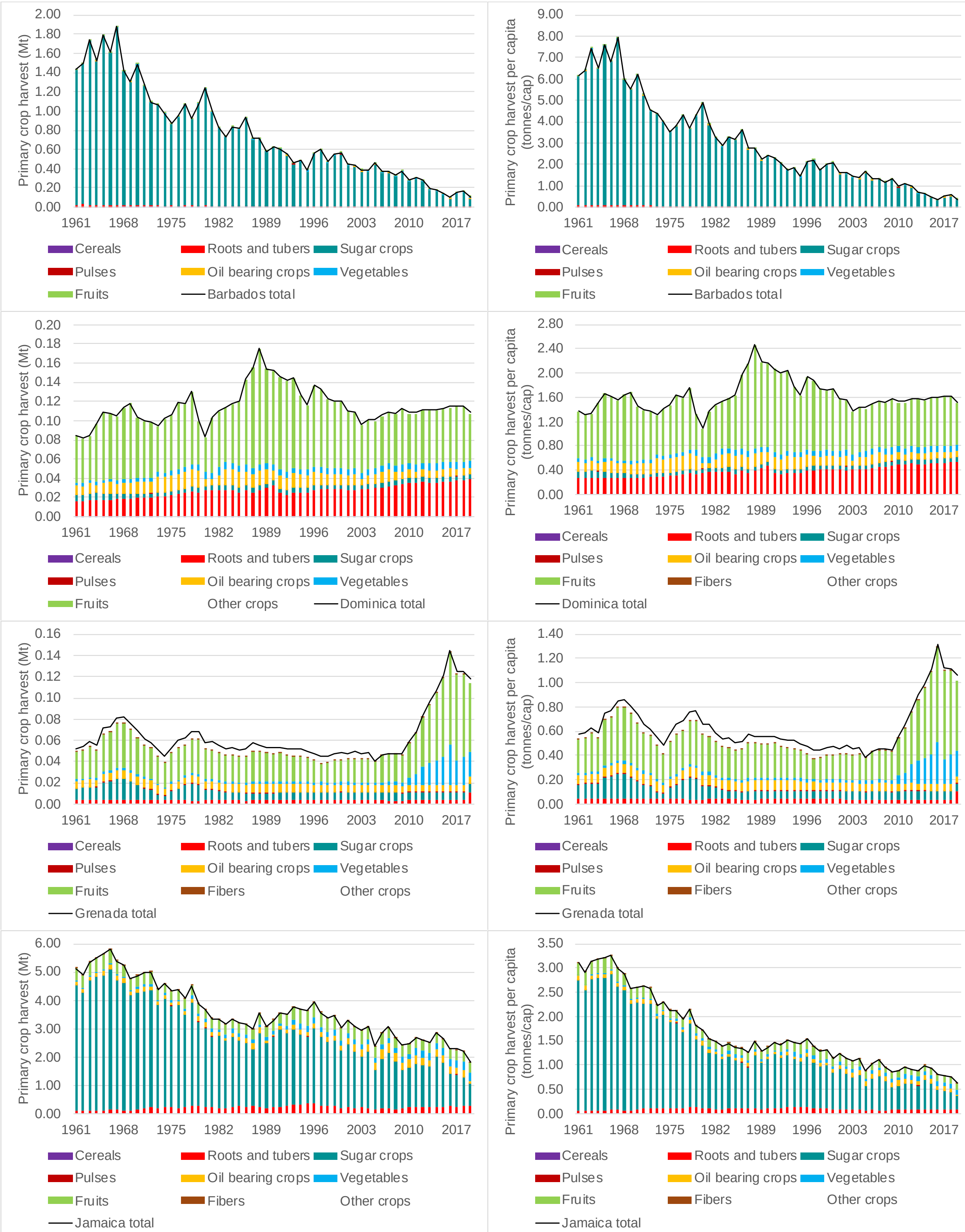

Fig A: Domestic extraction of biomass of crops/ Primary crop harvest of four islands in absolute (left) and per capita (right) values from 1961 to 2019. Underlying data for Figure A are available in Appendix E.

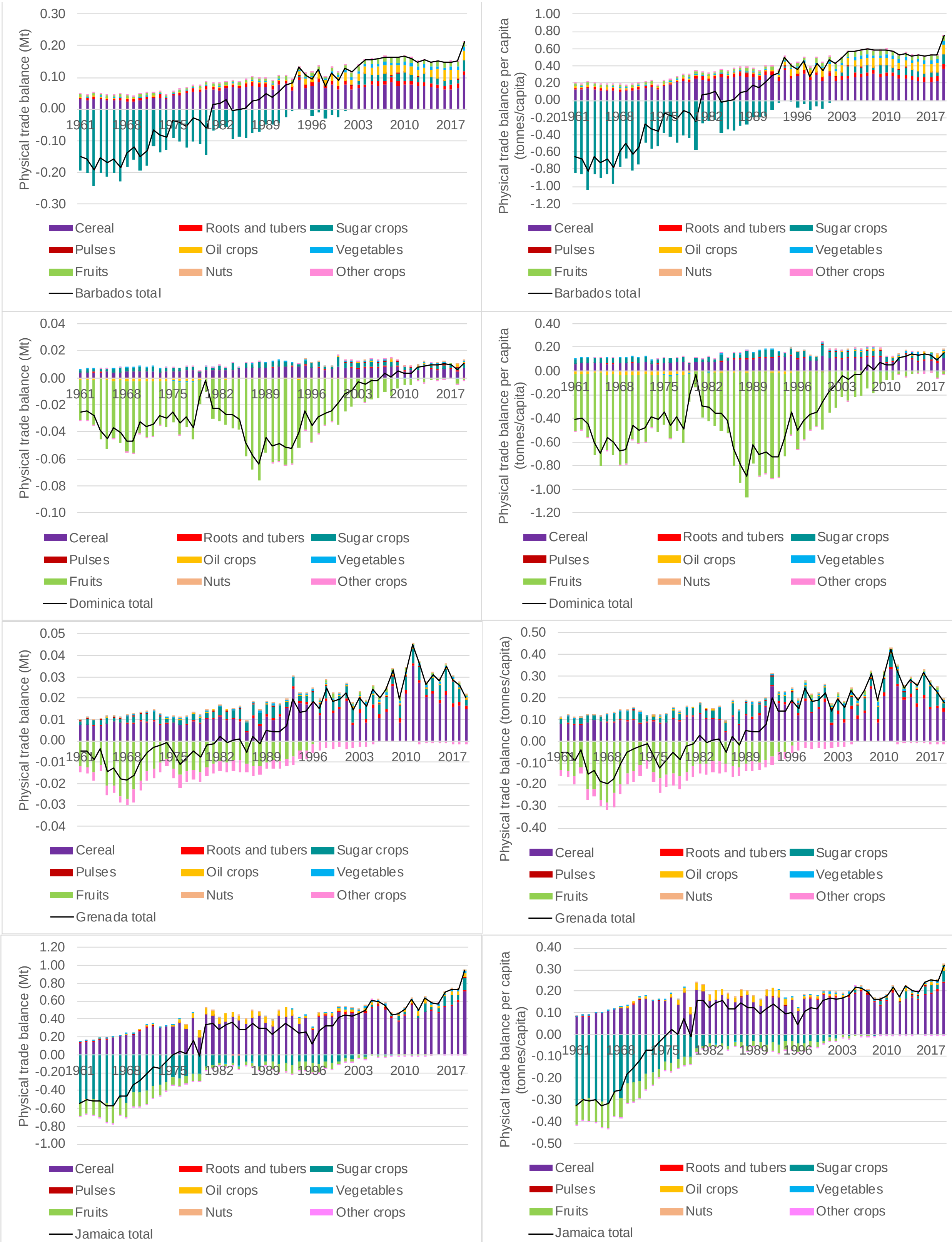

Fig B: Physical trade balance of biomass of crops of four islands in absolute (left) and per capita (right) values from 1961 to 2019. Underlying data for Figure B are available in Appendix E.

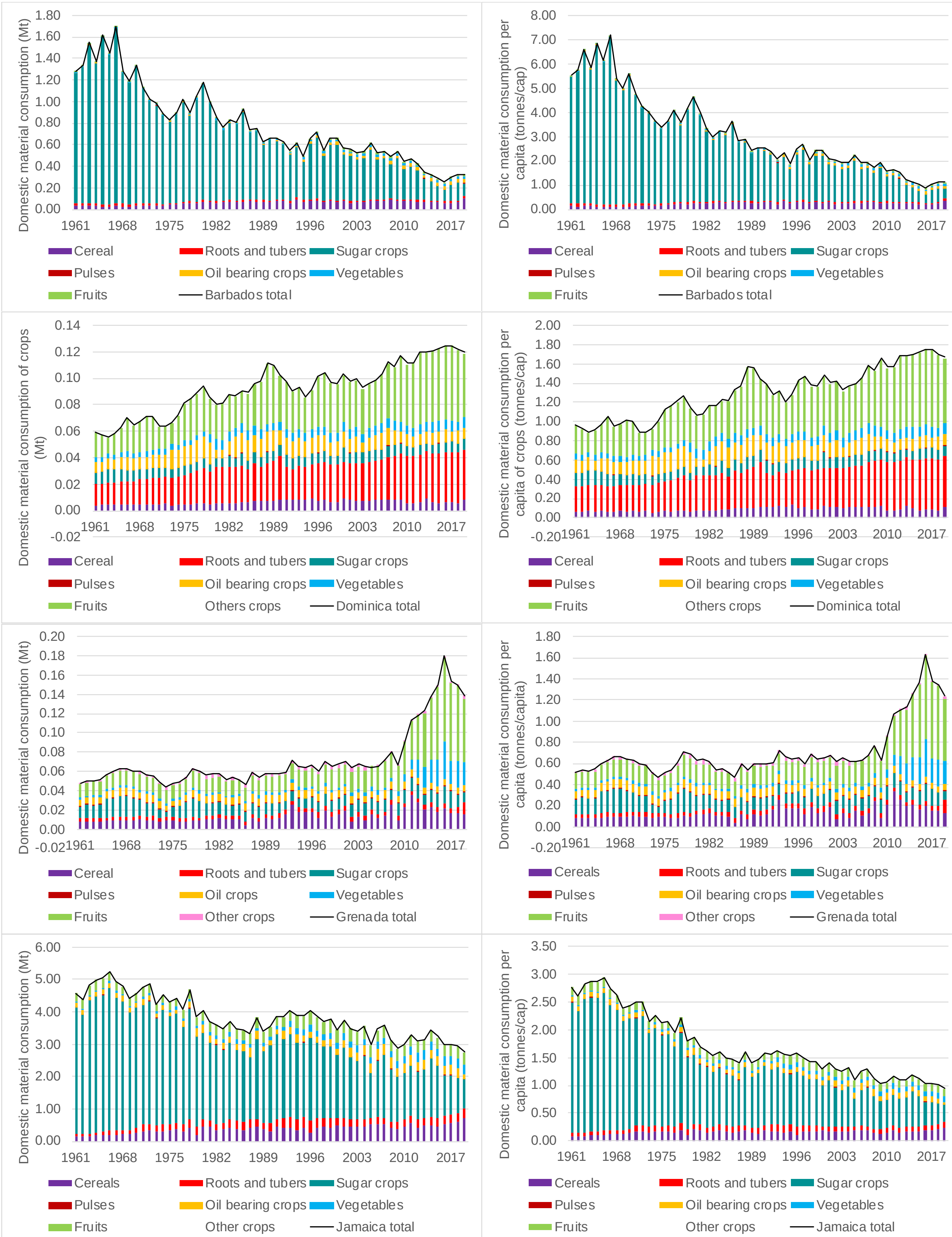

Figure C: Domestic material consumption of biomass of crops of four islands in absolute (left) and per capita (right) values from 1961 to 2019. Underlying data for Figure C are available in Appendix E.

Appendix D: Underlying data for figures

The underlying data for the figures in the main text (Figures 2, 3, 4, 5) and Appendix C (Figures A, B, C) of this thesis can be found through the link provided below:

https://onlinelibrary.wiley.com/action/downloadSupplement?doi=10.1111%2Fjiec.13241&file=jiec13241-sup-0005-SuppMat.xlsx

This link is from the supporting information of the article:

Rahman, S., Singh, S. & McCordic, C. (2022.) Can the Caribbean localize its food system? Evidence from biomass flow accounting. *Journal of Industrial Ecology.* Advance online publication. DOI: 10.1111/jiec.13241

The key to navigate the excel file:

- **Data_Fig 1:** This spreadsheet provides data for **Figure 2** in the main text of the thesis demonstrating: annual aggregate flows of domestic extraction, domestic material consumption and physical trade balance of Barbados in absolute values in Megatonnes (left) and per capita values in tonnes/cap (right) over a span of 59 years.
- **Data_Fig 2:** The spreadsheet provides data for **Figure 3** in the main text of this thesis demonstrating: annual aggregate flows of domestic extraction, domestic material consumption and physical trade balance of Dominica in absolute values in Megatonnes (left) and per capita values in tonnes/cap (right) over a span of 59 years.
- **Data_Fig 3:** The spreadsheet provides data for **Figure 4** in the main text of this thesis demonstrating: annual aggregate flows of domestic extraction, domestic material consumption and physical trade balance of Grenada in absolute values in Megatonnes (left) and per capita values in tonnes/cap (right) over a span of 59 years.
- **Data_Fig 4:** The spreadsheet provides data for **Figure 5** in the main text of this thesis demonstrating: annual aggregate flows of domestic extraction, domestic material consumption and physical trade balance of Jamaica in absolute values in Megatonnes (left) and per capita values in tonnes/cap (right) over a span of 59 years.
- **Data_Fig S1:** The spreadsheet provides data for **Figure A** in Appendix C of this thesis demonstrating: domestic extraction of biomass of crops/ Primary crop harvest of four islands in absolute (left) and per capita (right) values from 1961 to 2019.
- **Data_Fig S2:** The spreadsheet provides data for **Figure B** in Appendix C of this thesis demonstrating: physical trade balance of biomass of crops of four islands in absolute (left) and per capita (right) values from 1961 to 2019.
- **Data_Fig S3:** The spreadsheet provides data for **Figure C** in Appendix C of this thesis demonstrating: domestic material consumption of biomass of crops of four islands in absolute (left) and per capita (right) values from 1961 to 2019.