(TMG)
ThinkTank for Sustainability
Töpfer Müller Gaßner

TRUE COST ACCOUNTING AND DIETARY PATTERNS:

AN OPPORTUNITY FOR COHERENT FOOD SYSTEM POLICY

FULL VERSION

ABOUT

WWF – the World Wide Fund for Nature is implementing a programme on Sustainable Consumption and Production (SCP) in the agri-food sector, funded through the International Climate Initiative (IKI) of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU). In Thailand, Indonesia, Philippines, Colombia and Paraguay, WWF is developing solutions towards sustainable food systems tailored to their own national contexts, whilst advocating systemic policy changes at global level.

To this end, TMG – Töpfer, Müller, Gaßner GmbH was commissioned to carry out an analysis of the true costs of sustainable and healthy food and develop a concept on how this tool (True Cost Accounting, TCA) can be argued for – and what political asks can be phrased from it – starting from the vantage point of sustainable diets.

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LIST OF ACRONYMS

COVID-19	Coronavirus Disease 2019
BMI	Body Mass Index
BMU	German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
BPA	Bisphenol A
BPF	Bisphenol F
BPS	Bisphenol S
CFC	Chlorofluorocarbons
EDC	Endocrine Disrupting Chemicals
EU	European Union
FAO	Food and Agriculture Organization of the UN
FCA	Full-cost Accounting
FReSH	Food Reform for Sustainability and Health
GDP	Gross Domestic Product
GEPAMA-UBA-Argentina	Grupo de Ecología del Paisaje y Medio Ambiente de la Universidad de Buenos Aires, Argentina
GHG	Greenhouse Gases
GMO	Genetically Modified Organisms
GPI	Genuine Progress Indicator
IKI	International Climate Initiative
IPBES	Intergovernmental Platform on Biodiversity and Ecosystem Services
NCP	Natural Capital Protocol
OECD	Organisation for Economic Co-operation and Development
SAFA	Sustainability Assessment of Food and Agriculture
SCAR	Standing Committee on Agricultural Research
SDGs	Sustainable Development Goals
SHCP	Social and Human Capital Protocol
SNAP	Supplemental Nutrition Assistance Program
SSB	Sugar-sweetened beverages
TCA	True Cost Accounting
TEEB	The Economics of Ecosystems and Biodiversity
TEEBAgriFood	The Economics of Ecosystems and Biodiversity for Agriculture and Food programme
TMG	Töpfer, Müller, Gaßner GmbH
UK	United Kingdom
UN	United Nations
UNEP	United Nations Environment Programme
UPD	Ultra-processed drinks
UPF	Ultra-processed foods
US	United States
WAVES	Wealth Accounting and the Valuation of Ecosystem Services
WHO	World Health Organization
WRI	World Resources Institute
WWF	World Wide Fund for Nature

FOREWORD

Everything has a price. But does the price of food represent its true value? Not really. The true value of food can only be understood when we take into account all of the various impacts of its production and consumption - including on natural resources, on livelihoods and on public health. All these impacts are costly to nature, climate and people, but are generally not accounted for in the price of food.

Globally, all food consumed has a market value of USD9 trillion, but external costs to the environment and society, for instance through healthcare, are estimated to be nearly double, at USD19.8 trillion. This means that food is roughly a third of the cost it would be if these externalities were included in food prices. External costs are made up of USD7 trillion in environmental costs, USD11 trillion in costs to human life and USD1 trillion in economic costs.

The price of food needs to incorporate the sum of all costs, including those associated with nature, climate and people. Not including these costs directly contributes to the climate and nature crises, and makes it difficult to achieve food and nutrition security. Implementing True Cost Accounting will be an important step in ensuring that we have healthy, sustainable and inclusive food systems.

Food producers must be rewarded for adopting nature-positive practices and consumers must have access to affordable food that is both healthy and sustainably produced. This paper highlights the vital role of adopting True Cost Accounting and explores a novel way of implementing it - starting from the end point of the healthy and sustainable diets that people could be eating, and finding ways to incentivise their delivery, rather than beginning with the impacts of certain food production systems.

It will only be possible to deliver nature-positive food systems with net-zero emissions, and nourish everyone with healthy and nutritious diets within planetary boundaries if we change how food is valued. The information in this paper will support us in working alongside governments to deliver policies and the private sector to create pricing structures that reflect the true value of the food we produce and consume. This paper will also challenge us to think about ways of including those who go hungry each day (811 million in 2020), none of whom can afford food even at current prices. A whole-of-society approach needs to be considered when aligning the true value of food to food prices.

We look forward to working with partners across food systems to achieve this shift and build just and equitable futures that are good for people and planet.

Joao Campari
Global Food Practice Leader, WWF

KEY MESSAGES

1. For the first time, this report presents how True Cost Accounting (TCA) can be used as a tool to assess and develop dietary policy in an innovative and systematic way. It can be used at various levels of governance of the food system to work towards human health, environmental sustainability and socially just food consumption.

2. TCA seeks to contribute to an increase in healthy and at the same time environmentally sound diets, ensuring that no part of the food system exceeds the nine planetary boundaries nor fails to meet the United Nations (UN) Human Rights goals (and thus helping to achieve the SDGs).

3. TCA can be used to analyse production and supply chain practices within different dietary patterns becoming the basis for food system-related policy action. The starting point of TCA is the analysis of existing, predominant dietary patterns and the associated hidden positive and negative aspects along entire food value chains.

4. TCA unveils externalities – the impacts of the food system that are not inherent to the listed price of the food at the point of purchase – and provides an approach to analysing the real costs of those externalized impacts.

5. The Economics of Ecosystems and Biodiversity for Agriculture and Food programme (TEEBAgriFood) systems approach provides a framework for TCA to capture the hidden positive and negative externalities along entire agri-food value chains. TEEBAgriFood takes into account natural, human, produced and social capital.

6. The idea of putting sustainable consumption at the centre of a TCA will guide the analysis and open new opportunities for policies transforming the whole food system.

7. TCA can be applied to the wide range of processing and distribution pathways and to all types of production systems and all points-of-consumption. For policymakers and practitioners alike two essential tools for TCA implementation are outlined in this report: the design of a framework and required data for a TCA analysis of diets.

8. The availability and systematic collection of data for the assessment of diets is in its infancy and needs further development. Because of very limited data availability on externalities, public-sector funded research and analysis are required to understand the full picture of food consumption and production effects.

9. The complexity of the challenge and the multitude of entry points to change food systems require coordinated public and private sector policies. TCA provides a framework for inclusive participation mechanisms and multi-stakeholder platforms, including food policy councils at various geo-political levels.

10. A TCA analysis starting with dietary patterns, assessing and valuing the entire agri-food system, and identifying real but economically invisible externalities, has the potential to provide unique support to a breakthrough in food system policies. Based on the framework further steps towards implementation must be developed.

INTRODUCTION

EXECUTIVE SUMMARY

This report has a clear value proposition: the goal of True Cost Accounting (TCA) is to support the development of policies that aim to ensure that the global population can access and consume a sustainable, socially inclusive diet on a daily basis and that food and nutrition security for all becomes a reality – while not exceeding the nine planetary boundaries nor failing to meet the UN Human Rights goals. TCA is a tool for analysing diets, supply chains, production strategies, business strategies, governance and public policy.

On average, to date global dietary patterns demonstrate relatively low consumption of fruits, vegetables, plant-based proteins and whole grains with high consumption of added sugars, salt and meat. It is clear from existing science that dietary patterns, looked at as a global average, need to change. But a global average tells little about pattern changes needed in individual countries. In some countries, there is a need for significant increases across a range of foods, including animal products, and the need to eliminate various micronutrient and macronutrient deficiencies. In others, the opposite is needed – a general decrease in caloric consumption and that of specific food categories, especially animal products.

These very general dietary statements, however, will have little information on the environmental sustainability or social justice/welfare aspects associated with specific dietary patterns. The environmental and social "costs" associated with food consumption and production are neither calculated nor captured, and they are thus not mirrored in food prices either. A "true cost of food" analysis can be a powerful tool for decision-making by addressing the most harmful practices of today, and illustrating new, positive pathways forward.

Both, the need for transforming food systems and the opportunities in this are huge. Sustainable consumption and production have been on the agenda of national and international meetings for quite some time now, but progress has been limited so far. Agricultural policies and food security/ food and nutrition policies are often made in isolation. This is no longer feasible. To achieve the objectives of sustainable development, environmental and climate goals, a dramatic policy reform is needed – one in which policy focuses on a deliberate end goal and moves backwards along a range of policy threads. This report presents for the first time how TCA can be used as an innovative and systematic tool to asses and develop dietary policy.

TCA can be used to develop environmentally sustainable and socially just food system policies. It brings to light all positive and negative externalities – impacts of the food system that are not part to the listed price of food at the point of purchase – and provides an approach for analysing the costs of those externalized impacts.

Utilizing the four capitals (natural, human, produced and social capital), TCA can be used to backtrack impacts along the supply chain to understand the external costs; the circularity or non-circularity of resources; and possible strategies for planetary health. TCA can also be used to identify externalized costs of human welfare, rights and security. It allows identification of what needs changing in order to deliver nutritious, socially just and environmentally sustainable food systems.

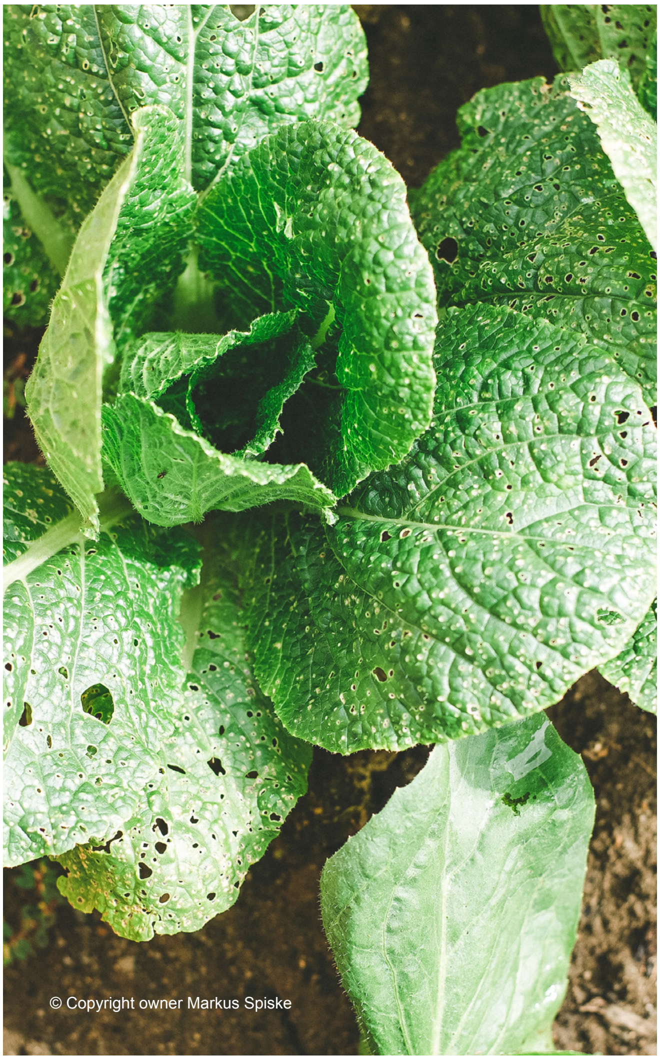
The complexity of the challenge and the multitude of entry points to change food systems requires coordinated public and private sector policies. Creating an enabling environment for a rapid and fundamental movement towards the goal of healthy and sustainable dietary patterns can be guided by applying a TCA. And TCA can provide a framework for inclusive participation mechanisms and multi-stakeholder platforms, including food policy councils at various geo-political levels. It can trigger a new momentum for overcoming the limitations of traditional policies.

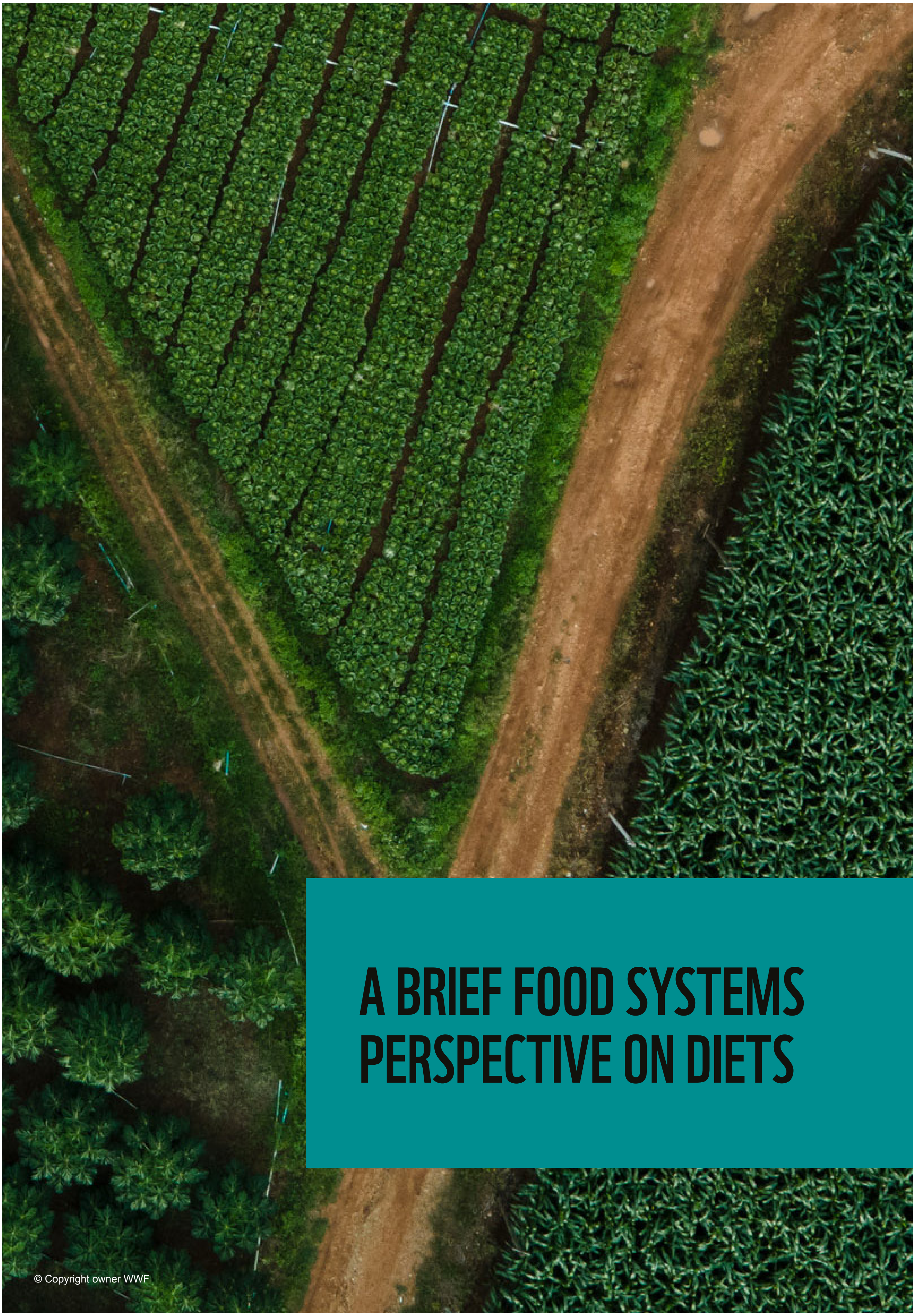
This report is structured to first provide a systems' perspective on human diets and then proceeds to outline positive and negative aspects of diets across food supply chains with respect to the four capitals based on the TEEBAgriFood Evaluation Framework. These are approached briefly in the main report and explored more extensively in an **Annex II.**

The use of the TCA approach as a tool for assessment and decision-making at various levels is explored, followed by a brief overview of existing TCA methodologies for analysing and comparing different dietary patterns as well as recognizing the nuances embedded within them. Guidance is provided for designing a TCA dietary pattern analysis including the necessary steps, data requirements and challenges.

The report outlines six phases for the analysis (frame, describe and scope, collect data and measure, predict and analyse, monetize/value and develop policy action). The report then provides ideas for translating TCA analysis into policy decisions and actions.

Finally, the report suggests a rationale, strategies and opportunities for policy development at various levels of governance, to shape dietary patterns in such a way that both environmental sustainability and social/ human right goals are realized. Achieving this requires the TCA tool to identify the best pathways for transformation, and to trigger an increase in know-how of and an understanding for sustainability/ human right paradigms.





A BRIEF FOOD SYSTEMS PERSPECTIVE ON DIETS

TCA AND DIETARY PATTERNS

THE STARTING POINT

While there is a strong theoretical framework for conducting a TCA analysis, it has not been done with dietary patterns as the starting point. Here, a systems perspective on human diets is examined, including trends in food consumption and dietary patterns as well as examples of sustainable and healthy diets. These serious facts command us to start our analysis with dietary patterns as the starting point:

- High footprint dietary patterns, if globalized, would pose a serious issue as the land requirements to produce those dietary patterns are unavailable on Earth.
- A large part of the world population consumes excess calories leading to overweight and obesity – with an estimated 2.1 billion people being obese.
- The minimum costs of a healthy diet are approximately double the global poverty level income – with estimates of 3 billion people unable to afford this.
- Within a country there is often a wide variation of dietary patterns[6] – with some being much more environmentally sustainable than others, in part depending on production practices.
- A large percentage of the population is either underfed and/or undernourished – in 2020, up to 811 million people faced hunger.[1]
- In general, people need to consume more fruits and vegetables, whole grains and plant-based protein while consuming fewer total calories, added sugar and added salt.

There is a wide array of externalities both negative (e.g. water contamination, greenhouse gas (GHG) release, low worker wages) and positive (e.g. carbon sequestration in some production systems) connected to dietary patterns that are not embedded in the pricing of our food. Externalities can be higher or lower depending on the production and supply chain practices for different components of the dietary pattern. A TCA framework examines these negative and positive externalities through the lens of four capitals: natural, human, produced and social capital. (Figure 1)

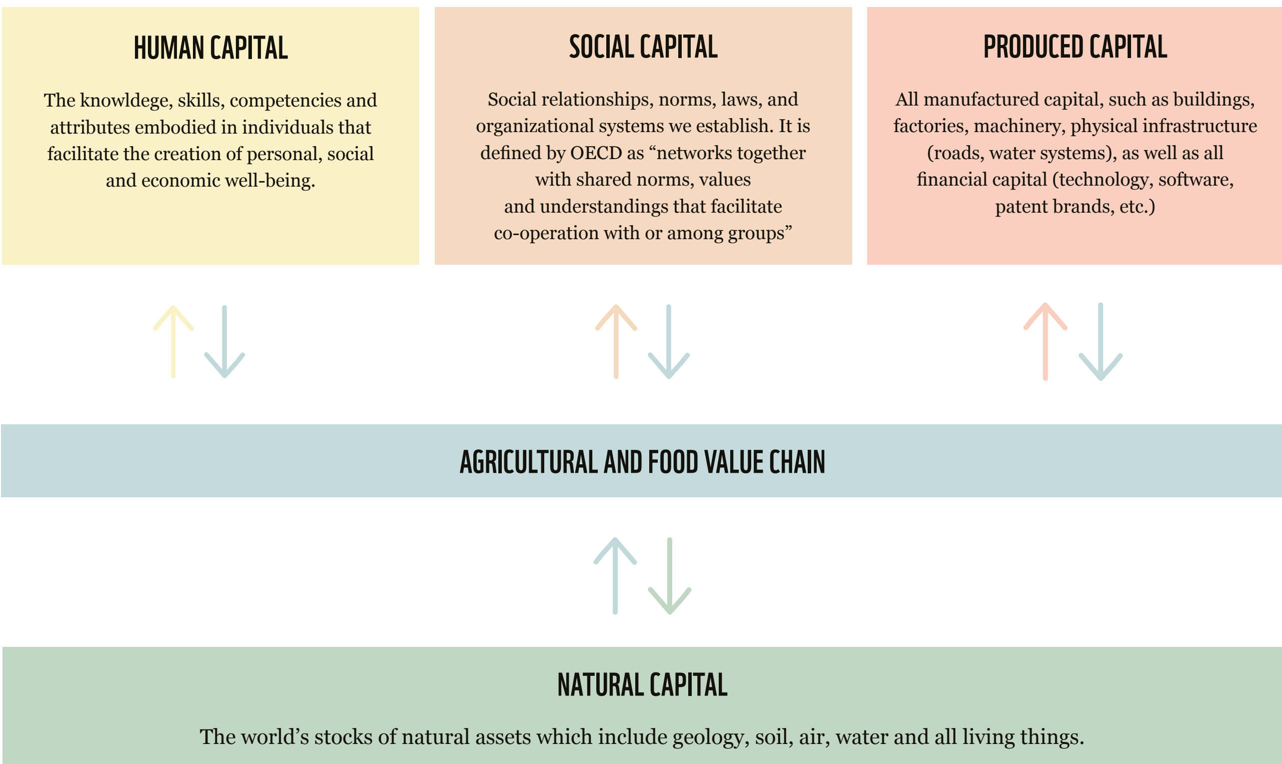


Figure 1: Natural, social, human and produced capital. TMG – Think Tank for Sustainability (2021).

[1]https://www.fao.org/publications/sofi/2021/en/

In a food system context, natural capital is the base for food production; human capital holds the knowledge and skills to use resources wisely and at the same time generate produced capital; social capital provides the structures and guidelines for the different components to work together in a global food system, with the potential for enhanced human health and environmental sustainability. All of these should be considered while examining dietary patterns and staying within a safe operating space.

Natural capital can be defined as "the world's stocks of natural assets which include geology, soil, air, water and all living things" (World Forum on Natural Capital, 2017). It is from the natural capital that a range of ecosystem services are derived (The Secretariat of the Convention on Biological Diversity, 2008). In the context of food these include provisioning services such as the genetic resources that form a basis for our food supply, food itself and fresh water; regulating services such as pollination and pest predators; supporting services such as water retention capacity in soil; and cultural services that include the aesthetic, cultural and spiritual values embedded in food and food provisioning.

Human capital includes human health, education, skills, various types of knowledge and is defined as "the knowledge, skills, competencies and attributes embodied in individuals that facilitate the creation of personal, social and economic well-being" (OECD, 2001; TEEB, 2018b). This is often measured by determining how much is invested in areas such as education and health care across countries. In this instance, human health and food security will be considered within this 'bucket'. Health is impacted in many ways including toxic chemical residues on/in food as well as production and processing exposure, fertilizer contamination in air and water supplies, work related injuries, antibiotic-resistant bacterial exposure and contaminated food and worker food insecurity through low wages. Food security, which has four dimensions: availability, access, utilization and stability[2], is also a component of human capital. All four dimensions must be present for a person, household or nation to consider itself food secure.

Produced capital includes farm equipment, community centres, food processing equipment, energy, fuel, fertilizers, pesticides, packaging, processing chemicals, etc. Moving towards sustainable and healthy dietary patterns for the global population has many implications for produced capital. As an example: in part, the food system has a high environmental cost because of food waste – while if perfectly distributed, there are enough fruits and vegetables produced for the global population to consume in a healthy amount; it is estimated that 42% of them are wasted (Lipinski et al., 2013). Harvest and post-harvest technology to reduce waste is variably available depending on scale and supply chains. There are a number of other developments in digitalization, precision agriculture and artificial intelligence that can be of benefit depending on a number of conditions and how different scales of production have access to the technology as well as the control of this technology.

[2] http://www.fao.org/3/al936e/al936e.pdf

Social capital connects all the capitals and includes the variety of norms, regulations, rules, laws that govern/ guide operations (e.g. trust, inclusion, gender equality), social relationships and organizational systems. Defined by the Organisation for Economic Co-operation and Development (OECD) as "networks together with shared norms, values and understandings that facilitate co-operation within or among groups" (OECD, 2007), it is an enabling capital that holds the food system together and functioning (TEEB, 2018a), and should include a variety of social protection policies and programmes (Kangasniemi et al., 2020). These include governmental laws and regulations, corporate norms and policies and societal/ community development.

Annex II provides further details on the positive and negative impacts of diets across food supply chains with respect to the four capitals based on the TEEBAgriFood Evaluation Framework.

Structures have emerged over the past thirty years to engage civil society with governments in the formation of food system policy. These fall under a broad category of 'food policy councils'[3] and have a range of more local terminology. In the United States (US) and Canada food policy councils exist at the local (e.g. city or rural region) or state/ province level. Across the United Kingdom (UK) and European Union (EU) there are a number of city-based entities (like the sustainable food cities network in the UK). There are also a wide range of entities across the global south, often not organized into formal 'food policy councils' that are pursuing the same types of goals vis-à-vis food policy and health/ social justice. These demonstrate a potential strategy for civil society to effectively engage with government to effect fundamental policy change.

There are a number of proposals for improving the environmental, social and economic sustainability of dietary patterns. These include the World Wide Fund for Nature's "Planet-based Diets" (WWF, 2020a) that proposes five strategic actions:

- reversing biodiversity loss;
- living within the global carbon budget for food;
- feeding humanity on existing cropland;
- achieving negative emissions; and
- optimizing crop yields.

Another strategy for more sustainable diets comes from the World Resources Institute (WRI) (Ranganathan et al., 2016). They recommend three fundamental shifts: 1) reduce overconsumption of calories; 2) a reduction in overall consumption of protein by reducing consumption of animal-based foods; and 3) a shift specifically away from beef. The Food and Land Use Coalition Report (The Food and Land Use Coalition, 2019) outlines ten critical transitions within the context of: 1) nutritious food; 2) nature-based solutions; 3) wider choice and supply; and 4) opportunity for all. The EAT-Lancet Commission Report (Willett et al., 2019) proposes substantial dietary shifts with a greater than 100% increased consumption in healthy foods such as nuts, legumes, fruits and vegetables and a greater than 50% global reduction in consumption of unhealthy foods like red meat and sugar.

> Overall, the above reports share one common thread concerning environmental sustainability and dietary pattern change: a need to reduce average global meat consumption – especially ruminant meats but not exclusively.

This does not mean that every country needs to see a reduction nor does it mean that meat cannot be produced in an environmentally improved manner compared to much of current meat production (Scarborough, P. et al., 2014a; van Dooren et al., 2014). From a human health point of view there are other common threads among reports: a need to increase average fruit and vegetable consumption and a need to keep caloric consumption at a level to ensure healthy body weight. What is typically not addressed in these reports are human health-related issues such as consuming more whole grains, reducing sugar and salt intake and keeping fat intake to a healthy level.

Furthermore, there are nuances to these recommendations when it comes to sustainability. For example, vegetarian and vegan dietary patterns generally demonstrate greater sustainability than a high meat diet. If water use, however, is the key consideration then under some circumstances a high-almond vegetarian diet could actually be more detrimental than high meat intake (as almonds are produced primarily using irrigated water and animal feed can be produced using rainfall). When addressing dietary patterns there are thus two aspects to consider: (i) on average dietary patterns that meet World Health Organization (WHO) standards and are relatively low in animal products (while still meeting all micronutrient needs) tend to be more environmentally sustainable when considering current dominant production strategies and production locations; (ii) within a particular dietary pattern there can be great variations in terms of environmental sustainability for various reasons. Utilising TCA can discern these variations.

The ability to compare dietary patterns for negative and positive externalities is part of the power and currently unrealized potential of TCA.

[3] http://www.foodpolicynetworks.org/fpc-map/FPC-around-the-world.html
[4] http://www.fao.org/nutrition/education/food-dietary-guidelines/home/en/

In the context of coherent policy development around food system sustainability and social justice, it is important to understand the current status of national dietary guidelines. While national dietary guidelines are in place for over 100 countries[4] , only a few contemplate environmental sustainability (or social welfare/ justice) as part of their considerations. One of the values of TCA in analysing diets is that it allows to link human health to environmental and social health dimensions. TCA is a key tool to address the imperative that national dietary guidelines must incorporate environmental and social sustainability dimensions.

TCA AS A TOOL FOR ANALYZING DIETS AND INFORMING DECISION-MAKERS

TCA IN PRACTICE

ANALYZING DIETS AND INFORMING DECISION-MAKERS

Food and agricultural policy has a wide array of impacts as it shapes the range of research conducted at institutes and universities, the type of support provided to producers and industries, the direction of financial investments, and the incentives or encouragement (e.g. through prices provided to consumers) for certain dietary patterns.

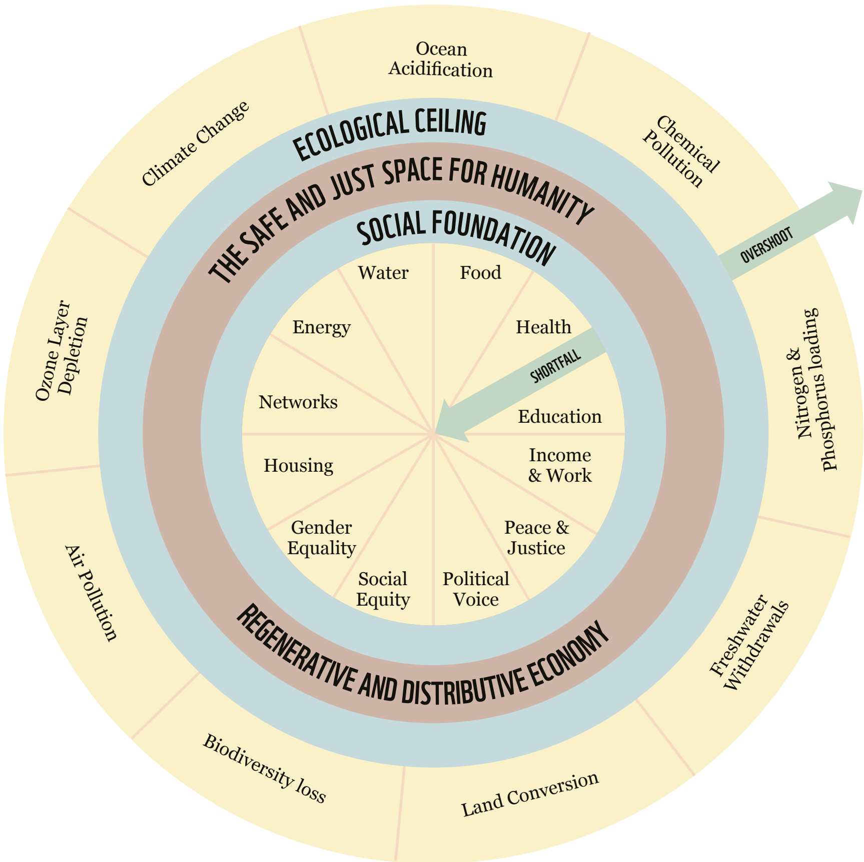
Our suggestion to focus on consumption is a result of serious issues at the consumption side such as overconsumption, waste, aggressive marketing in food environments, and mainly, the fact that some consumers are ill-equipped or have little access to better diets. Public policy in food and agriculture should use consumption as a starting point – what should/ could people be eating, on average, to meet several simultaneous goals:

- staying within Earth's planetary boundaries;
- ensuring food and nutrition security for all residents;

- reducing diseases and deaths that are the result of unhealthy dietary patterns as well as other human health issues caused by the food system;
- ensuring dignity, opportunity and liveable wages for all workers in the supply chain;
- meeting the UN Human Rights domains for all residents (staying above Raworth's "social floor", see doughnut economics below);
- ensuring gender equity across the supply chain and for consumers;
- ensuring reasonable profit/ income for supply chain companies and primary producers (farmers);
- ensuring dignity for the animals in our food system.

The structure of food systems varies across the globe and understanding the dynamics across and within nations is crucial. Researchers have divided 'food systems' into three broad types: traditional (generally low external inputs, small scale production, short supply chains); 'modern' (generally high external inputs, larger scale production, longer supply chains) (Pengue et al., 2018); and mixed (elements of both traditional and 'modern' food systems). Approximately 1 billion people eat the crops of traditional systems, about 4 billion people eat within mixed food systems, and about 2 billion within 'modern' food systems. It is crucial to understand the basic typology and extent of a nation's food system mix as part of a TCA analysis.

2.1 THE NEED FOR MORE HOLISTIC ACCOUNTING OF COSTS AND BENEFITS OF DIETS



DOUGHNUT ECONOMICS

Dr. Kate Raworth first developed the concept of Doughnut Economics in 2012 (Raworth, 2012) and described it more fully in 2017 (Raworth, 2017). Its simplest description is as a new heuristic for sustainability – not as a 'three-legged stool' or 'the three pillars' of social, environmental and economic aspects – but rather as a trilogy of non-equal domains. In this case the 'doughnut' is a metaphor for inner and outer rings with economic activity in the middle. The outer ring (environmental sustainability) uses the nine planetary boundaries and the inner ring uses the UN Human Rights domains. In both cases economic activity has to stay within the rings – neither exceeding the planetary boundaries nor falling below the social floor. They provide the boundary conditions for engaging sustainable economics – the safe and just operating space for humanity.

Figure 2: The Doughnut of social and planetary boundaries. Reprinted from Raworth, K.. (2017). A Doughnut for the Anthropocene: humanity's compass in the 21st century. The Lancet Planetary Health, 1(2), e48-e49.

The TCA tool can be used for understanding the externalities in the food system and then using the outputs from this tool to define coherent and forward-thinking policy. Dietary patterns, including inherent environmental sustainability and social equity aspects, should be the entry point for targeting coordinated policy actions related to food systems. Natural capital (using the planetary boundaries) and human/ social capital (using the UN Human Rights dimensions) provide a set of social, human and environmental boundary targets. Raworth's doughnut economics provides an attractive heuristic for policy development that prioritizes keeping our economic systems 'within the doughnut' (see Figure 2 and Text Box 1).

TCA can serve as a tool to analyse the options for a food system transition: What are the dominant patterns? What are alternative possibilities? What opportunities can be imagined given ongoing developments in science, technology and human development? What would maximize food system resilience in an unknown future? What changes in dietary patterns, in production and supply chain practices would be needed?

This is the value of a comprehensive method of accounting, both in a qualitative and a quantitative sense, as suggested in one lead-up paper to the Fall 2021 UN Food Summit (Laborde et al., 2020).

The use of TCA and TCA-like tools has so far mainly taken place in the private sector to analyse the impacts of individual products or product categories either at the firm and/or the supply chain level (Natural Capital Coalition, 2016b). TCA is used by companies to understand their environmental and human sustainability performance and identify strategies for substantial improvement. A TCA considering diets and dietary patterns is of a different nature, since no single firm (outside of retailing and some food distribution firms) encompasses the whole range of nutrition. TCA should be used as a tool for companies to understand strategies to improve their environmental and social performance – although recently this has been strongly critizied as being largely driven by public relations and 'greenwashing' motives (Pucker, 2021). A review of 40,000 corporate responsibility reports found that only 5% of companies referred to ecological limits and of these only 31 companies made mention of aligning products or performance with these limits (Bjørn et al., 2017).

Yet a proper analysis appears to be feasible while maintaining a profitable venture – as demonstrated in a recent meta-analysis of 100 studies looking at sustainability. The authors found that all but two studies demonstrated positive to neutral impacts of pursuing sustainability metrics on a variety of economic performance indicators (Hermundsdottir et al., 2021). Across the 'social floor' a key determinant is a liveable wage along the supply chain. Even though there is research, little data is available on firm performance. A recent paper (Mair et al., 2019) regarding the fashion industry indicates that increasing wages to a liveable wage does not detrimentally affect the industry or employment – rather their modelling illustrates a slight decrease in hours worked within the industry with labour compensation (wages and benefits) increasing by as much as 100%. While not definitive, this is suggestive that there is a much greater margin for wage increases across individual firms and sectors than might be assumed.

Hence it is the task of the public sector to undertake or fund a dietary pattern approach to understand the impacts of overall food consumption. Within a dietary pattern there are diverse distribution channels in play given that a food's source can be global, continental, regional, national or local. A range of processing and distribution pathways, points-of-consumption (eating out vs. eating at home), production systems (e.g. conventional vs. organic) as well as variable amounts of waste need to be considered. Also, countries have varying degrees of traditional and 'modern' food systems.

This is where TCA becomes extremely useful and relevant for public policy. Without a TCA approach as a standard operating procedure in public policy, regulation and law development, there will continue to be an extremely mixed record globally – with some companies, some farmers and some localities performing better than others. In addition, the scattered policy situation among agricultural policy, food policy and dietary policy will remain.

2.2 TCA – A TOOL FOR ASSESSMENT AND DECISION-MAKING

TCA has been described by the Global Alliance for the Future of Food as:

> "A critical tool to help us, as a global community, better understand the impacts of food systems, address the most harmful practices, and find new, positive pathways forward. By evaluating the impacts—both positive and negative—inherent in different food systems and making these impacts transparent, decision-makers on farms and in governments, institutions and businesses can make better informed decisions that consider the economic, environmental and social impacts of their choices." (Global Alliance for the Future of Food, 2019).

TCA is a tool for considering both positive and negative externalities – impacts of the food system that are not inherent to the listed price of food at the point of purchase – providing an approach to analysing their true costs. TCA can thus be used for assessment and decision-making. What follows is a procedural description – using a hypothetical scenario – showing how TCA can work both for assessment and decision-making.

TCA FOR DIETARY ANALYSIS – 'HOW DOES TCA HELP TO UNDERSTAND THE STRUCTURES AND IMPACTS OF DIETARY PATTERNS

Initially, dietary and food system targets need to be set. In the following scenario, a national government wants to develop a strategy for increasing annual fruit and vegetable consumption by 50% in its population, with 90% of fruits and vegetables produced domestically, ensuring equitable treatment of workers throughout the supply chain and environmental sustainability being a hallmark of the system. This implies several threads of policy:

1. policies that provide for national food and nutrition security while generating conditions for people to consume more healthy food;policies that provide incentives for farmers and others along the supply chain to produce adequate amounts over the year while doing so sustainably;
2. policies providing for equitable worker rights along the supply chain;
3. policies to ensure different scales of production have market access and reasonable returns; and
4. policies to fill research gaps and collect data on continuous improvement over time.

This includes both food produced and consumed domestically and imported food. It further means understanding all the trade-offs regarding domestic versus international sourcing. The next thing to be done is to determine the current status. TCA via the four capitals provides a structure for doing this by answering the following types of questions:

Within natural capital:

- Where does the food come from and how does it contribute to GHG emissions?
- What are the environmental impacts of production and the supply chain with respect to the planetary boundaries?
- What are the losses along the supply chain?

Within human capital:

- What are the levels and dynamics of food insecurity and malnutrition?
- What amounts of fruits and vegetables are being consumed by the population? What can be said about the range of consumption, and the products consumed?
- What does the data say about diet-related non-communicable diseases and premature deaths (as a result of total calorie intake)?
- Under what working conditions is the food being produced (e.g. work-related health and safety standards, human rights, labour rights)?

Within produced capital:

- What type of transportation is being used to move products along the value chain?
- What is the status of mechanization/ hand labour in current production systems?
- Do current negative externalities drive high real costs?

Within social capital:

- Concerning national food security, how much food is produced domestically and how much is imported? What are seasonality and other climatic constraints on production? Will those constraints shift over time with climate change?

- Is research being funded on fruit and vegetable production/ processing/ post-harvest management?
- What is the wage structure of workers along the supply chain, including farm workers? What do their rights of participation look like in democratic institutions?
- What is the mix of large and small-scale producers for different categories of fruits and vegetables?
- How high is farmers' income?

While not exhaustive, this gives an idea of the type of questions needed to do a thorough assessment for constituents (i.e. fruits and vegetables) of dietary patterns. The same can be applied to individual commodities (e.g. grains, dairy products) or dietary patterns (e.g. grains, protein/ animal products/ nuts/ legumes, total calories).

TCA FOR DECISION MAKING – 'HOW DOES TCA HELP INFORM DECISION-MAKING AND HOW CAN TCA BE INTEGRATED INTO THE DECISION-MAKING PROCESS?'

The analysis informs about the desired change. It shows where change is needed (e.g. does policy need to intervene regarding living wages and/or implement stronger environmental regulations?). Depending on the monetization method, different information is provided by TCA results. If a damage cost approach is used, it shows the costs/ damage by current dominant food system paradigms and alternatives (e.g. the costs of the damage one tonne of carbon is causing). If a marginal abatement cost/ prevention cost approach is used it shows the costs of preventing damage (e.g. the costs of reducing CO_2 emission to zero by using 100% renewable energies).

Data from the above-mentioned scenario shows that on average residents consume about 250 grams of fruits and vegetables a day; that every Euro of produce purchased by citizens entails another Euro of externalized costs; that only 50% of consumption is produced domestically; that there is a weak processing sector for frozen/ canned produce; that workers are on average paid well below liveable wages; and that the labour/ ownership structure is unevenly distributed between men and women (women make up a very small portion of any kind of decision-making positions, including land-owning farmers, and their average wages along the supply chain only come up to 70% of their male counterparts' wages). Part of the externalized costs is down to low fruit and vegetable consumption (leading to higher health care costs), the other part is due to all the other factors from production processes along the supply chain. The main goal is to reduce the externalized costs, and then secondly, to internalize the remaining externalized costs.TCA then provides a tool for decision-making in several ways:

1. It illuminates areas where data is lacking in order to be able to make fully informed political decisions (Where is additional data needed?).
2. It helps to clarify what the externalized costs are in environmental and social realms, and provides an overview over some of the variations – i.e. differences in practices and processes along the supply chain leading to different amounts of externalized costs. In particular, a TCA analysis will provide specific answers to questions on changes for a coordinated impact to help determine a timing strategy. One can start by asking questions about different practices in the supply chain to identify those to be promoted or discouraged (e.g. organic vs. conventional production).
3. It provides insight to conditions for workers and professionals along the supply chain – farmers' income, barriers to market entrym, disadvantages for female workers, etc.
4. It provides insight to dietary patterns: What fruits and vegetables are consumed within a population? Which part of the population need the intervention the most?

This could be the background for questioning any kind of intervention and look at the possible alternatives (e.g. policies, regulations, research funding, innovations, development funding, subsidies, etc.). An area of increasing public interest is the use of technologies for fruit and vegetable production, especially in indoor production. Depending on the latitude, season and seasonality constraints, wanting to produce more domestically and having shorter supply chains may require increasing indoor production. This will entail a range of decisions having to be made for increased indoor production, and its relationship to environmental sustainability will have to be closely monitored. One author's work in Michigan, USA indicates that the carbon footprint is lower when producing off-season leafy greens closer to home rather than shipping them by truck 2000 miles from California (Plawecki et al., 2013). This again leads to considerations, e.g. on the best strategy for increasing access to this technology for local farmers, on the best marketing channels for these products (i.e. direct marketing, retailing, gastronomy sector, etc.), or on effective nudges to be used to enhance consumption.

2.3 OVERVIEW OF EXISTING TCA METHODOLOGIES AND TOOLS FOR ANALYSING AND COMPARING DIETS

A comparison of dietary patterns is generally a rather difficult and complex undertaking. While there have been a range of studies investigating dietary patterns and environmental characteristics (Hallström et al., 2017; Peters et al., 2016; Soret et al., 2014), there have been none that took a TCA approach to look at a range of capitals (e.g. natural, human and social) and attempt to monetize the respective indicators. To date, most identified studies investigated individual characteristics – most notably dietary variations, GHGs and global warming – but did not monetize the findings. There are very few studies that have taken on a complete diet or food system perspective in conducting an analysis. While this is largely uncharted territory, there are some studies looking at different aspects of the food system as well as several design strategies that provide a sound basis for development. TCA methodologies can be employed to value positive and negative externalities associated with dietary patterns, to analyse and to compare diets. This is the "added value" of TCA.

For an overview of assessment frameworks and links to frameworks, tools and databases the reader is referred to the Inventory (Soil & More Impacts et al., 2020a) jointly created by TMG-Think Tank for Sustainability and Soil and More Impacts. Highlights and aspects most useful for the purposes of this report will be framed below and is summarized in Table 1. It is might also be helpful to look at a report prepared in parallel to the resource database (Soil & More Impacts et al., 2020b). This site[5] has tabs that include 'frameworks and standards', 'tools and resources', 'databases' and 'application case studies', among others. The 'database' tab contains links to 48 active databases. The frameworks, standards and case studies described below are all listed in this database.

SOURCE	TYPE/DESCRIPTION	USEFULNESS FOR TCA AT POLICY LEVEL
Principles for True Pricing (True Price Foundation et al., 2020)	Principles	Provides a strategy for deciding principles for TCA with dietary patterns
'Monetisation Factors for True Pricing' (True Price Foundation, 2020)	Brief handbook	Illustrates a strategy for monetizing a number of capitals
Case Study: Chocolate (True Price Foundation, 2018)	Case Study	Illustrates a useful strategy for explicitly incorporating human rights and environmental attributes
Natural Capital Protocol (NCP)	Protocol for analysis	Helps understand externalities of natural capital
Social and Human Capital Protocol (SHCP)	Protocol for analysis	Helps understand externalities of social and human capital
Sustainability Assessment of Food and Agriculture (SAFA)	Protocol for analysis	Helps understand weakest performance areas in agriculture
Full-cost accounting framework	Protocol for analysis	Shows how to value and monetise environmental, social and economic impacts
Food Reform for Sustainability and Health (FReSh) true cost report (Schenker et al., 2018)	Case Study	Provides a useful product-based example
A Framework for Assessing Effects of the Food System (National Research Council, 2015)	Case Studies	Provides useful examples
The Hidden Cost of UK Food from the Sustainable Food Trust (Fitzpatrick et al., 2017)	Case Study	Provides a useful case at the national level across the food supply chains
Wealth Accounting and the Valuation of Ecosystem Services (WAVES)[6]	Analytical framework	Provides strategies for natural capital accounting
True Cost Accounting For Food (Gemmill-Herren et al., 2021)	Edited Book with chapters on various aspects of TCA and food	Provides a number of examples of TCA

Table 1: Summary of useful resources for TCA analysis at policy level

[5] https://airtable.comshr3eH7gXan4SqHxB/tbljDWE6q4e5d0Nuj/viw62p6Mcr4yv8CEb
[6] https://www.wavespartnership.org/en/natural-capital-accounting

Trueprice.org developed a set of Principles for True Pricing (True Price Foundation et al., 2020) that outlines a rights-based approach across human and environmental domains, as well as a brief handbook 'Monetisation Factors for True Pricing' (True Price Foundation, 2020) that outlines the process and dollar factors used. It considers negative external costs as "the negative effects on external stakeholders who did not participate in the production or consumption of that product (or, if they did, did not do so sufficiently freely). Externalities include effects on the environment, such as accelerating climate change and water pollution and on people, such as health and safety accidents and child labour." The rights-based approach uses internationally agreed rights and agreements as a starting point and includes human rights, fundamental labour rights and environmental rights. It also considers four types of costs: 1) restoration costs; 2) compensation costs; 3) prevention of re-occurrence costs; and 4) retribution costs. Using this strategy, a benchmark chocolate is compared to a human-rights oriented chocolate company to outline the differencies (True Price Foundation, 2018) and illustrates the path to incorporating human rights and environmental attributes. Interestingly, in many cases the extra costs per unit for ensuring living wages in production are relatively low. Their study on roses sold on markets in the Netherlands found that on average 1.3 eurocents per rose were required to raise farm laborers in Kenya, Zambia and Ethiopia up to living wage standards (Renon et al., 2018).

Rights, power concentrations and means of participation are crucial considerations when proceeding from a dietary pattern starting point, though they are often not considered in analyses. From a living wage perspective, little extra costs (relative to current costs) will be caused when making sure to provide living wages. The Coalition of Immokalee Workers' Fair Food Campaign in the southern USA estimates, for example, that an additional USD 0.01 per pound of tomatoes harvested would increase farmworkers' incomes from USD 10-12,000 to USD 17,000.[7]

STAGE	FRAME Why?	SCOPE What?			MEASURE AND VALUE How?			APPLY What next?	
STEP	01 Get started	02 Define the objective	03 Scope the assessment	04 Determine the impacts and/or dependencies	05 Measure impact drivers and/or dependencies	06 Measure changes in the state of natural capital	07 Value impacts and/or dependencies	08 Interpret and test the results	09 Take action
QUESTIONS THIS WILL ANSWER	Why should you conduct a natural capital assessment?	What is the objective of your assessments?	What is an appropriate scope to meet your objective?	Which impacts and/or dependencies are material?	How can you impact drivers and/or dependencies be measured?	What are the changes in the state and trends of natural capital related to your business impacts and/or dependencies?	What is the value of your natiral capital imapcts and/or dependencies?	How can you interpret, validate and verify your assessment process and results?	How will you apply your results and integrate natural capital into existing processes?
PRINCIPLES: RELEVANCE, RIGOR, REPLICABILITY, CONSISTENCY									

Figure 3: The Natural Capital Protocol Framework, Reprinted from Natural Capital Coalition (2016). "Natural Capital Protocol". (Online) Available at: www.naturalcapitalcoalition.org/protocol.

[7] https://en.wikipedia.org/wiki/Coalition_of_Immokalee_Workers

The Natural Capital Protocol (NCP) and the Social and Human Capital Protocol (SHCP) merged to form the Capitals Coalition in early 2020 (Lok et al., 2018). The NCP is a framework designed to help generate trusted, credible and actionable information that business managers need to inform decisions" (Natural Capital Coalition, 2016a). It is designed around improving metrics for a business and provides an extensive strategy of frame, scope, measure and value, and application in understanding impacts – both positive and negative (Figure 3). Primarily for use by businesses, it is oriented to help improve the internal environmental sustainability characteristics of a company or product line. However, there is also an increased interest in encouraging governments to understand natural capital management as a lever for a range of policy objectives. The SHCP is similar to the NCP in nature, aimed primarily at business improvements (Social & Human Capital Coalition, 2019). Both protocols start from the premise of improving company performance, either from a natural capital and/or a social and human capital perspective. The steps outlined by the SHCP are very similar to those in the NCP and they offer a good overall framing of the steps needed. But neither is designed to start at the consumer endpoint – not considering consumer health nor consumers impacts on the four capitals, and neither will make any judgements on the value of the business itself, as they are only interested in internal business improvements relative to the capitals. For example, a large vertically integrated poultry producer could use this tool to develop a strategy for improving the external capital costs of their business model, but this would not lead to questioning the business model itself.

Targeting national (or other governmental scale) dietary patterns would entail starting from a different vantage point. This does not imply that from a governance standpoint, and beginning with dietary patterns, it is necessary to make value judgements of a particular entity's mission per se. Rather, it implies that through analysis one identifies strategies and directions that should be supported – directing research funding, development support, public funding and innovation funds to the identified pathways rather than putting public resources into areas of high externalities and negative impacts.

Sustainability means ensuring human well-being (and achieving global food security) without depleting or diminishing the capacity of the Earth's ecosystems to support life or at the expense of other's well-being	GOOD GOVERNANCE	G1. Corporate Ethics G2. Accountability G3. Participation G4. Rule of Law G5. Holistic Management
	ENVIRONMENTAL INTEGRITY	E1. Atmosphere E2. Water E3. Land E4. Biodiversity E5. Materials and Energy E6. Animal Walfare
	ECONOMIC RESILIENCE	C1. Investment C2. Vulnerability C3. Product Quality and Information C4. Local Economy
	SOCIAL WELL-BEING	S1. Decent Livelihoods S2. Fair Traiding Practices S3. Labour Rights S4. Equity S5. Human Health an Safety S6. Cultural Diversity

Figure 4: SAFA sustainability dimensions and themes. Reprinted from SAFA sustainability assessment of food and agriculture systems: Guidelines version 3.0. (2014) Rome: FAO. (Online) Available at: http/ www.fao.org/3/i3957e.pdf. Reproduced with permission.

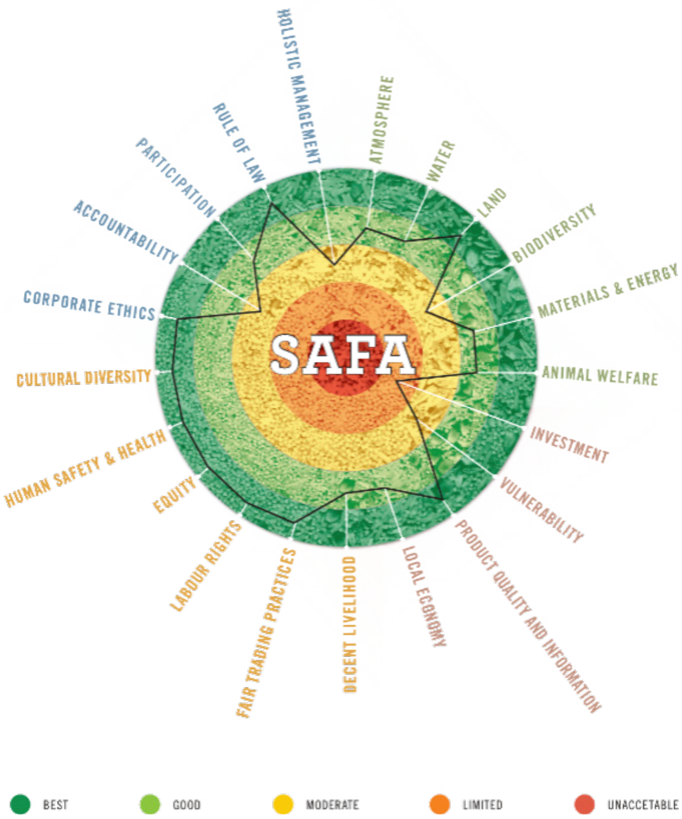


Figure 5: SAFA sustainability polygon (example of an enterprise performance). Reprinted from SAFA sustainability assessment of food and agriculture systems: Guidelines version 3.0. (2014). Rome: FAO. (Online) Available at: http://www. fao.org/3/i3957e/i3957e.pdf. Reproduced with permission.

The Food and Agriculture Organization of the UN (FAO) published an comprehensive strategy for analysing food system sustainability with a broad set of four dimensions (Figure 4) (FAO, 2014b) and an accompanying set of indicators (FAO, 2013), a tool for analysis (FAO, 2014c) and a smallholders application (FAO, 2015). This is less of a monetization strategy than it is a quantitative-qualitative assessment with the endpoint reporting taking into account all twenty-two domains. The report is in the form of a sustainability polygon (Figure 5) providing a snapshot of hotspots for further action.

In addition, FAO has released a full-cost accounting (FCA) framework for food waste. It "measures and values in monetary terms the externality costs associated with the environmental impacts of food wastage. The FCA framework incorporates several elements: market-based valuation of the direct financial costs, non-market valuation of lost ecosystems goods and services, and well-being valuation to assess the social costs associated with natural resource degradation." (FAO, 2014a).

ENVIRONMENTAL	SOCIAL	ECONOMIC	FOOD SAFETY/NUTRITION
Atmosphere (GHG & air quality emissions widely available)	Farmer Livelihoods Product Social Impact Assessment Handbook	Investment Food Security Index, EIU & CIA long-ranging investment lacking	Residues (Not available)
Water (Quantity & Quality) widely available	Labor Rights SGDB	Resilience Food Security Index, EIU - liquidity lacking	Hazardous Substance Some models available
Land (Not widely available) in particular regarding production practices	Equity (Not widely available)	Product Quality % Information N./A	Dietary Energy FAOSTAT & Global Burden of Disease
Biodiversity In progress	Human safety & Health Some in SGDB	Local Economy CIA Factbook, World Bank, Knoema	Macronutrients FAOSTAT & Global Burden of Disease
Materials and Energy Widely available	Cultural Diversity Some in SGDB, but generally complex	Technology FAOSTAT, HDR	Macronutrients Some info in Global Burden of Disease
Waste Reduction & Disposal			Dietary Diversity Missing
Animal Welfare Rarely available			

Good data availability Partial data availability Poor data availability

Figure 6: Mapping of data availability on different food system sustainability and health indicators. Adapted from Schenker, U., et al. (2018). True Cost of Food: Unpacking the value of food system: FReSH Discussion Paper. Geneva, Switzerland. World Business Council for Sustainable Development (WBCSD). FReSH. (Online) Available at: https://docs.wbcsd.org/2018/10/FReSH_True_Cost_Discussion_Paper.pdf

Food Reform for Sustainability and Health (FReSH) is a project of the World Business Council for Sustainable Development (WBCSD). As such it takes a decided starting point of internal company evaluation. The FReSh true cost report (Schenker et al., 2018) identifies data availability for the dimensions of concern. A strong point of this reporting is their indication of the level of data that is available – as can be seen in Figure 6. It should be rememberd that some data will, by their nature and maturity, be quantitative and some will be qualitative. The main problem with a literal true cost accounting approach from a monetization framework is, though, that some things cannot be monetized. For example, living wages can be expressed in monetary terms, but other aspects of human rights (e.g. freedom of assembly) are hard to monetize and must remain qualitative. This implies that any final 'report' will include a monetized portion and a qualitative portion to the analysis/ recommendations. Both portions are useful for policy development.

The US Institute of Medicine published A Framework for Assessing Effects of the Food System (National Research Council, 2015) which can arguably count as a true cost accounting approach. There is a great deal of useful information in it, though the examples provided (e.g. fruit and vegetable consumption in the USA) tend to be viewed with a narrow, disciplinary lens. It does provide valuable examples (e.g. nitrogen in agricultural systems; biofuels; dietary recommendations for fish) spaning a wide range of issues.

A good national-level study that looks at both natural and human capital is The Hidden Cost of UK Food from the Sustainable Food Trust (Fitzpatrick et al., 2017). This study concludes that for every British pound (GBP) spent, another GBP 0.97 of hidden costs exist. It is important and useful to realize that the overall calculated impact of GBP 116 billion per annum is more than the 2005 estimate of GBP 8 billion. Though a minor part of this stems from dempgraphic changes and inflation, the largest part os due to the fact that more issues have been 'measured' and hence more data exists. Even so, many aspects of the food system are still missing from the calculations. On top of that, this one is strictly an analysis of the overall food system, based on the assumption that the dominant production strategy is used throughout the entire system. No attempts were made to identify alternatives to the predominant production system (e.g. organically certified production), nor was taken into account how these impacts vary depending on the 'type' of food system. One of the variables included is domestically produced vs. imported food, so that calculations for these two options could be differentiated.

Another strategy used for natural capital accounting is led by the World Bank (with 22 partner countries) as part of their Global Program for Sustainability.[8] Known as WAVES (Wealth Accounting and the Valuation of Ecosystem Services), it works with national governments to incorporate natural capital accounting into their national accounting schemes and to move somewhat beyond Gross Domestic Product (GDP) as a measure of 'success'.

> The focus is on "produced capital (buildings, the machinery used in factories, infrastructure like highways and ports, etc.), natural capital (including land, forests, fish, minerals and energy), human capital and net foreign assets. Wealth accounting is a methodology for measuring these assets."

Other analyses conducted using the TCA framework are commodity-focused and often underlie several scenarios of production assumptions. For example, one study of wheat production in the northern Punjab, India compared organic and conventional production systems (Gundimeda, 2019), while another study of organic vs. genetically-modified organism (GMO) corn in Minnesota, USA looked at the four capitals – partly quantitatively and partly qualitatively (May, 2019; Sandhu et al., 2019). Other initiatives have investigated strategies for modifying production practices to improved outcomes across the capitals – for example cattle and soy-maize systems in the Brazilian Amazon (May, 2019). Finally, a recent book True Cost Accounting for Food (Gemmill-Herren et al., 2021) includes chapters ranging across a number of topics critical to TCA and food system analysis.

SUMMARY

'What can be said about the existing literature, frameworks and tools for conducting a TCA analysis on dietary patterns?'

1. There is a strong theoretical framework for conducting the analysis, but it has never been done with dietary patterns as the starting point.

2. There are a range of commodity-based studies that illustrate pathways for looking at different production strategies and supply chains. However, this has mostly been done for individual production systems or supply chains and never for a wide array at once, as is required to assess diets.

[8] https://www.wavespartnership.org/en/natural-capital-accounting

3. TCA frameworks and analyses have often been designed from a business perspective and thus still fall within the heuristic of economics being a co-equal 'partner' with environmental sustainability and social justice/ rights.

4. The outcome of a TCA assessment of diets will likely be a combination of qualitative and quantitative results. This is because TCA is in its infancy, hence data will be missing and monetization will not be meaningful in all cases.

5. There is the potential to use such an analysis as a strategy for forward-thinking and context-specific policy development.

6. Improving situations that involve an array of human perspectives and often competing interests is a complex issue. Without strong democratic and inclusive processes, the potential for positive outcomes relative to natural, human and social capital are limited.

There are limitations of TCA studies which fall into three broad categories: limitations of data, limitations of future predictability and limitations to cultural transitions.

LIMITATIONS OF DATA

In his recent Harvard Business Review article, Kenneth Pucker (Pucker, 2021) outlines how the complexity of existing supply chains often makes it impossible to track components from source to manufacturer and develop a reliable carbon footprint (or water footprint, nitrogen use, etc.). Other data is moreover not necessarily collected (e.g. exact pesticide usage data at sub-national level).

LIMITATIONS OF FUTURE PREDICTABILITY

To date, the role of future conditions in altering the framework under consideration is often not considered in a TCA analysis. In this context, it is useful to remember a key outcome from the Rodale Institute's Farming Systems Trial in which researchers compared over 30 years the production of row crops (corn, soybean, wheat) in two organic systems (one with manure as the primary added nutrient source and one with cover crops) versus the conventional system in the area (Kutztown, PA, USA). On average, the organic row crops behaved similarly to the conventional system in terms of yields (profits were higher in the organic system with lower energy inputs). However, the organic system outperformed in times of drought and underperformed slightly in times of plentiful rain. There was also higher soil organic matter over this time in the two organic systems compared to the conventional one (The Rodale Institute, 2011; Pimentel et al., 2005). This triggers the question of forward-thinking decision-making: is it best to encourage a production system that appears more reliably productive under a range of conditions (especially drought) or one that has greater variability?

LIMITATIONS TO CULTURAL TRANSITIONS

Another potential for TCA analytical approaches is to identify possible radical departures from the existing status quo. Such an analysis was conducted by Dr. Stephanie White while looking at the Malawi maize agri-food system (White, 2019). Maize, a New World crop was introduced to Africa during colonial times and displaced a number of indigenous crops. White argues that, given the combination of inputs required for maize and the types of soil dominant in Malawi, it is plausible to look at moving away from maize, and back towards crops more acclimated to the natural resource base of the region. As noted in her primary assertions:

1. "The focus on maize is disproportionate to the benefits it currently or can reasonably be expected to provide, especially in light of the devastating and widespread predicted impacts of climate change;

2. Maize-centricity is held in place by prevailing assumptions, values and analytical frameworks that prevent citizens, policymakers and development economists from perceiving how and why maize-centric agrifood systems are limited, and perhaps even antithetical to a goal of food security; and

3. Conceptual frameworks that compel attention to a wider set of indicators that recognize the multi-dimensionality of food security and well-being are critical for strategic decision making that aims for sustainable and equitable food security in a context of climate change, environmental degradation, urbanization and growing inequality."

The question thus is: 'Should we completely re-think what we are doing?' And consider the importance of traditional and local food production strategies as well as recovery of more distant cultural practices in regions across the globe? Many indigenous communities have held onto their ancestral traditions while others are actively working on recovering them. This has positive implications for natural, human, and social capital.

2.4 GUIDANCE FOR DESIGNING A TCA ANALYSIS OF DIETS

This section is structured as steps to be taken and questions to be asked to conduct a TCA analysis, and outlines some of the assumptions made (based on a range of data) in providing guidance. Also, this section frames a recommended analytical framework, defines a scope for the analysis and defines strategies for measuring and analysing diets.

STEP 1: FRAME

In the first stage, the basic question to ask is: "Why is the TCA analysis being done?" In the context of dietary and food policies typical reasons are: (i) to expand the understanding of what a population currently consumes and the impacts around the four capitals as well as to identify pathways for improving dietary patterns, i.e. eliminating or greatly reducing externalities; and (ii) to develop policy that will align the food system (including production, all actions within the supply chain, and the management of waste at all stages) and dietary patterns with markedly improved metrics in the region (e.g. national, sub-national, global), regarding environmental sustainability, human rights development and preservation, human health and social cohesion, especially with regard to democracy, power and participation. This means taking account of the stocks, flows, outcomes and impacts of various dietary patterns within the population (TEEB, 2018b).

The ultimate indicator of these food system impacts is represented in the food consumed, thus the starting point of the analysis is the food a population eats and wastes annually. Within a population there are a range of dietary patterns, and moral, ethical, cultural or practical considerations behind purchasing decisions. While the first step in conducting a TCA analysis is finding out what the dietary patterns in a population are (not just as averages), an important parallel step in the process is deciding the geographic boundaries for food production analysis (e.g. in the UK study outlined above, the UK is used as the production boundary, everything else is considered as 'beyond the UK').

It is important to clarify the assumptions embedded in any analysis as these will vary across nations and regions. Generally the following assumptions can be made in the context of sustainable dietary patterns (note: these will vary country-by-country and not all of them are applicable everywhere):

1. A larger percentage of a region's food supply should come from within the region depending on what is feasible under local conditions.
2. The current food system has a wide array of externalities that should be internalized and accounted for.
3. Through peoples' dietary patterns, the current food system is strongly impacting environmental, climatic, social and human health indicators. Negative impacts that worsen planetary and human health should generally be reduced, positive impacts increased.
4. Less animal products should be consumed (this is very country/ region specific and might vary).
5. Adequate, but not excessive calories should be consumed (for many this means reducing calorie intake).
6. On average, there should be a doubling of fruit and vegetable consumption.
7. Consumption of refined grains should be reduced, whole grain consumption increased.
8. Consumption of sugar-sweetened beverages and foods should be reduced.
9. Consumption of ultra-processed foods and beverages should be reduced.
10. Consumption of biodiverse foods with a greater degree of genetic variation and a broader range of species consumed should be increased.
11. The food system needs to become a circular system with safe recycling of all types of organic waste (including human waste).
12. The food system should be 'zero carbon' (or net negative).
13. Power structures in the food system should be spread more evenly across various dimensions.
14. Meeting the UN Sustainable Development Goals (SDGs) is to be incorporated into the analysis.

STEP 2: DESCRIBE AND SCOPE

During the second phase, the systems underlying the different components of diets are described, including agri-food value chains, processing activities, capital stocks and flows, outcomes, impacts and trends. Using vegetable consumption as an example the description starts with how much is consumed; where and how the vegetables are produced; where the vegetables are sourced from (grocery stores, local farm markets, restaurants, etc); how they reach markets; what is used as intermediate storage; logistics and means of transport, etc. Aspects to be considered are: size of farms; labour and income standards along supply chains; inputs (irrigation water, energy (amount, source and type), fertilizers, pesticides, preservatives, packaging, etc.); natural resources needed (e.g. required land area); child labour practices; gender equity; participation and governance.

This will help identify the differences between production systems. Surprisingly, in some cases, similarities also emerge.

Setting a geographic boundary for analysis is critical and most often this will be the national level. However, in large countries (e.g. USA, China) it may be more useful to look at parts of the country, while in other cases (e.g. EU) it might be useful/ necessary to consider the supra-national level. Whichever the case, it is helpful to set the boundary at a scale where policy can be utilized to transform activities. If data is unavailable at the scale of interest, then data at the next larger scale for which it is available or from a parallel region with similar characteristics should be used. Food consumption data is most readily available nationally but, in some cases, there are regional subsets of data. It is important not to rely on averages alone – it is the range of dietary patterns that provides opportunities and nuances to any analysis.

STEP 3: COLLECT DATA AND MEASURE

In the third stage, data is collected on the dietary patterns under consideration and their impacts, using a number of metrics for natural, human, social and produced capital. In terms of identifying data, depending on the geographic scope of analysis there may, or may not, be a coherent set of data. A good example looking at dietary patterns, in this case for GHG impact, is that of Rose et al. (Rose et al., 2019). Another example divided eaters into vegan, vegetarian, fish consumers and several levels of meat intake (by quantity) (Scarborough, Peter et al., 2014b). Broad and ancillary questions regarding dietary patterns that can be explored include:

1. Are there differences across the population in patterns of meat consumption (ruminant vs. poultry/ pork)?
2. Are there differences in the level of ultra-processed foods and beverages? Free (added) sugar consumption? Free (added) oil consumption?
3. Is dairy a significant component of subsets within the broad consumption pattern trends?
4. Relative to either national or WHO guidelines do some groups meet various recommendations for intakes? How much of a deficit is there in the groups?
5. How are global migration patterns affecting dietary and cultural patterns within the country?

Moving along the supply chain towards production, the amount of questions increases exponentially, so that choosing a discrete number of groups for dietary calculations is recommended. For example, the region's average diet, vegetarian, vegan and three levels of meat intake would give six discrete groups while providing some dietary pattern boundaries for the analysis. Next is the identification of impacts using a number of metrics as a minimum and starting point:

1. **Natural capital:**
    - Net GHG release
    - Blue water footprint relative to regional water sufficiency
    - Chemical use impact (ecotoxicity)
    - Land use and deforestation rate
    - Biogeochemical cycles (N and P)
    - Biodiversity impacts
    - Soil erosion
    - Soil build up (and soil carbon)
    - Energy sources
    - Animal welfare
2. **Human capital:**
    - Human health impacts – direct and indirect
    - Human rights and working conditions
    - Living wages in the supply chain
    - Gender equity and opportunities
    - Child and elder labour
    - Food and nutrition security
3. **Social capital:**
    - Size and distribution of farms and companies in the supply chain
    - Power balance and capacity to organize (i.e. unionization, cooperatives)
    - Ownership concentration, property rights, land grabbing
    - Access to technology
    - Data ownership at all levels of the food system
    - Human migration laws and food system labour
4. **Produced capital:**
    - Mechanization, artificial intelligence, equipment based on renewable energies
    - Size and distribution of processing companies
    - Post-harvest infrastructure
    - Barriers to market entry; concentration of know-how and resources

STEP 4: PREDICT AND ANALYSE

The fourth phase monitors secondary data and accounts for future scenarios. Regional production data will provide a sense of what is produced currently – but it will only provide a limited context for what is feasible in future given the challenges of climate change, water stress, population growth and urbanization. Useful questions to address include:

1. What do projections indicate for the region with regard to these four challenges?
2. How much and what kind of technologies will need to be developed to keep up business-as-usual from the perspective of production, processing and distribution?
3. What additional complications will this imply?

In most cases only part of the food consumed is produced within the same region, so another question arises from this: 'What are the climatic/ water resource scenarios of our food's sourcing area, and for the different parts of the food value chain?' For example, much of EU produce comes from Spain – which, predictions show, is likely to endure a great deal more periods of drought – so maintaining production at its current level might become challenging. This could be exacerbated by urbanization and specific urban food security challenges (Gentilini, 2015) and opportunities (Khan et al., 2020; Pulighe et al., 2020). The Coronavirus Disease 2019 (COVID-19) pandemic has provided insights to the challenges of food security in a climate changed/ water stressed world – for example, significant disruptions in groundnut value chains in South India and attendant food security challenges have occurred (Nandi et al., 2021).

One example for predictions and analyses is distribution transportation, which is generally considered a relatively unimportant part of agriculture and the food system with respect to GHGs. However, this is largely due to averaging across the whole food system and all of production. If looked at in the context of specific dietary components (e.g. fruits and vegetables), it will become a lot more important (Plawecki et al., 2013). With regard to the supply chain we should ask ourselves: "Where do we stand right now and where can we move to over the next decade in terms of GHG release in each part of the food system?" (Liimatainen et al., 2019).

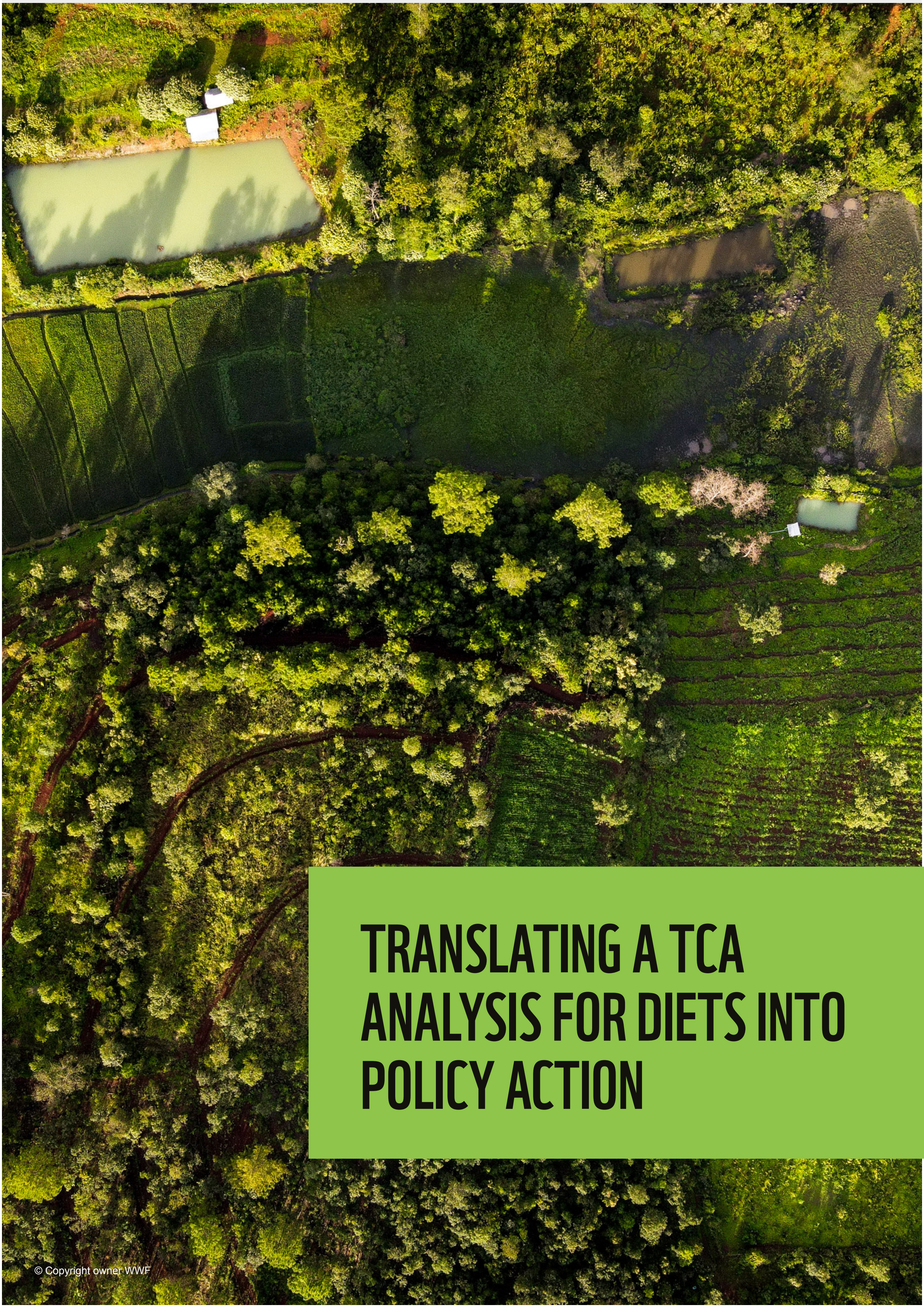
It will be necessary to both set up a comparative analysis and to recognize that no food system, supply chain or dietary pattern will demonstrate best practices in all categories – yet some will certainly perform better than others. For example, the dominant production strategy in hybrid and modern food systems is conventional production using a range of pesticides, fertilizers and other input factors. Much of this will be larger scale in the global north, and biomass-based commodity trade from the global south (UNEP, 2015), involving under-compensated labour. Analyses undertaken in parallel could be focused on organic production within the region, and on fair trade supply chains. Drawing on databases and methodologies outlined in the previous section will be most useful – for example Airtable (Soil & More Impacts et al., 2020a) provides access to a number of databases; the FAO Sustainability Assessment of Food and Agriculture (SAFA) protocol provides very useful indicators on a range of capital metrics (FAO, 2014b) along with a worksheet/ database to help inform the analysis.

STEP 5: MONETIZE/VALUE

As a fifth step, positive and negative environmental and social impacts should be valued, so as to better understand the magnitude of impacts and to be able to compare different dietary patterns. The product of a TCA assessment of diets will likely be a combination of quantitative and qualitative results. Some factors of current dietary patterns can be monetized (e.g.:"How much does the current dietary pattern cost regarding damage to the environment, poverty, health, etc.?"). As we know a fair bit about alternatives to the dominant food system paradigm, some statements about sustainable and healthy dietary patterns can be made, such as "What does a transition to a sustainable and healthy diet cost and what are implementation costs?" Having said that, not all valuation will be quantitative. Monetization is not always feasible or suitable, which is why qualitative assessment and valuation is also important. The Happiness Index (Helliwell et al., 2020) is an example of a non-monetized assessment with important implications for policy.

STEP 6: DEVELOP POLICY ACTIONS

Finally, once steps 1-5 have been completed for the various value chains in the dietary pattern – fruits, vegetables, dairy products or substitutes, proteins, grains, etc. – they can be combined to understand the overall impact and provide the basis for comprehensive and targeted policy development.



TRANSLATING A TCA ANALYSIS FOR DIETS INTO POLICY ACTION

TCA IN PRACTICE

GUIDING POLICY DEVELOPMENT

As mentioned earlier, TCA is a tool to help guide policy development while identifying strengths and weaknesses among alternative strategies for the food supply chain. The starting point for any policy action is a theory of change. The starting point for any theory of change is the question 'what are our long-term goals or outcomes?', followed by the question 'what conditions must be in place to reach our goal or outcome?' (Brown, 2016). In this case, the broad goal is to make sure that the global population is able to access and consume a sustainable, socially-responsive diet on a daily basis that imparts food and nutrition security for all, while limiting food-related non-communicable diseases. At the widest scale it means ensuring that the food system resulting in dietary patterns does not exceed planetary boundaries nor fails to meet the UN Human Rights dimensions.

This is based on public and private sector policy enabling urgent movement towards the goal and making sure that any movement away from it is quickly corrected. It implies a drastic reform of current patterns of policy development. Agricultural policy and food security/ food and nutrition policy are often made in isolation, but this is no longer suitable. To achieve the objectives of sustainable development, environmental and climate goals a dramatic policy reform is needed – one in which policy starts with the very deliberate end goal of sustainable dietary patterns, and moves backwards along the value chain.

3.1 THE ROLE OF POLICY AS A DRIVER OF CHANGE IN TRIGGERING SHIFTS IN CONSUMER BEHAVIOUR

Baumgartner and Jones (Masse Jolicoeur, 2018; Baumgartner et al., 1993) borrowed from palaeontology and evolutionary theory to develop the punctuated equilibrium model of policy change by arguing that policy goes through relatively long periods of stasis with short, rapid bursts of policy change. Their analogy to palaeontology provides a good visual and reinforces the need for a major shift in policy with emergence of a host of new policy species and an alignment of food and agricultural policy to create a coherent food system policy platform.

To simultaneously address staying below the ceiling of planetary boundaries and above the floor of the UN Human Rights domains (and thus achieve the SDGs) radical policy change is needed. The multitude of political instruments that can be used to effect this change fall within four broad categories:[9]

- legal and regulatory;
- economic and financial;
- social and cultural; and
- rights-based.

In the case made in this report, these policy instruments are brought to bear from the vantage of healthy and sustainable dietary patterns and can be affected or developed at different policy levels. For example, ensuring healthy lunches for school children involves laws and regulations at the national, sub-national and local levels – and a variety of actions at each of these levels. The goal requires additional financial support as making sure that only healthy food is put on childrens' plates is typically more costly than the high calorie, low nutrient meals that are often offered today. It requires social and cultural interventions – meals should be harmonised with local culture – and it typically means some level of education of the children, their parents and the general community. It also means ensuring that all children have a right to the meal without stigmas. A good example is the World Food Program's 'Home Grown School Feeding' in 46 countries working with local farmers to provide meals for the school children in their area.[10]

Another point of interest is monitoring where current political priorities are set, by looking at where funding goes (research funding is a good indicator of political priorities). In the approach advocated in this report, there needs to be significant research at the level of consumers and consumption as well as up the food value chain and within agricultural production itself.

Most but not all (e.g. packaging) environmental impacts happen at the production/ cultivation stage. While the majority of human health impacts happen at the consumption stage (including dietary patterns affecting health, food contaminants and deleterious ingredients) there are still a number that happen within the supply chain (accidents, pesticide poisoning in the field, etc.).

With most research funding currently spent in other areas it is clear that a major shift in publicly funded research needs to occur. For example, research and investment in the EU showed that the closer one gets to the consumer the less investment there is – most of the research and investment interest is at the level of production (Standing Committee on Agricultural Research (SCAR) Strategic Working Group on Food Systems, 2018). This also implies a general disjoint between consumer-oriented and agriculture-oriented research and investment. It is interesting to see where the 11 EU countries participating in the study put their emphasis moving forward relative to the EU's FOOD 2030 key areas. With one exception (Finland), the largest percentage went to agricultural research, with processing and food safety encompassing the majority of the remaining funding, and only a small percentage allocated to 'consumption'. This is also typical of other countries – especially in high income ones. Of the agricultural research funds, a small amount mostly goes to any regenerative, organic or agroecological production research. An analysis of the US Department of Agriculture external research program found that only 5-10% of the research funds analysed (a total of USD 294 million) had any emphasis on agroecology (DeLonge et al., 2016). The finding indicates that beyond an emphasis of food system-related research on production components, most of this is not focused on regenerative or agroecological practices (Altieri et al., 2017).

3.2 GLIMPSES OF WHAT IS POSSIBLE REGARDING EFFECTIVE POLICY INTERVENTIONS

'Are there examples of demand-side policy interventions that make a difference and could be scalable to impact a wider range

[9] https://www.ipbes.net/policy-instruments
[9] https://www.wfp.org/home-grown-school-feeding

of people?' A recent study (Temme et al., 2020), Demand-Side Food Policies for Public and Planetary Health, investigated the literature with respect to demand-side policies to date.

It specifically explored policies aimed at increasing fruit and vegetable consumption, reducing meat consumption and reducing overconsumption. The largest tranche of these were information-based policies with large numbers of market-based and administrative policies. There were relatively small numbers of behaviour change based strategies. In addition, the work of Garnett and colleagues (Garnett et al., 2015) is extremely useful in understanding interventions that seem to have an impact on various aspects of sustainable dietary patterns.

Some of the most common punitive-type policies are sugar taxes – especially for sugar-sweetened beverages. Most of the evidence comes from modelling studies which are often limited due to their inherent assumptions. Some empirical data does not indicate a strong correlation of 'fat taxes' to consumption pattern changes (e.g. Clark et al., 2014). The exception to this appears to be taxes on sugar-sweetened beverages (SSB). Lavin and Timpson (Lavin et al., 2013) examined these taxes and found differing impacts. In Hungary, Ireland and France a decrease in SSB purchases occurred after implementation of a tax while other countries or states-within-countries have had mixed to no effects. A recent analysis of the SSB tax in Mexico (effective since 1 January 2014), determined that the .042 Euro per litre tax would prevent 239,900 cases of obesity over ten years with 39% being children (Basto-Abreu et al., 2019). Awareness of the tax seems an important component of it having the desired impact – reducing sugar consumption (Álvarez-Sánchez et al., 2018), which was found to decrease in Mexico (Colchero et al., 2016).

'Can purchase supports be effective in increasing fruit and vegetable purchases?' In the USA, a program first developed by the Wholesome Wave Foundation and expanded by the Fair Food Network provides matching dollars to low-income households on Supplemental Nutrition Assistance Program (SNAP) benefits (the US version of food support coupons) for fresh fruit and vegetable purchases at farmers markets. In the last US Farm Bill this was incorporated as a pilot program and made available to grocery stores as well. A recent analysis of its use in supermarkets found an average 5% increase in fruit and vegetable purchases relative to stores without the program (Rummo et al., 2019). There is other evidence that such health subsidies generally tend to shift consumption somewhat in the desired direction.

A range of policies have targeted other aspects of the food system – for example soil erosion. Considered one of the key impactors of agricultural production, FAO highlighted the need to greatly reduce erosion (Panagos et al., 2019). Recent successful examples include experiences in Uruguay where an updated conservation law in 2013 mandated soil management plans and as of 2017, 95% of Uruguayan cropland is under a management plan (FAO, 2019). Payments for ecosystem services have also seen somewhat widespread adoption – especially within the framework of ecosystems and biodiversity. As of 2018 it was estimated that there were 550 such programs globally with USD 36-42 billion in annual transactions (Salzman et al., 2018).

Socio-cultural impacts should also be considered – for example, an evaluation of a Meatless Monday program in New York, USA found that there were three fundamentally different groups of people – those already consuming little to no meat, those willing to consider eating less meat, and those not interested (Altema-Johnson et al., 2020). These groups are surprisingly similar to the quintiles of dietary pattern established by Rose et al. in their study of dietary pattern and GHG impacts (Rose et al., 2017). Policy is a critical tool to drive change in the food system – however it is not a one-size-fits-all proposition and needs to be developed carefully so as to avoid as many unintended consequences as possible (e.g. regressive taxes that fall disproportionately on those with the least ability to pay).

These are just glimpses of what is possible, yet it is important to remember that policies can have both positive and negative impacts as well as unintended consequences.

3.3 USING TCA RESULTS AS A POLICY TOOL TO SUPPORT THE DESIGN OF COORDINATED/INTEGRATED POLICIES

Anderson and Rivera-Ferre (Anderson, Molly D. et al., 2021) show the critical importance of narrative and framing. By referring to the food system impacting all seventeen SDGs illustrated in Annex I, the answer to the question 'TCA is a policy tool for what?' can be found. What is described there is a narrative supporting a food system framing that is centred on people, their right to power and control over their lives, inherent resilience for responding and reacting to a largely unforeseeable future, the environment, circularity of material flows, as well as governance that strives for social equity. The importance of having such a narrative is to frame and policy development. The absence of a framing narrative can impede progress towards achieving healthy and sustainable dietary patterns. The last decade has not seen declines in obesity rates, cancer rates, GHG releases, phosphorus pollution of waterways, or plastic waste in the oceans, to name a few – and yet there have been innumerable efforts to improve all of these. In addition, without an aspirational narrative it is more difficult for TCA to be best used - the breadth of options is too large to make sense of.

What this narrative says is that it is not possible to 'solve' the problem of food and nutrition insecurity in a manner that allows for agency by individuals without 'solving' other issues in the food system (e.g. poverty level wages or gender equity). It also strongly implies that starting at the agricultural production end of a supply chain will preclude accounting for other SDGs, production is typically taken out of the 'production for what' context. Policy development cannot be separated from people within the region of interest. Finally, this framing narrative implies that local/regional systems should take precedence, without being exclusive over global supply chains. It does, however, also imply the need to maintain global supply chains to ensure continued food security in times of regional crisis (e.g. severe drought) and for products that are not feasible to grow/ raise regionally given the global levels of migration and attendant cultural patterns.

Without incorporating this as a constituent of the analysis it is impossible to achieve natural resource circularity (i.e. organic waste back to production) since production is typically taken out of the 'production for what' context. Policy development cannot be separated from people within the region of interest. Finally, this framing narrative implies that local/regional systems should take precedence, without being exclusive over global supply chains. It does, however, also imply the need to maintain global supply chains to ensure continued food security in times of regional crisis (e.g. severe drought) and for products that are not feasible to grow/ raise regionally given the global levels of migration and attendant cultural patterns. Without incorporating this as a constituent of the analysis it is impossible to achieve natural resource circularity (i.e. organic waste back to production).

TCA can support the development of policies. For example, policy development that should be focused around staying below planetary boundaries and above the social floor would consider the perspective of what constitutes a healthy diet, avoiding unintended consequences as much as possible (i.e. using a precautionary approach). The first implication of this is that beyond whatever boundaries are set (unless they are global political/geographical boundaries), international regulations, agreements and laws need to be reformulated to retreat from the notion that all international trade is positive. The second implication of this is that within the established political/ geographical boundaries, greater agency needs to be afforded to civil society and less agency to the private sector.

Given this, TCA 'mandates' the development of a coordinated set of policies that are continually checked against one another and against the ultimate goal of desired dietary patterns, where food has a set of intrinsic qualities amongst the largest swath of the population. A number of domains need to be nurtured via TCA-derived policy in developing and supporting healthy, sustainable dietary patterns: 1) being centred on people; 2) people's right to power and control over their lives; 3) inherent resilience for responding and reacting to a largely unforeseeable future; 4) circularity of material flows; 5) staying within the planetary boundaries; and 6) governance that ensures social equity. Using the example of policy around increasing fruit and vegetable consumption, where power dynamics are at the forefront of the policy construction, a first question to ask is: 'who has a say in the construct?'. Other stakeholders in the construct include consumers (e.g. food access and security, recycling of waste); retailers (e.g. support for post-harvest technology in underserved areas; domestic sourcing expectations, renewable energy use, liveable wages, right to unionize); distributors (e.g. packaging, renewable energy transportation, liveable wages, right to unionize); processor(e.g. packaging, renewable energy, liveable wages, right to un ionize, chemical use); and producers (e.g. production techniques that eliminate or greatly minimize chemical inputs, compost use and waste recycling, efficient water use, soil building, liveable wages, right to unionize for farm workers, reasonable farmer income, renewable energy use) levels. Depending on the primary type of food system – traditional, modern or mixed – these will take different forms. Next, policies are considered that implement research and development to improve processes and materials, and develop new technologies that are scale- and price-appropriate for a range of scales in production, processing and distribution. The goal in all of this is to answer the following questions: 'Is this policy helping to achieve a healthy and sustainable intake of fruits and vegetables for the entire population? Does it allow the ability to recover from catastrophes and maintain the same function (resiliency)? Does it give the broadest measure of the population the ability to participate?' In essence, 'does it make it easy for the population to consume a healthy, sustainable and culturally acceptable dietary pattern?'

With these questions in mind, the next section explores some recommendations for policymakers to enable/adopt/ mainstream TCA and integrate the findings into policy design. The aim is for the policy to lead to regenerative, resilient and sustainable food systems and enable people to consume a dietary pattern commensurate with such a system.

3.4 RECOMMENDATIONS FOR POLICYMAKERS TO ENABLE/ADOPT/ MAINSTREAM TCA AND INTEGRATE TCA DIETARY PATTERN FINDINGS INTO POLICY DESIGN

TCA can be applied at various policy levels. For the purpose of this exercise, dietary patterns and the use of TCA at the national level will be considered. There is an unavoidable global complexity with variations across continents, regions and nations. Yet, TCA is adaptable for all with an understanding of the local/ national context and it is reasonable to scale this up to a multi-national region (e.g. the EU) or down to a sub-national region (e.g. the Federal States of Germany, States in India) as desired. In some cases national-level strategies may have to abide by supra-national policies (e.g. German policy and the EU) and/or it also has the ability to influence/direct activities at higher and lower levels of governance organization. The private sector cannot be the driving force for this needed change. There is a broad spectrum of businesses which are increasingly committed to improving their sustainability portfolio. However, overall, they do not ask the question 'if the focus is on healthy and sustainable dietary patterns should my business exist in its current scale or scope?'. Their primary interest is improving their within-business metrics against either an industry standard or an internal standard from some past baseline. This does not mean to imply business is not important, but is meant to imply that businesses cannot be the arbitrators of the necessary metrics and needed policies – this should predominantly be up to a combination of civil society and government.

The desire for a TCA of a nation's dietary pattern must not preclude immediate action. Change can be initiated and much can be learned through a TCA analysis and implementation of dietary patterns that can serve as a basis for further integrated policy and legislation.

Table 2 summarises food system arenas in which policy change will need to occur over the long run to contribute to sustainable transformation, and provides examples of how this can be informed by using TCA. Some of the areas mentioned are discussed in more detail below.

AREAS IN WHICH SHIFTS THROUGH POLICY CHANGE WILL NEED TO OCCUR	EXAMPLES OF TCA SUPPORT
Highlighting **domestic production**.	Analysing the externalities of not recycling natural resources.
Agriculture and farming incentives to stay within planetary boundaries and above the social floor – requiring a good understanding of what this means at the farm level with regards to: • eliminating chemical pollutants; • eliminating soil and soil carbon loss with net carbon sequestration as feasible (i.e. enhancing soil quality); • maintaining nutrient balance in soil and avoiding nutrient losses to air or water; • enhancing biodiversity in the agricultural landscape; • using blue water resources cautiously (surface and aquifer waters); • minimizing the use of mined and manufactured nutrients, with those used not escaping the agricultural landscape (either to aquifers, as surface runoff or volatilization); • developing non-fossil fuel mechanization; • living wages for farm workers and average net incomes for farmers; and • safe working conditions for farm workers.	Identifying and quantifying negative (e.g. pollutants, losses in natural resources) and positive externalities (e.g. enhancing soil quality and soil carbon).
Production and supply chain incentives to stay within planetary boundaries and above the social floor: • eliminating chemical pollutants (including endocrine disrupting chemicals or EDCs (see below) in packaging), net zero or better carbon, water use, transition to renewable energies; • living wages and safe working conditions across supply chains; • gender equity in treatment and opportunities across supply chains; • developing know-how that is broadly shared; • governance power distribution and the ability of people at all scales of operation to participate including unionization rights; • circularity of nutrient and organic waste flows; • zero waste in the system.	Identifying negative externalities (e.g. of issues such as income below living wages) and positive externalities (e.g. being above the living wage level across the supply chain).
Ensuring that **consumers** are facing: • greatly reduced health risks resulting from food related diseases or chemical pollutants; • a food environment that ensures that the healthy and sustainable option is the most affordable one and easiest to access; • access to and availability of healthy and environmentally friendls food options, at all times and to all parts of society, ensuring zero food insecurity; • a food supply that respects cultural habits.	Highlighting the externalities of current food and health care systems. If extrapolated, TCA can even help identify better ways to spend health care resources as a result of avoiding costs related to a misfuncitioning food system.
Government-funded research, innovation and development to gather details about food system externalities and to gain greater insights into those practices that stay within the social and planetary boundaries (e.g. what is needed for a net zero-carbon food system?). It follows that the economy must be recognized as an outgrowth of the four capitals and therefore kept within social and planetary limits.	Indicating where additional research is needed by highlighting areas lacking data.

Table 2: Required policy change and examples for possible TCA interventions.

DOMESTIC PRODUCTION

Ideally the global food system should become quantitatively more regional/ local in nature while still having a national/ global context and connectivity. The geographic context argues that global, national, regional, and local governance should work together proactively to organize cooperatively on this issue – minimizing or eliminating environmental degradation so as to stay within planetary boundaries while ensuring that all people are above the social floor. While there have been studies indicating that, in some cases, imported food has a lower carbon footprint than locally produced (e.g. lamb and the UK/ New Zealand (Saunders et al., 2009)) this fails to account for a number of opportunities and developments – for example reconstructed pastures with high legume content, intensively managed grazing with virtual fencing, renewable energy driven infrastructure including movement to market, nutrient circularity and net carbon sequestration potential of the production system. Also, there are implications generally for: nutrient circularity; the ability of current technology to electrify shorter supply chains with renewable energy; the coupling of consumption to values of our food supply; and emerging issues in production for some imports in the home country of origin (especially water and drought). Hence, there are significant reasons within the matrix of needs to secure greater domestic production across the dietary pattern.

AGRICULTURE AND FARMING

In the report, we have taken organic production and processing as an example of a direction to move in developing sustainable food systems. This does not imply that organic production is the ultimate or gold standard for all areas of concern. It has been shown, though, that this production practise has the potential to feed the world – under certain preconsitions (Muller et al., 2017): a need to reduce land devoted to animal husbandry and a reduction in food waste, both needed for sustainably feeding the world anyhow. The one challenge that remains is nitrogen usage, which can partly be improved through resource circularity – another argument for greater localization/ regionalization.

PRODUCTION AND SUPPLY CHAINS

Endocrine Disrupting Chemicals (EDCs) in the food supply are “an exogenous substance or mixture that alters function(s) of the endocrine system and consequently causes adverse health effects in an intact organism, or its progeny, or (sub)populations” (World Health Organization et al., 2013). They are widely used in food and agriculture within pesticides, taste and appearance enhancers, flavour preservatives and for food packaging. Among other impacts, there is strong linkage with male testicular cancer, female breast cancer, and hints to long term effects. Estimates reckon that the economic costs (health, lost productivity, etc.) of these side effects amount to about USD 217 billion in the EI (1.28% of GDP) and USD 340 billion in the US (2.33% of GDP, of which USD 42 billion is due to pesticides alone) (Attina et al., 2016; Trasande et al., 2016). By starting from a vantage point ot healthy diets ad moving up the value chain, these chemicals would be banned from all packaging materials (e.g. not just Bisphenol A (BPA) but also its cousins Bisphenol S (BPS) and Bisphenol F (BPF) (Service, 2018)) as well as in their use as taste and flavour enhancers and as pesticides (e.g. atrazine and derivatives). This means policy, research and innovation would encourage a much greater percentage of the food supply to be provided from organic or organic+ production as well as the supply chain management being more rigorous in eliminating these chemicals especially from packaging materials.

Additionally, it is important to recognize that there is an opportunity. A new study estimates 8.7 million deaths in 2018 due to the fine particulates from burning fossil fuels (Vohra et al., 2021). Along with all the other data regarding our food system and health care costs – both from dietary patterns and production practices – this indicates a massive opportunity. It may be reasonable to engage either the government health care sector (where there is nationalized health insurance), the health sector generally (including nutritionists) or private insurers to see how they can be engaged in developing policies and practices to encourage shifting to more healthy dietary patterns.

Returning to the aspirational narrative discussed earlier in this report there are also opportunities for a range of manufacturing and supply needs. Increasing localization in the global north will mean greater numbers of farmers who have the chance to scale up without linear increases in labour (e.g. the use of scale-appropriate robotics especially for weed control but also planting and harvesting). Domestically, ensuring that this occurs in a way that negates monopolization of technology and provides greater opportunities for a greater number of people is of importance to meet environmental, social and individual needs. Moving towards a renewable-energy driven production and processing-based food system implies a range of equipment needs – from tractors and cultivators to scale-appropriate processing. This begins to drive a strategy for robust economic development that stays within the planetary boundaries and the UN Human Rights social floor.

FOOD ENVIRONMENTS

In the global south it is likely that the ratio of urban to rural population will increase over the next several decades. As most food is produced by small holder farmers in rural areas this has implications for food security. As fewer rural farmers, relative to the urban population, generate the food supply it is imperative that strategies around scale-appropriate, land tenure, stakeholder driven technology changes and equity in technology access be emphasized and prioritized.

Given that people derive their daily dietary pattern from a variety of sources, there are a variety of strategies that can be used to modify behaviour. Schools and other institutions are key sources of food for many people and often government funding is involved. Mandates over dietary pattern distribution, calorie content and sourcing can be useful. In Michigan, US a State program provided US$0.10 per meal towards use of Michigan fruits, vegetables and dry beans (with a required 1:1 match from the local school district).

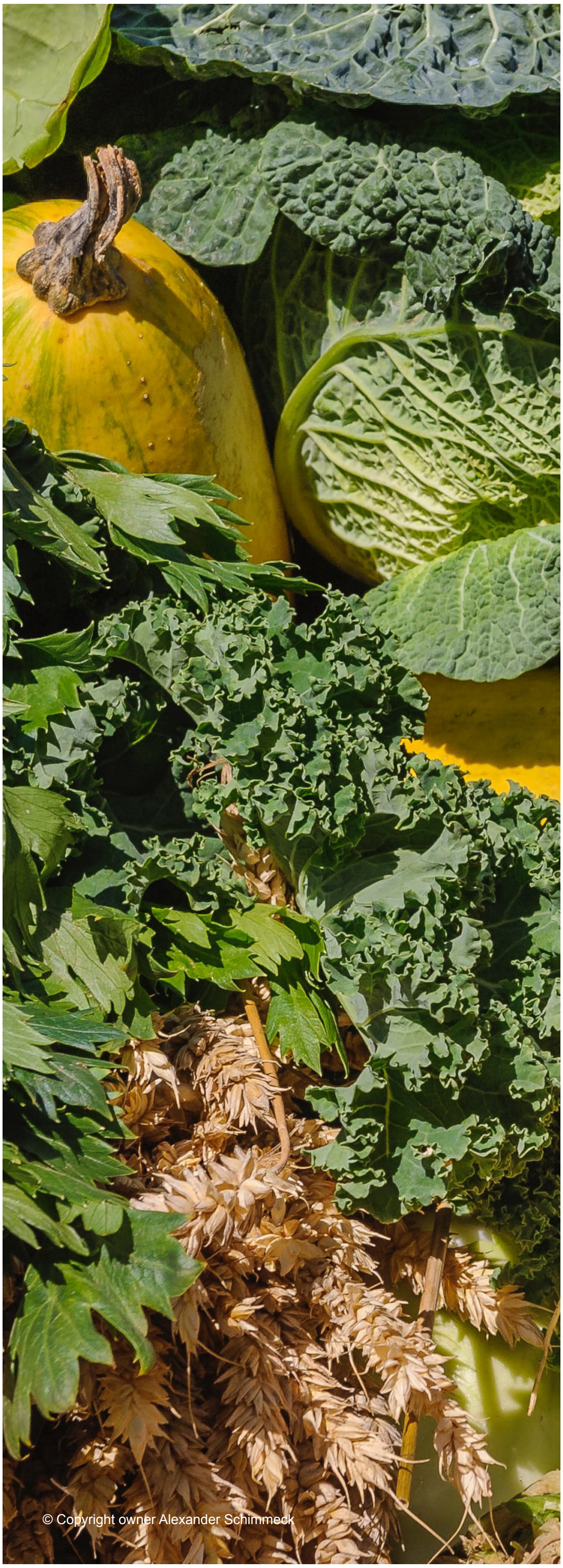
This added US$2 million dollars of State money in the fiscal year to fruit and vegetable purchasing for school meals.[11]

Administratively there are a range of instruments that can be used. For example, food can be mandated for reformulation to have less calories, fat and salt as in the case of the new EU regulation on the use of industrially produced trans-fatty acids in foods (European Commission, 2019).

GOVERNMENT FUNDED RESEARCH

Most countries have universities and/or government-run research facilities receiving government funding for agriculture and food system related research. Shifting this funding to de-emphasize research that does not move in the direction of staying within the planetary boundaries while meeting social and individual rights and scaling up funding for research, would be a definitive move in this direction and is essential. Also, private philanthropy could do more to drive research in this manner.

As an example for a possible political setting to apply a TCA analysis staring from a diets perspective, we could look at the European Commission's 'Farm to Fork Strategy' (European Commission, 2020). With dietary patterns as the entry point, it might be renamed 'Fork to Farm Strategy'. A report states that "even though the EU's transition to sustainable food systems has started in many areas, food systems remain one of the key drivers of climate change and environmental degradation.



[11] https://www.tencentsmichigan.org

There is an urgent need to reduce dependency on pesticides and antimicrobials, reduce excess fertilisation, increase organic farming, improve animal welfare and reverse biodiversity loss" (emphasis theirs). The report outlines a wide range of supporting policy as well as the range of policies needed and promised within the EU. There are others reports for other geopolitical settings, with similar messages.

It becomes clear from reports that have been published that there are a range of strategies and tools in place for policy-makers. TCA can help in quantify impacts, giving more weight to the arguments in favour of changes, and providing analyses where they are lacking – given the necessary research funding ismade available.

CONCLUSION

REDESIGNING FOOD POLICY

The diets that people consume daily are the product of a large number of complex food system factors, and they have far-reaching implications. Dietary choices determine how natural resources are managed and used, how livestock is reared and crops are grown, how many and which types of inputs are used, how much processing is done, how fair producers are paid and treated, how healthy and nutritious daily meals are, how far food has to travel, and how much waste is generated along the way. What is eaten is driven and influenced by a variety of factors, including a wide range of supply and demand side policy measures and interventions (i.e. administrative, market-based, information-based and behavioural policies).

These policies have in large parts been developed using partial, incomplete or omitting information, often neglecting significant impacts on the environment, livelihoods and human health. A more holistic, integrated and systems-based approach is needed for (re)designing food policy that supports sustainable and healthy diets while taking into account the true cost of food. As argued in this report, TCA seeks to respond to this call by assessing the economic, ecological and social costs and benefits of food systems in order to provide more accurate and reliable data to policymakers.

It is also a call for more robust policies in terms of research, development and business/ consumer/ farmer support, so that the planetary boundaries are upkept and everyone stays above the social floor. While TCA is still developing, the report provides suggestions for how it can be used as a policy tool to incentivize sustainable and healthy food consumption and a broader transformation of food systems.

Overarching global strategies for food system transformation are essential to meet the Paris Climate Accord agreements and the UN SDGs. Moving from a 20th to a 21st century global food system that meets environmental and social justice goals depends on a willingness to change behaviours. National policy actions need to be coordinated across current policy silos for agriculture, food, health and environment allowing for an integrated policy approach. TCA provides a tool for assessing best-case scenarios across multiple domains.

Assessments based on TCA results are needed to create the best fitting food system leading to sustainable dietary patterns. Solutions for sustainable food systems need to be developed in the context of a global goal.

This goal should ensure that every human being is able to access and consume a healthy, sustainable diet every day and in line with cultural traditions. This report proposes that political strategies should be developed starting from dietary patterns and moving backwards along supply chains to identify the most suited policy interventions. It is for the purpose of well-informed policy interventions that application of a TCA approach is recommended, to acquire knowledge on trade-offs across the potential paths of development. Strategic decision-making in a participatory governance approach will be the way forward, making sure that the food system stays within the bounds of environmental sustainability and human rights.

Since TCA is still in its infancy, this synthesis and in particular the related report outlines a stepwise approach and offers practical guidance on the design of TCA at policy level. This should help to enable the uptake of TCA as a policy guidance tool. Supporting activities, i.e. funding of further research in the field as well as provision of additional data, will be necessary for a thorough TCA analysis of diets. Caveats aside, TCA is both a necessary and useful tool for developing integrated food system policy that is serious about ensuring healthy, sustainable diets for the global population today and into the future.

ANNEX I: FRAMING THE OPPORTUNITY TO IMPROVE ENVIRONMENTAL, HUMAN, SOCIAL AND ECONOMIC WELL-BEING BY PROMOTING SUSTAINABLE DIETS

This report starts from the perspective of consumption and dietary patterns. They are both a signal to production and supply chain behaviour as well as driven by them. The notion of supply driving demand or demand driving supply is one that can (and is) debated regularly, but is an unnecessary debate for purposes of this report. Rather, there is a need for a more holistic accounting of costs and benefits to various dietary patterns – a True Cost Accounting (TCA) approach. TCA is a tool for helping make transparent both positive and negative externalities in the food system. It means nation-states critically evaluating what and how their residents currently eat. To some extent it means consumers (especially in the global north but not entirely) developing a global perspective on their dietary patterns. The report is focused on using TCA and starts from a dietary pattern perspective to develop government-based policies for food, agriculture and the food system. A dramatic policy reform is needed – one in which policy starts with the very deliberate end goal of sustainable, healthy and culturally appropriate dietary patterns. Moving along the supply chain on a range of policy threads the report describes a heuristic – keeping our economic activity within the environmental and social boundaries; a strategy – begin with dietary patterns and work backwards up the supply chain as a starting point for policy development; and a tool – True Cost Accounting for analysing the positive and negative externalities of different options. Finally, there is a need for global and national governance, strongly supported by civil society, to meet this challenge.

Entering the 21st century's third decade, all indicators point to a relatively short period of time in which to markedly improve negative environmental and social impacts globally and within nation states – especially regarding effective climate change mitigation. The current food system is responsible for 24% of GHG release, 70% of freshwater withdrawals, is the primary driver of tropical deforestation and biodiversity loss and increases the risk of future pandemics (WWF, 2020a). Since 1970, there has been a decline in nearly all areas of nature's capacity to contribute ecosystem services and enhance life quality (IPBES, 2019). In the absence of fundamental change to the food system, imminent irreversible environmental consequences and increasingly conflict-laden social conditions can be expected. This is inarguably the greatest challenge that has faced modern human kind; this also comes with decided opportunities. The investments needed to tackle the climate crisis are – if used wisely – an important building block towards peace, sustainability and the broadest human welfare seen in the modern world. There is an opportunity to shift from non-renewable to renewable energy while also drastically reducing the incidence of air pollution-related diseases; to advance gender and racial equity while exponentially expanding opportunity and meaningful work; and to significantly improve fresh water quality and to virtually eliminate human pollution. Conditions like the COVID-19 global pandemic force changes but are not necessarily permanent while solutions are needed that have a degree of permanence. For example, in the early stages of the pandemic global GHGs released dropped precipitously as people quarantined, but emissions have returned to pre-pandemic levels quickly (Le Quéré et al., 2021). Permanent and substantive changes start with inclusive governance and government policy driven by strong participatory and shared power strategies.

Sustainable production does not simply mean tweaking a set of production practices that have caused issues including: massive soil loss; water pollution with nitrogen, phosphorus and a range of toxic chemicals; toxic air pollution in communities from confined animal feeding operations; escalating rates of species loss as new, biodiverse areas are ploughed (especially in the Indian subcontinent, Brazil, South East Asia, Central America and Eastern China (International Resource Panel, 2019)); and 24% of total atmospheric CO2 additions annually. It does mean rethinking what the 'dominant production paradigm', while exploring regional differentiation, should be. It does mean that currently dominating companies will either adapt to this new way of thinking and acting or become obsolete. It does mean that the framing of our economic system needs to drastically alter and work differently – for example using the doughnut economics model of Dr. Kate Raworth in which economics is 'expected' to stay within the social floor and the environmental ceiling (Raworth, 2017). It does means national accounting needs to move away from GDP as an indicator of progress and move towards indicators such as the Genuine Progress Indicator (GPI) that incorporate environmental and social factors not measured by GDP. This is presented as a tool to help make transparent best strategies for a global food system moving into a critical phase of the Anthropocene Era (Carey, 2016) and providing a way to construct national dietary guidelines with linked policy across the supply chain – especially with regards to production targets and strategies.

Figure 7 illustrates how sustainable (in terms of land use) the diets are for various countries (Ritchie, 2017). Note that the average dietary pattern of many countries is either impossible for the world to adoptinsufficient global land to generate that nation's dietary pattern for the global population) or would require an expansion of currently agricultural land (at great risk to a variety of environmental and social metrics).

(As can be seen in Figure 8 this is predominantly because of the vast amount (77%) of agricultural land utilized to produce meat and other animal products (Ritchie, 2017) where land use per capita for food is typically directly correlated with meat consumption, most often ruminant meat.

The UN 2030 Agenda and SDGs [12] provide a starting point for conceiving of the type of transformation necessary in the global food system – rearranged as a 'wedding cake' (Figure 9) of economy, society and biosphere by Rockström and Sukdhev.[13]

[12] https://sdgs.un.org/goals

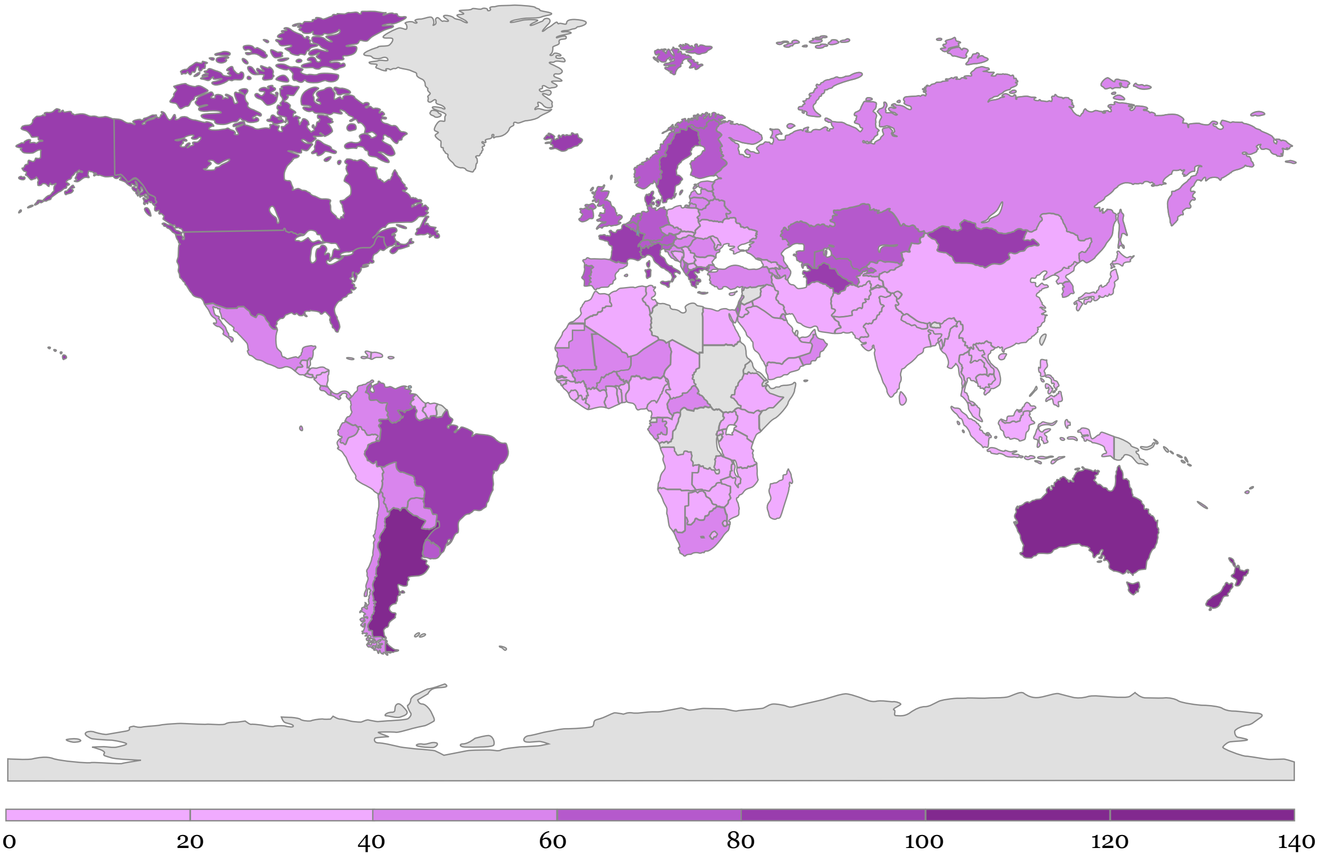


Figure 7: Global land use for food production. Adapted from Ritchie, H. (2019). Half of the world's habitable land is used for agriculture. Published online at OurWorldInData.org. (Online) Available at: https://ourworldindatav.org/global-land-for-agriculture.

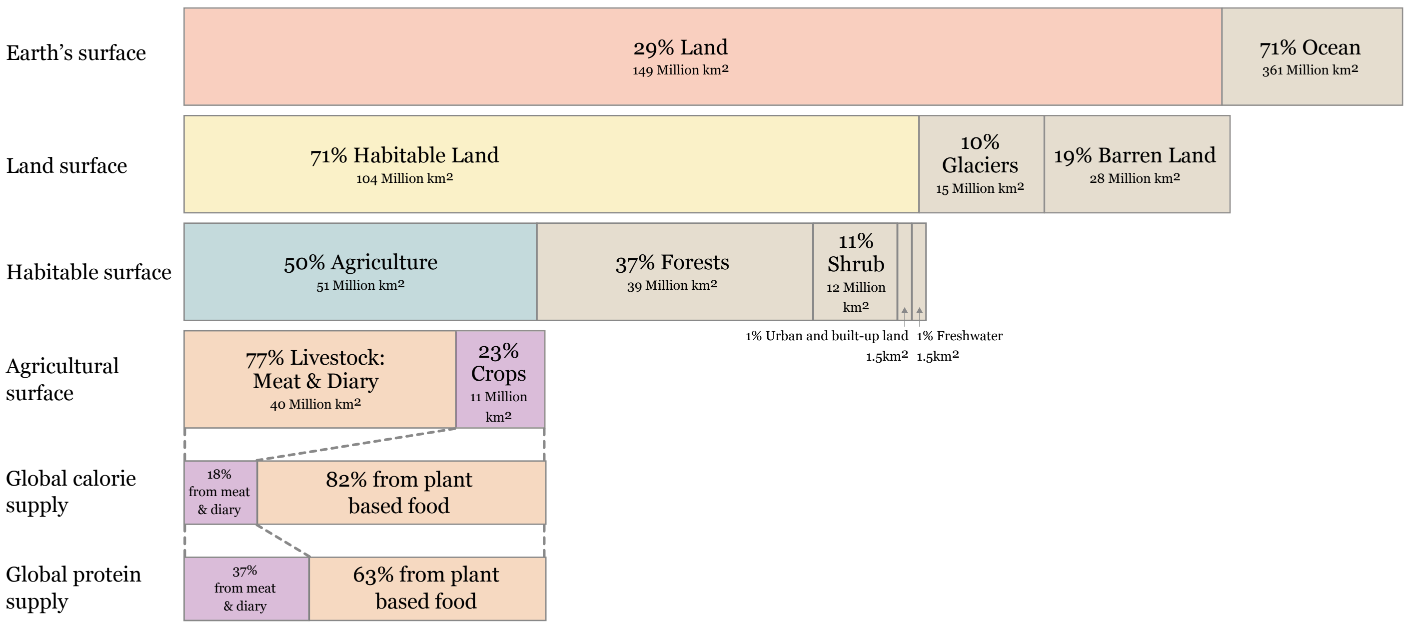


Figure 8: Global land use for food production. Adapted from Rithchie, H. (2019). Half of the world's habitable land is used for agriculture. Published online at OurWorldInData.org. (Online) Available at: https://ourworldindata.org/global-land-for-agriculture.

They offer a set of targets that collectively provide goals for the food system while the food system provides a framework for visualizing how the SDGs relate to one another. In an earlier report (Hamm, M. W. et al., 2018), Hamm outlined an aspirational narrative for the food system that linked the seventeen SDGs. This was then modified through a global outreach to professionals and food system actors (White et al., 2018). Again, it is an aspirational narrative of what the food system can/could accomplish with a strongly linked set of policies and norms that prioritize people's well-being and planetary health

"Let us start by imagining a future where all forms of malnutrition are eliminated (SDG 2) and we have achieved low levels of obesity/chronic disease globally, with greatly reduced levels of acute disease (SDG 3). A world composed of connected webs of cooperation across regions, ensuring diversity, resiliency, and global communication (SDG 17). Local food systems embedded in regions across the globe provide good livelihoods for those engaged in the production, processing, transportation, storage, and marketing of foods, as well as the management of compostable and reusable waste. Food from larger regions and global supplies is embedded with this as needed to ensure food security. The food system is doing its part to eliminate poverty (SDG 1) and provide living-wage work and economic growth (SDG 8) by supporting the creation of jobs of a new middle class in rural areas (including farmers). Women have the same rights and rewards as men in this system (SDG 5), with strong educational systems (SDG 4) supporting sustainable and healthy consumption patterns. While the majority of people live in urban areas, there are robust urban-rural relationships that ensure food security for all urbanites and industries supply healthy processed and fresh foods, as well as appropriate, responsible technology required in the production, processing, storage, and movement of the food supply (SDG 9). Rural people can afford to purchase the food farmers supply to cities. Advertising and market placement are skewed to promote healthy dietary patterns. This helps ensure both food and employment security – markedly reducing the threat of urban uprisings (SDG 16), aiding in sustainable city development (SDG 11), and reducing inequalities (SDG 10). Technical assistance, appropriate technology access, and incentive programs to produce and market food are equitable and increase the information and knowledge flow across the food value chain to all partners. The cycle of production and consumption is completed responsibly (SDG 12) with the use of renewable materials and energies as well as appropriate technology – available to all (SDG 7) – and making use of materials and practices that conserve fresh water and provide clean water (SDG 6). Our lands and waters are conserved and regenerated for humans as well as the flora and fauna we rely upon (SDG 14 & 15).). All of this ensures that our food systems do not contribute to increasing climate challenges – but rather acts as a tool for resolution - and has successfully adapted to changing climatic conditions (SDG 13). This includes continuous public participation in policy and practices to improve these food systems as more is known and experienced. In other words, a network of food systems across the globe embedded in regions provide a strategy for securing a future for healthy people." (White et al., 2018)

Agenda 2030 outlines strategies for accomplishing this and makes very clear that it is the responsibility of each nation-state working in concert with one another by stating, "Cohesive nationally owned sustainable development strategies, supported by integrated national financing frameworks, will be at the heart of our efforts. We reiterate that each country has primary responsibility for its own economic and social development and that the role of national policies and development strategies cannot be overemphasized." (United Nations General Assembly, 2015).

There are a number of issues across the food system that need to be simultaneously addressed - in the field, in the supply chain and at home. Although this includes yield improvement for many crops in many parts of the world and waste reduction (especially food itself) across the food system this report focuses on the key topic of dietary patterns and their relation with sustainability.

[13] https://www.stockholmresilience.org/research/research-news/2016-06-14-how-food-connects-all-the-sdgs.html

Figure 9: The 17 Sustainable Development Goals positioned in relation to the biosphere foundation and the safe operating space for humans on Earth. Reprinted from Folke, C., R. Biggs, A. V. Norström, B. Reyers, and J. Rockström. (2016). Social-ecological resilience and biosphere-based sustainability science. Ecology and Society 21(3):41

ANNEX II: A SYSTEMS PERSPECTIVE ON DIETS, DIETARY PATTERNS AND THE FOUR CAPITALS

GLOBAL AND REGIONAL TRENDS IN FOOD CONSUMPTION AND DIETARY PATTERNS

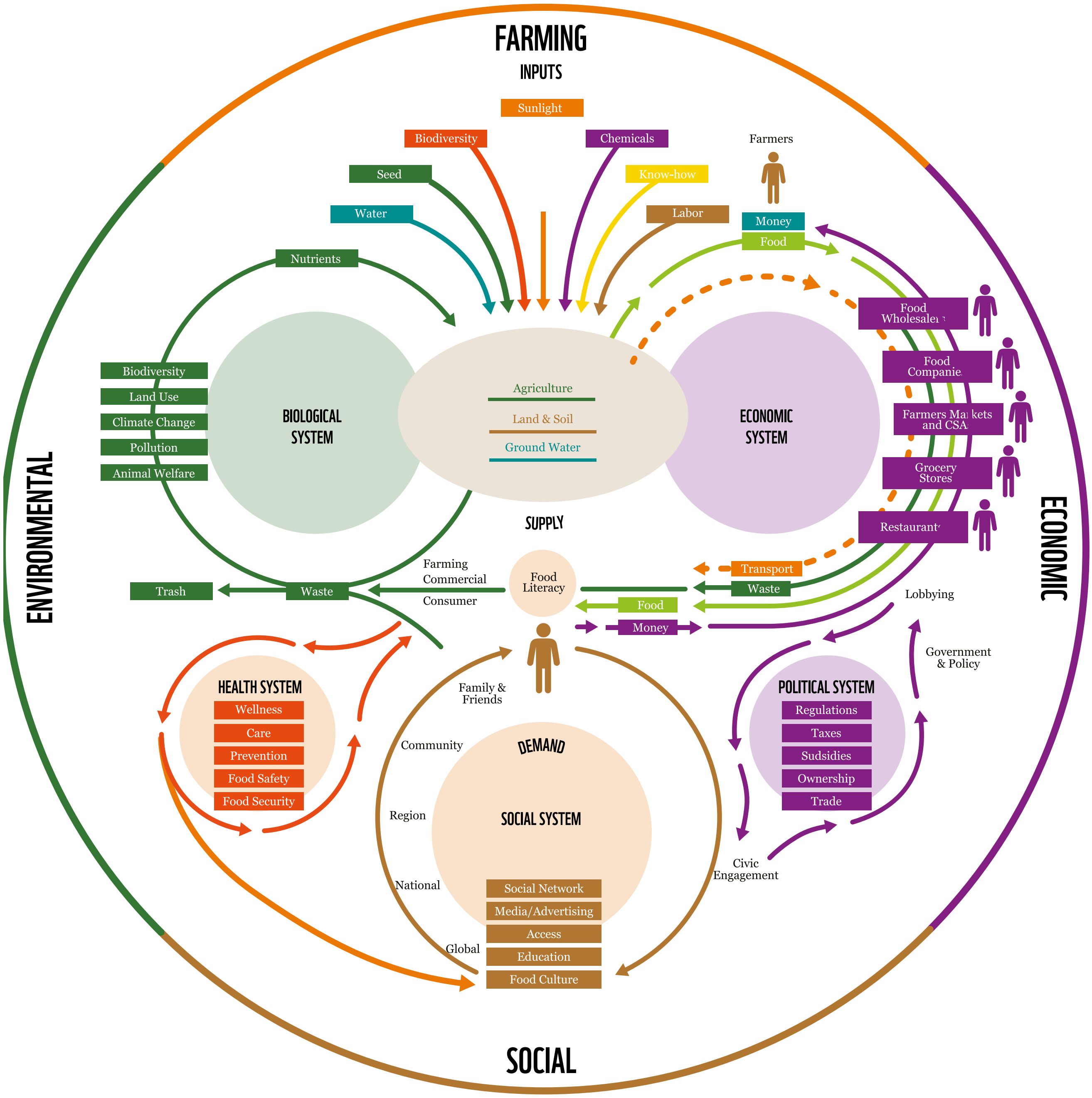


Figure 10: Food systems map that shows how multiple subsystems interact. Reprinted from Zhang, W. et al. (2018). Systems thinking: an approach for understanding 'eco-agri-food systems'. In TEEB for Agriculture & Food: Scientific and Economic Foundations. Geneva: UN Environment. Chapter 2, 17-55. (Online) Available at: https://www.researchgate.net/publication/331385701_Systems_thinking_an_approach_for_understanding_'eco-agri-food_systems'.

What people eat is at the end of set of global, regional, national, sub-national and local supply layers, which often interact in complicated ways – competing with one another, complementing each other and steering consumers towards an array of food products. Overall, they are parts of traditional and 'modern' food systems, often interacting to create in 'mixed' food systems (Pengue et al., 2018). They are embedded in a complex of systems – biological, economic, political, social and health (Figure 10)[14]. However, this is not where dietary patterns begin. They begin on rural and urban lands, in greenhouses, in ponds-lakes-rivers-oceans, on rooftops, in aquaponics facilities and today even in vertical farms. Historically, they begin with local/regional culture – both in the practices of production and the patterns of consumption. They also begin with what food companies decide to pursue as product categories in an increasingly globalized, commoditized food system. They begin with food and agriculture policy often supporting this globalization of supply and demand. Much of this is abetted by advice from researchers at national research institutes, agricultural colleges and universities, as well as private corporations, which in turn can be predetermined by two things: (i) where and what types of funds can be procured to conduct research (e.g. public and private research funding sources); and (ii) the conservative nature of scientific research, where science conducted within these institutions tends to stay within existing paradigms and not move beyond their history. Often, this is reinforced by private sector research support. All this more or less determines a set of agricultural production inputs – including fertilizers and pesticides – that starts the cascade onto the plate (Buttel, 2005).

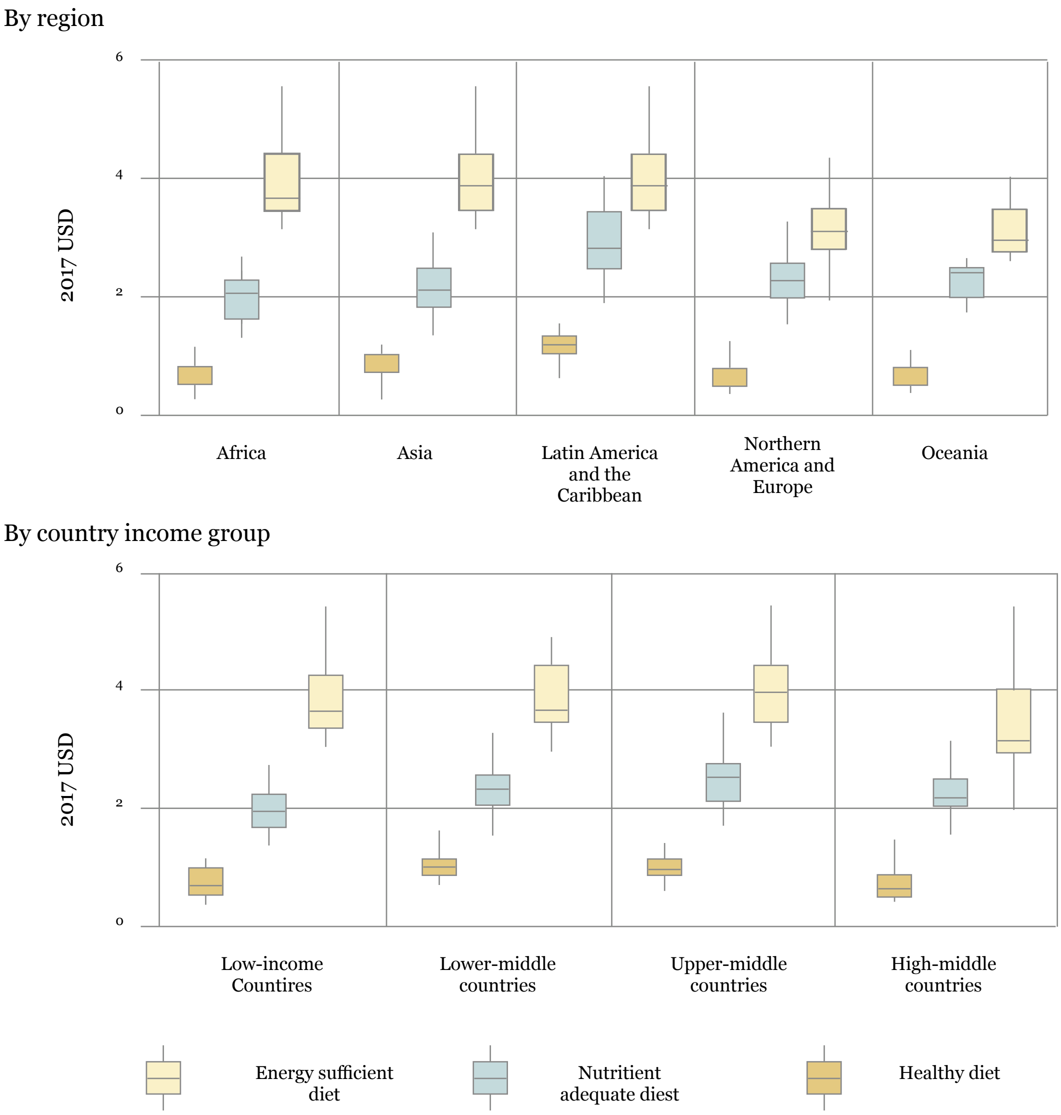


Figure 11: The cost of energy sufficient, nutrient adequate and healthy diets by region and country income group. Adapted from Herforth, A., Bai, Y., Venkat, A., Mahrt, K., Ebel, A. & Masters, W.A. (2020). Cost and affordability of healthy diets across and within countries. Background paper for The State of Food Security and Nutrition in the World 2020. FAO Agricultural Development Economics Technical Study No. 9. Rome, FAO. (Online) Available at: http://www.fao.org/3/cb2431en/cb2431en.pdf

[14] https://www.nourishlife.org/teach/food-system-tools/

Concerning healthy diets, there are variations in national dietary guidelines[15]. A benchmark to use are the WHO guidelines for a healthy diet (WHO, 2020b), which include:

- balancing energy intake with energy expenditure;
- include fruits, vegetables, legumes (e.g. lentils, beans), nuts and whole grains (e.g. unprocessed maize, millet, oats, wheat, brown rice);
- total fat <= 30% of calories, with a shift away from saturated and trans-fats towards unsaturated fats;
- free (added) sugar intake <10% of calories (reducing to 5% increases health benefits) which is equivalent to about 50 grams (12 level teaspoons) in a person consuming 2000 calories. As an example, one 16 ounce (473 ml) bottle of cola has approximately 52 grams of sugar;
- salt intake at less than 5 grams per day (equivalent to about 1 level teaspoon); and
- >= 400 grams (five portions) of fruit and vegetables per day (excluding potatoes, sweet potatoes, cassava and other starchy roots).

Numerous studies also investigate the relationship of various types of foods and dietary patterns to human health (Scarborough, P. et al., 2012; Afshin et al., 2019) and/or sustainability (Tilman et al., 2014; Scarborough, P. et al., 2014a). Most of these studies focus primarily on the end point of the dominant production/processing/distribution paradigm – the bulk of food consumed – and typically fail to account for variations in production strategy, processing, or distribution within various food categories. What is clear are the general trends in consumption and production as well as the implications of these trends for environmental sustainability and human welfare/human rights.

It is far easier to consume sufficient energy than either a nutrient adequate or healthy diet (Figure 11). The minimum cost for a healthy diet ranges from US$3.27 - US$4.57 per day – far in excess of the global poverty level set at US$1.90 per day (Herforth et al., 2020). It is estimated that at least 3 billion people cannot afford such a healthy diet (WHO, 2020a); regionally, there are wide ranges as evidenced by patterns of childhood stunting (FAO et al., 2020). There is also a significant number of people – estimated at 690 million in 2019 – who go hungry. Due to COVID-19, an additional 83-132 million are estimated to go hungry in 2020 (FAO et al., 2020). Although an increasing number of people are calorically malnourished, there is also the opposite problem – a positive net caloric consumption – leading to a global pandemic of obesity.[16]

Figure 12 (World Population Review, 2020) illustrates the levels of obesity in 2019; the total number of obese is estimated at 2.1 billion (or about 30% of the global population). This number has tripled since 1975. Globally, dietary patterns demonstrate relatively low consumption of fruits, vegetables and whole grains, with high consumption of free sugars, free salt and meat.

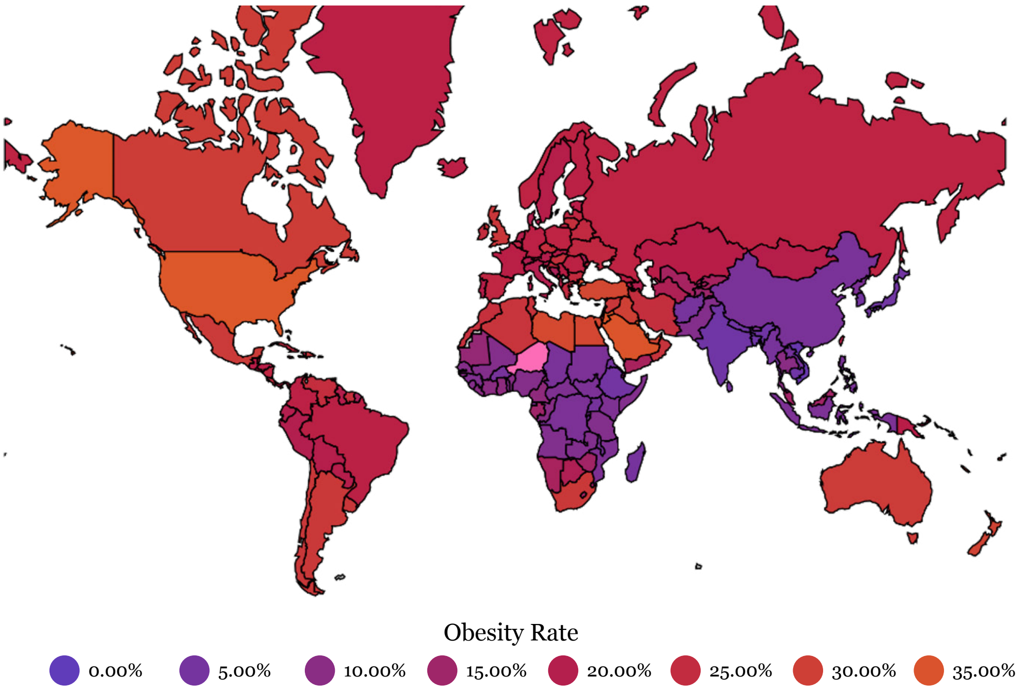


Figure 12: Most Obese Countries 2020. Adapted from World Population Review (2020). Most Obese Countries 2020. World Population Review. https://worldpopulationreview.com/. Available from: https://worldpopulationreview.com/country-rankings/most-obese-countries

[15] http://www.fao.org/nutrition/education/food-dietary-guidelines/home/en/

[16] A person is considered obese if their Body Mass Index (BMI) is over 30.

Having said that, there is also a great deal of national variation for fruit and vegetable consumption, as can be seen in Figure 13 (Micha et al., 2015). The clearest global trend is an increase in overall meat (ruminant and non-ruminant) production, and hence also of consumption (Ritchie et al., 2017). Global production has increased from 71.4 million tons in 1961 to 342.4 million tons in 2018 – a 380% increase in all meat production, including cattle, poultry, sheep/mutton, goat, pork and wild game. Europe and North America dominated production in 1961 while currently, this sector is dominated by China. If current trends continue, global production is expected to double by 2050 (FAO et al., 2019a). Increases have been seen across all species with the largest changes in poultry and pork (Ritchie et al., 2017). In addition, large increases in fish production/consumption have also occurred this century (Naylor et al., 2021).

Per capita meat consumption varies widely across the globe. For example, in India 2019 consumption was about 3.6 kg/capita/yr while in the US it was about 100.7 kg/capita/yr (OECD, 2020).

A global overall increase in ultra-processed foods (UPF) and ultra-processed drinks (UPD) can also be seen (Vandevijvere et al., 2019). In 2016 the largest UPF sales were in North America and Australasia (113.3 kg/capita) and lowest in Africa (14.4 kg/capita) and South and Southeast Asia (14.6 kg/capita). Volume sales of UPDs were highest in North America and Australasia (157.6 kg/capita) and lowest in Africa (37.4 kg/capita). UPFDs already account for over 50% of food sales in the US and Canada. Consumption is increasing rapidly in middle-income countries. This important for two reasons: (i) these foods often have added salt, sugar and/or oils contributing to excess salt and calorie intake; and (ii) a correlation has been found between increases in UPD and UPFs and obesity rates within countries (Poti et al., 2017).

All of this implies that moving forward with a 'business-as-usual' global scenario will lead to greater incidences of malnutrition – both over and under – resulting in greater incidences of food-related non-communicable diseases and prematiure deaths.

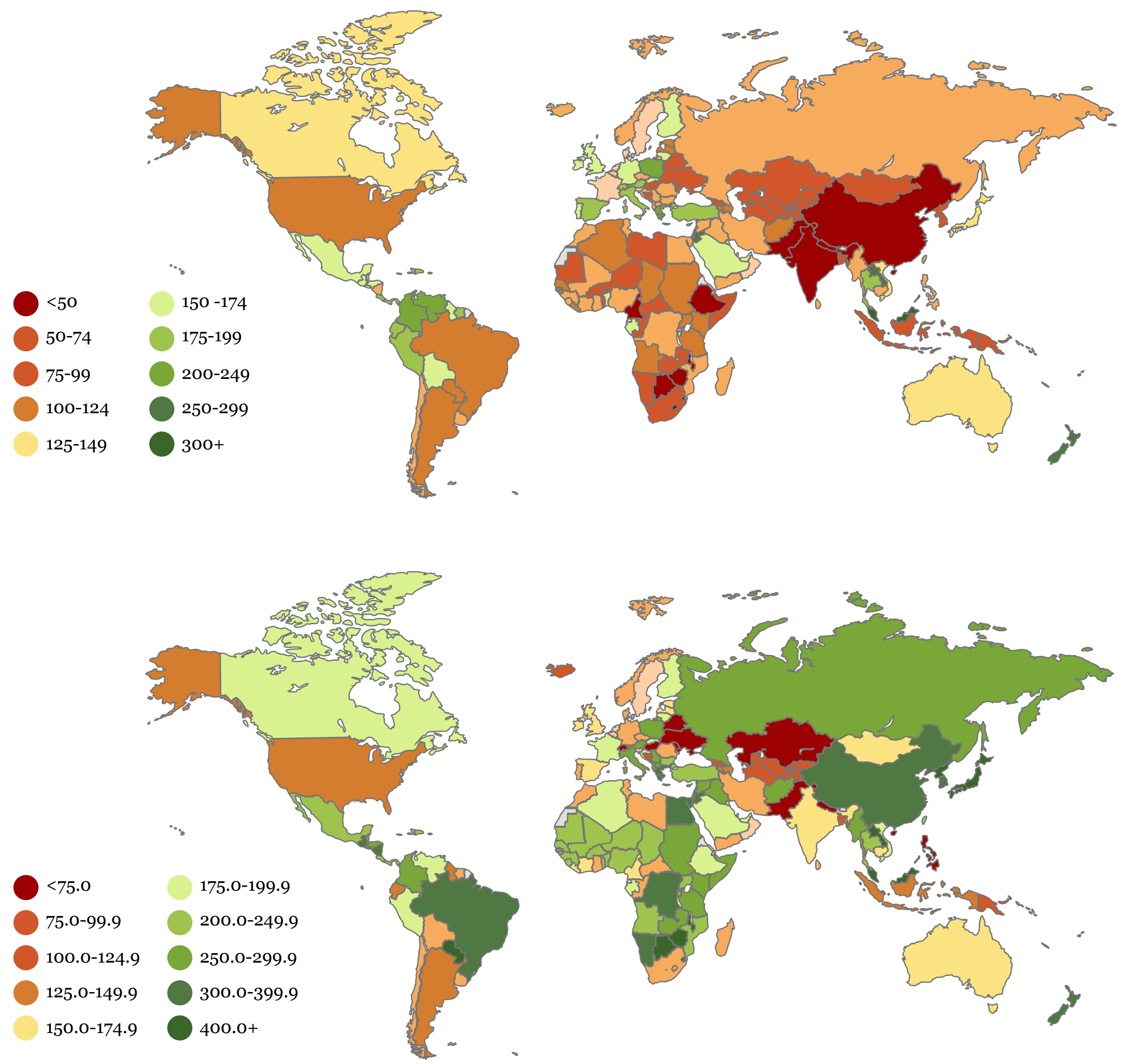


Figure 13: Global and regional mean fruit (A) and vegetables (B) intake (g/d) in 2010 for adults ≥20 years of age in 2010. Reprinted from Micha, R., et al. (2015). Global, regional and national consumption of major food groups in 1990 and 2010: a systematic analysis including 266 country-specific nutrition surveys worldwide. BMJ Open, 5(9), e008705.

POTENTIAL SUSTAINABLE AND HEALTHY DIETARY PATTERNS

The above section explored healthy diets. Here, both healthy and sustainable diets are considered, addressing issues including how these may vary based on cultural and geographical differences, and if it is possible to identify a global dietary pattern that would simultaneously be both healthy and sustainable. A number of papers, both academic and public policy oriented, have been produced to identify options and best-case scenarios (Willett et al., 2019; WWF, 2020a). The first thing to bear in mind is that consumption data typically works in averages – average meat consumption per capita; average daily caloric consumption; etc. However, most people will consume either more, or less, than the average. People also have different needs. Those who expend more calories need to consume more calories, while those with higher normal body weights need to consume more total protein. Hence, one needs to consider the range of typical dietary patterns and determine best strategies for moving those dietary patterns to ones that are healthier and more sustainable. A 2018 study of US dietary patterns is illustrative (Heller et al., 2018); the US dietary patterns were divided into quintiles of total GHG release, reporting that approximately 69% of diet-related GHG emissions are accounted for by people in the top two quintiles. The bottom two quintiles account for about 16%. Thus, dietary patterns vary considerably across a country making it useful to develop strategies that account for wide variations in their current environmental impact – providing assistance for improvement while not expecting, or needing, every individual to shift to the 'best' quintile.

From a planetary boundaries perspective (Rockstrom et al., 2009), a question to ask is: 'what would be the most environmentally sustainable dietary patterns that are also healthy patterns?' The WHO/FAO Sustainable Healthy Diets: Guiding Principles (FAO et al., 2019b) is a very useful starting point – it outlines 16 steps to healthy and sustainable diets that incorporate the general healthy dietary recommendations of Table 3 coupled with environmental and sociocultural impacts.

Table 3: Healthy reference diet, with possible ranges, for an intake of 2500 kcal/day.	Macronutrient intake (possible range), g/day	Caloric intake, kcal/day
Whole Grains		
Rice, wheat, corn and other	232 (total gains 0–60% of energy)	811
Tubers or starchy vegetables		
Potatoes and cassava	50 (0–100)	39
Vegetables		
All vegetable	300 (200–600)	-
Drak green vegetables	100	23
Red and orange vegetables	100	30
Other vegetables	100	25
Fruits		
All fruits	200 (100–300)	126
Dairy foods		
Whole milk or derivative equivalents (e.g cheese)	250 (0–500)	153
Protein sources		
Beef and lamb	7 (0–14)	15
Pork	7 (0–14)	15
Chicken and other poultry	29 (0–58)	62
Eggs	13 (0–25)	19
Fish	28 (0–100)	40
Legumes		
Dry beans and peas	50 (0–100)	172
Spy foods	25 (0–50)	112
Peanuts	25 (0–75)	142
Tree nuts	25	149
Added fats		
Palm oil	6.8 (0–6.8)	60
Unsaturated oils	40 (20–80)	354
Dairy fats (included in milk)	0	0
Lard or tallow	5 (0–5)	36
Added sugars		
All sweeteners	31 (0–31)	120

Source: Reprinted from Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., ... & Murray, C. J. (2019). Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. The Lancet. 393 (10170), 447-492).

Most research on sustainable diets has focused on the environmental aspects – and most typically concerned themselves with carbon footprint/climate change impacts. A few have looked more broadly at the planetary boundaries. Probably the most far-reaching set of recommendations in this regard is the EAT-Lancet Commission Report (Willett et al., 2019). This report has generated a great deal of response – both positive and negative[17] - and provides a valuable starting point for thinking about dietary patterns. The broadest tranche of critique concerns the recommendations regarding meat but disregards data demonstrating the potential positive environmental attributes of grazed ruminants as well as disregarding cultural variation across the globe. The report uses dominant production paradigms throughout its analysis and is therefore not particularly useful for considering positive and negative externalities of alternative production paradigms as well as traditional food systems. The key point regarding pattern shifts outlined in this report is: Transformation to healthy diets by 2050 will require substantial dietary shifts, including a greater than 50% reduction in global consumption of unhealthy foods, such as red meat and sugar, and a greater than 100% increase in consumption of healthy foods, such as nuts, fruits, vegetables, and legumes. Table 3 provides a healthy reference diet, with possible ranges, for an intake of 2500 kcal/day. This pattern of ranges is greatlyreduced in animal product intakes – with little ruminant meat and pork and very limited amounts of chicken/poultry, eggs and fish. It is essentially a semi-vegetarian diet. It should be considered that studies of this type only analyse the carbon released in the process of production (gross carbon release) without considering potential 'carbon offsets' of any carbon sequestration (e.g. soil carbon increases) that could be occurring. It is a systemic analytic fallacy to use gross carbon release rather than the sum of release and capture (net carbon release) in considerations of GHG load and dietary pattern.

Another strategy for more sustainable diets comes from the WRI (Ranganathan et al., 2016). They recommend three fundamental shifts: 1) reduce overconsumption of calories; 2) reduction in overall consumption of protein by reducing consumption of animal-based foods; and 3) a shift specifically away from beef. As can be seen in Figure 14, caloric availability, a surrogate for intake, is increasing across a range of countries and regions.

This increase in calories per capita generally involves the use of more land and more natural resources. It is very region/country specific. As can be seen in Figure 15, there is a broad range of daily protein intake, especially animal protein, regionally. An overall reduction in animal meat consumption would decrease land and fresh water use (Ranganathan et al., 2016).

The Mediterranean Diet has been promulgated as both healthy (Lăcătușu et al., 2019) and sustainable (Berry, 2019) with reductions in fresh water use, land use and GHG release (Germani et al., 2014). Generally, this diet is not dissimilar to the one promulgated by the EAT-Lancet Commission except for the conscious inclusion of olive oil, an oil rich in monounsaturated fatty acids, and being slightly less stringent on meat and meat product consumption as it has been practiced in the Mediterranean region. However, it is questionable how broadly adoptable this is, given the fairly narrow ecological band for olive production. Other dietary patterns that have good metrics both related to human and planetary health are vegetarian and vegan diets (Soret et al., 2014).

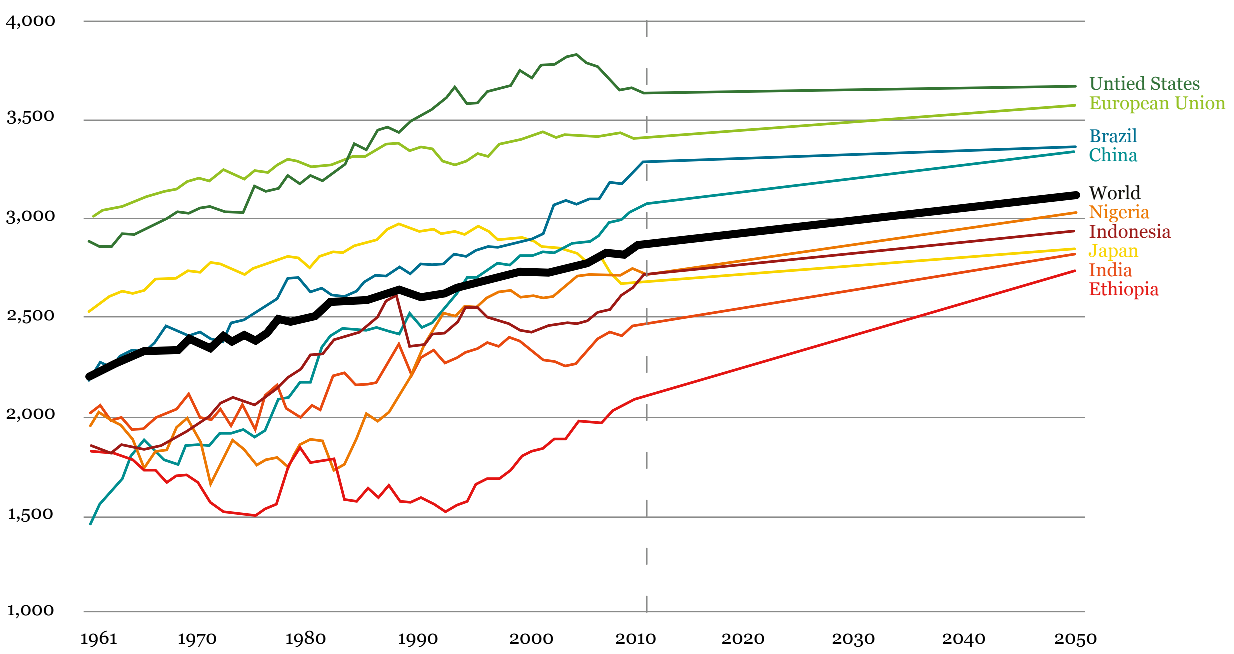


Figure 14: Per Capita Calorie Availability is on the Rise. Reprinted from Ranganathan, J., et al. (2016). Shifting Diets for a Sustainable Food Future: Working Paper, Installment 11 of Creating a Sustainable Food Future. Washington, D.C. World Resources Institute. (Online) Available at: https://files.wri.org/d8/s3fs-public/Shifting_Diets_for_a_Sustainable_Food_Future_1.pdf

[17] https://www.tabledebates.org/research-library/reactions-eat-lancet-commission

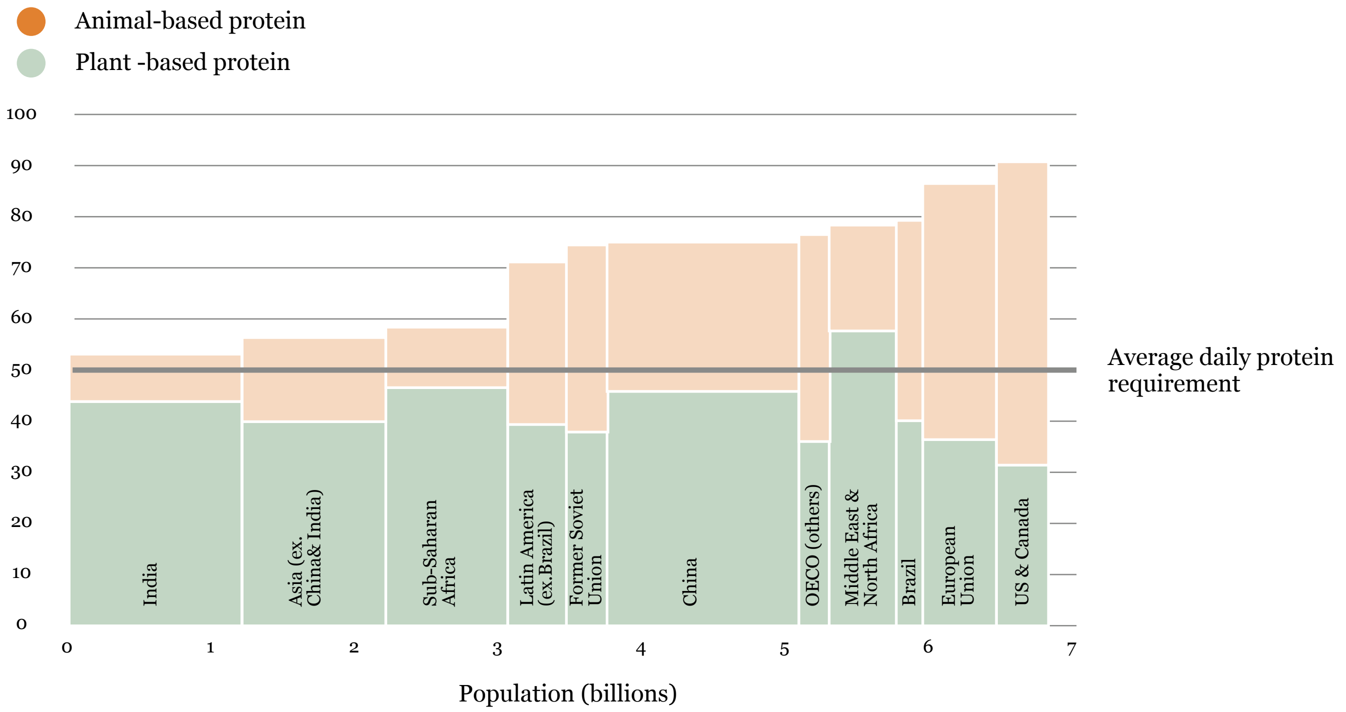


Figure 15: Protein Consumption Exceeds Average Estimated Daily Requirements in All the World's Regions, and is Highest in Developed Countries. Adapted from Ranganathan, J., et al. (2016). Shifting Diets for a Sustainable Food Future: Working Paper, Installment 11 of Creating a Sustainable Food Future. Washington, D.C. World Resources Institute. (Online) Available at: https://files.wri.org/d8/s3fs-public/Shifting_Diets_for_a_Sustainable_Food_Future_1.pdf

The WWF released its Planet Based Diets in 2020 (WWF, 2020a). This report proposes five strategic actions:

- reversing biodiversity loss;
- living within the global carbon budget for food;
- feeding humanity on existing cropland;
- achieving negative emissions; and
- optimizing crop yields

The Food and Land Use Coalition Report (The Food and Land Use Coalition, 2019) outlines ten critical transitions within the context of: 1) nutritious food; 2) nature-based solutions; 3) wider choice and supply; and 4) opportunity for all. This is a broad reaching report that seeks to monetize the needed transitions. Here, a global economic analysis was conducted and found US$5.7 trillion of economic prize by 2030 with US$300-350 billion of investment required each year for the transformation of food and land use systems through 2030.

This is the only such report seen to date that compares the carbon footprint of national dietary guidelines to the nation's per capita dietary carbon footprint. As seen in Figure 16 some countries current guidelines recommend a higher footprint that others. Some countries, such as Bangladesh, have a low footprint per capita that is consistent with the nation's dietary guidelines. Country comparisons of other planetary boundaries relative to dietary guidelines do not appear to have been conducted to date

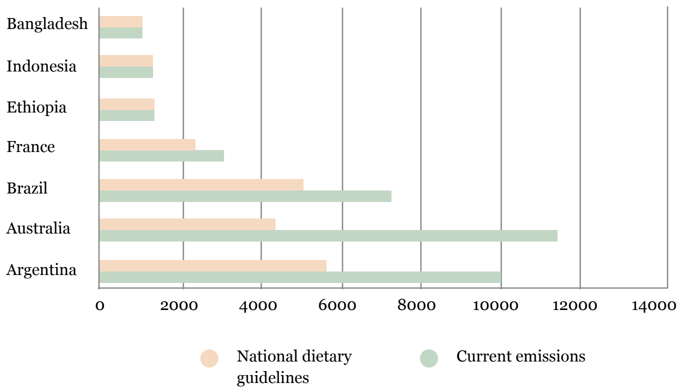


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Figure 16: Per capita food-related GHG emissions in various countries for current consumption patterns and if NDGs were followed. Adapted from Loken, B. et al. (2020). Bending the Curve: The Restorative Power of Planet-Based Diets. WWF, Gland, Switzerland. (Online) Available at: https://c402277.ssl.cf1.rackcdn.com/publications/1387/files/original/Bending_the_Curve__The_Restorative_Power_of_Planet-Based_Diets_FULL_REPORT_FINAL.pdf.pdf?1602178156

Overall, the above reports share one common thread concerning environmental sustainability and dietary pattern change: a need to reduce average global meat consumption – especially ruminant meats but not exclusively. From a human health human health): a need to increase average fruit and vegetable consumption and a need to keep caloric consumption at a level to ensure healthy body weight. What are typically not addressed in these reports are such human health-related items as consuming mostly whole grains, reducing salt intake as necessary and keeping fat intake to a healthy level of total calories. There is a great deal of nuance to these recommendations when related to sustainability. Thus, for example, vegetarian and vegan dietary patterns generally demonstrate greater sustainability than a high meat diet (Scarborough, P. et al., 2014a; van Dooren et al., 2014). However, if water use is a key consideration, then a high-almond vegetarian diet could actually be more detrimental than a high meat diet under some circumstances (e.g. almonds are produced primarily using irrigated water whereas animal feed is produced primarily with rainfall). Thus, when speaking of dietary patterns there are two threads to consider. First, on average, dietary patterns that meet WHO standards and are relatively low in animal products (while still meeting all micronutrient needs) tend to be more environmentally sustainable when considering current dominant production strategies and production locations. Second, within a particular dietary pattern there can be a great deal of environmental sustainability variation for a range of reasons. A utility of TCA is discerning this variation. This discriminatory aspect, the ability to compare dietary patterns for negative and positive externalities, is part of the power and currently unrealized potential of TCA.

It is also clear that national dietary guidelines, while in place for over 100 countries,[18] typically do not consider environmental sustainability (or social welfare/justice) as part of their development calculation. In the next section, the impacts of dietary patterns are explored in greater detail through the four capitals (TEEB, 2018b) – natural, human, produced and social. Through this, a strategy for using TCA as a tool for government policy will be developed.

POSITIVE AND NEGATIVE IMPACTS OF DIETARY PATTERNS ACROSS FOOD VALUE CHAINS BASED ON THE FOUR CAPITALS

In this section, the four capitals as utilized in the TEEBAgriFood TCA development (TEEB, 2018b) – natural, human, produced and social – are used to explore both the positive and negative impacts of current dietary patterns (also see Figure 1). Simply put, 'capital' is anything that helps to generate value. In this case, capitals are compartmentalized into four 'buckets' to classify and denote origins. As part of this, the impacts of various food systems and supply chains are explored – for example, those that generate food for consumers via commodity production with high levels of inputs – but also those that currently play a quantitatively minor role (e.g. organic production). Also, solutions need to address the fact that today there are about 7.4 billion people on Earth, with estimates predicting approximately 10 billion by 2050. This means that strategies to improve the situation need to address scalability: 'can alternative production systems currently used on a smaller scale be part of the solution for feeding 7.4-10 billion people, or are they destined to stay at a small scale quantitatively?'.

Natural capital encompasses natural resources (land, fresh water, oceans, minerals, etc.). Human capital includes human health, education, skills and various types of knowledge. Produced capital is human-made and includes things like farm equipment, community centers, food processing equipment, etc. Finally, social capital brings these all together and includes the variety of norms, regulations, rules and laws that govern/guide operations (e.g. trust, inclusion, voice, power, gender equality). In a food system context natural capital is the base for food production; human capital generates the knowledge and skills to use these wisely and in turn generate produced capital; social capital generates structures and guidelines. These capitals work together to create a global food system that has the potential for enhanced human health and environmental sustainability. All four capitals must be considered when examining dietary patterns and staying within a safe operating space.

A TCA analysis utilizes the four capitals. Given that TCA is fundamentally a tool for right-sizing the concept of profit/loss and the relationship of economics to human health, human welfare and environmental sustainability, it is useful to incorporate the concept of doughnut economics (Raworth, 2012). This concept focuses on embedding the economy between two boundary conditions - maintaining the natural resource base and global human rights. In essence, it is suggested that the economy should function within a 'safe space' that does not exceed an environmental ceiling (represented by Rockström et al.'s Planetary Boundaries) and a social floor (represented by the UN Declaration on Human Rights). In other words, an economic system needs to account for staying within this 'safe space'. TCA provides a tool for moving towards this. It is useful to examine some of the positive and negative impacts current dietary patterns have on the four capitals, beginning with natural capital.

Natural Capital can be defined as "the world's stocks of natural assets which include geology, soil, air, water and all living things" (World Forum on Natural Capital, 2017). It is from this natural capital that a range of ecosystem services are derived (The Secretariat of the Convention on Biological Diversity, 2008). In the context of food these include provisioning services such as the genetic resources that form a basis for our food supply, food itself and fresh water; regulating services such as pollination and pest predators; supporting services such as water retention capacity in soil; and cultural services that include the aesthetic, cultural and spiritual values embedded in food and food provisioning.

[18] http://www.fao.org/nutrition/education/food-dietary-guidelines/home/en/

There is seemingly no end to the list of deleterious effects our patterns have on natural capital while there is a great potential for turning these into positives. It is generally considered a given that agriculture, by its very nature, has an impact on natural capital – for example it has typically involved some modification of native ecosystems. Thus positive impacts to natural capital are relative – 'are there ways to reduce the negative impacts dramatically such that natural capital is not further debilitated, but rather restored?' In this context those currently generating positive impacts generally come from quantitatively small portions of the food system – these include many of the initiatives globally falling under organic production and processing, regenerative agriculture, agroecology and intensively managed rotational grazing (and other terms for a similar process of animal production). In general, there is strong data to indicate positive impacts such as increases in soil carbon and water holding capacity, net carbon sequestration in ruminant production and native pollinator habitat.

Negative impacts of current dietary patterns to natural capital include:

- destruction of native ecosystems, including land use change;
- contribution to climate change by net release of GHGs;
- land degradation, loss of soil and attendant impacts;
- microbial poisoning of fresh waters – both surface waters and underground aquifers;
- chemical and biogeochemical pollution of soil, air, fresh water and ocean waters;
- solid waste pollution of oceans waters;
- destruction of biodiversity, including wholesale destruction of ecosystems in various parts of the world as well as loss of native pollinators;
- stratospheric ozone depletion;
- animal welfare;
- quantitative water depletions through extensive irrigation; and
- crop competition that often displaces local foods with cash crops.

Destruction of native ecosystems: It is generally true that as population growth continues and global standards of living improve, the negative impacts of current dietary patterns on native ecosystems will, in the absence of change, continue to increase. In other words, current levels of excess calorie consumption and increased meat consumption will continue to have negative impacts on ecosystems. In the absence of a reduction in overall global meat consumption, more land will be cleared to generate animal feed. While this can be abated to some extent by decreasing food wastage and increasing global average yields on feed grains, the general trend will be one of continuing ecosystem destruction. This is independent of production strategies, organic certification or grazing strategies. About 37% of the earth's total land area is used for agriculture (2018 data).[19] It is estimated that in a 'business-as-usual' context, approximately 70 million net hectares more land will be under crops by 2050 – with increases primarily in developing countries and decreases in developed ones (Alexandratos et al., 2012). Also, there are serious constraints to land availability for expansion with a small number of countries accounting for the bulk of available, suitable and arable land still available for 'conversion to agricultural use'. This conversion leads to the destruction of native ecosystems and habitats. Tilman et al. predicted that 109 hectares of natural ecosystems will be converted to agricultural lands between 2001-2050 (Tilman et al., 2001) - an area almost equivalent to the European continent. Recent projections and scenario building outline key determinants and ways in which land use for food and agriculture could be decreased (Stehfest et al., 2019). Land use change is largely due to the increasing demand for corn/soya in animal feed (May, 2019; Bringezu et al., 2014). There are also carry-over effects. Much of this land conversion is through forest burning – resulting in the double impact of releasing large amounts of stored carbon and the reduction of carbon sequestration potential. In fact, the opposite should be happening – preservation of existing perennial plant ecosystems and reseeding/planting of some current croplands to perennial crops. In this regard, rangelands and pastures may be more resilient sources of carbon sequestration in more temperate areas susceptible to drought (e.g. much of California) (Dass et al., 2018) as carbon is largely stored underground as opposed to forests storing it largely above ground. Thus, grassland ecosystems could be rebuilt and ruminant animals could potentially be raised sustainably.

Contribution to GHG: Agriculture and the food system is the largest single contributor to GHG build-up, accounting for about 24% of all GHG emissions (Climate Change 2014 Mitigation of Climate Change, 2014) - with the largest source being from tropical deforestation and other land use (~9%); the second largest source is methane emissions by ruminants (Project Drawdown, 2020). Most studies demonstrate a dramatic lowering of the carbon footprint when eliminating meat and animal products from diets – yet animal products are today a key source of micronutrients for many. So it is useful to see that agricultural lands can also be seen as carbon sinks and thus contribute to reducing the global carbon footprint. Across different types of agriculture/agro-forestry land uses there is the potential for significant carbon sequestration over anywhere from 5-100 years without declines in the rate of soil carbon sequestration (Project Drawdown, 2020) by using regenerative annual cropping techniques, 'perennializing' agriculture and proper management of grazing lands and pastures. The Project Drawdown researchers estimate that in total, the global potential for agricultural sequestration is limited but important.

[19] https://data.worldbank.org/indicator/AG.LND.AGRI.ZS?end=2018&start=1961&view=chart

For agriculture and food systems, the important points are that: 1) agriculture and the food system contribute greatly to GHGs; 2) without a significant reduction in total net releases in this system, meeting any target for limiting global climate temperature increases will be exceedingly difficult to temperature increases will be exceedingly difficult to impossible; 3) average temperature increases will cause greater rates of drought and flooding that will further exacerbate food production challenges; and 4) there are significant strategies through dietary pattern change, production strategy changes and decreasing food waste that can help sequester carbon in soil and biomass, or eliminate release in the first place. Other points are more ambiguous based on current research – such as reducing food's travel distance (or food miles) from field to fork. Some research demonstrates significant decreases in carbon footprint with reduced shipping distance (e.g. (Plawecki et al., 2013) while other research demonstrates the opposite (DEFRA, 2008).

Land degradation, loss of soil and attendant impacts: Globally, the range of estimates for degraded lands varies between 1 and 6 billion hectares (Gibbs et al., 2015) - much of it either currently or formerly agricultural lands that were previously forests or grasslands. This land degradation is typically caused by overuse and/or erosion (wind or water). The accompanying soil carbon losses are estimated to amount to 133 Pg C for the top two meters due to agriculture (Sanderman et al., 2017) - 133 billion tonnes or 8% of total global soil carbon stocks. By comparison it is estimated that the top meter of soil carbon amounts to three times the total atmospheric carbon (Dunne, 2017) so that losses through erosion and oxidation are significantly damaging. As discussed above concerning GHGs and soil carbon sequestration – the magnitude of this impact is a combination of what is produced and how, and the magnitude of production. There is no question that over the years, knowledge of how to reduce soil erosion and land degradation has greatly improved. However it is still at unacceptably high levels – for example from 1982-2007 US cropland had a 43% decrease in soil erosion rates yet still lost 1.73 billion tons in 2007 (NRCS-USDA, 2010; Springmann et al., 2018). Globally, the best explanation for high soil erosion country-by-country is their level of agriculture (Wuepper et al., 2019). Also, while per hectare erosion rates have declined, the total rate of global soil erosion has continued to increase because of increasing land conversion (Borrelli et al., 2017), especially for agriculture.country-by-country is their level of agriculture (Wuepper et al., 2019). Also, while per hectare erosion rates have declined, the total rate of global soil erosion has continued to increase because of increasing land conversion (Borrelli et al., 2017), especially for agriculture.

Poisoning of fresh waters – surfaces waters and underground aquifers/chemical pollution/biogeochemical pollution: Below, human capital and contaminant impacts are discussed, with a focus on the impact they have on natural capital. There are three main sources of water chemical pollution of concern for natural capital – industrial, agricultural and personal/social. An estimated 38% of EU water bodies are under pressure for nitrate and phosphorus contamination from agriculture. Globally, nitrate is the most common contaminant of groundwater aquifers (Mateo-Sagasta et al., 2017). In the EU, North America, China and much of the developed world, agriculture has become the primary polluter of fresh water. In a number of OECD countries (for example, Denmark, US, UK, Belgium) over 50% of the coastal water nitrate and over 30% of phosphorus pollution is derived from agriculture (Parris, 2011). In low-income countries, industrial wastewater and municipal/human waste are primary concerns but agricultural runoff is becoming an increasing concern. The primary chemicals/biogeochemical pollutants vary with nitrate being most common in aquifers and some mixture of sediment, fertilizers and agricultural chemicals of major concern for surface waters. Nitrogen and phosphorus eutrophication-associated dead zones are associated with over 400 systems globally (Diaz et al., 2008) with severely altered ecosystems that ultimately have severe implications for humans (Erisman et al., 2015). As a side-note – terrestrial ecosystems are also at risk of excess nitrogen deposition – it has been estimated that the world's 950 Protected Areas are expected to receive >30 kg N/ha/yr by 2030. Many of these areas are known to be sensitive to nitrogen and this could greatly affect biodiversity (Bleeker et al., 2011). In addition, where monitoring exists,[20] 68.4% of the monitored sites found either surface waters or sediments exceeded the regulatory threshold levels for the particular chemicals (Stehle et al., 2015). Glyphosate has also been reported in rainwater (Lupi et al., 2019).

Poisoning and pollution of oceans waters: Beyond various impacts of agricultural production, dietary patterns have significant impacts on waterways and oceans. A large part of this comes from solid waste pollution, especially plastics. This is ironic given that the role of plastic packaging is, in part, to reduce food waste. The role that food and beverage packaging plays cannot be overstated – the packaging of frozen foods, bottles of various beverages, bags for fresh produce and the bags that much of it goes home in across the globe. Overall, about 350 million tonnes of plastic are produced each year – and about 8 million tonnes of that ends up in the oceans – it is estimated that at this rate there will be more plastic than fish by 2050 (Askew, 2020). Marine plastics typically start in a freshwater system – rivers, lakes and streams. A meta-analysis of UK and EU studies identified the top-10 macro-plastic categories found in these fresh waters – food wrappers were number one comprising about 10% of plastic litter; bottles and lids were second with 9.8% of total litter; takeaway containers, cups and straws, stirrers and cutlery were numbers 8-10 and comprised 6% of plastic litter. If bags are included, then six of the top ten plastic categories are food/beverage related (Winton et al., 2020). Furthermore, 'ghost gear' makes up about 10% of marine litter – about 500,000 – 1 million tonnes of fishing gear per year is left in the oceans (WWF, 2020b). As outlined in a report by the Convention on Biological Diversity (Secretariat of the Convention on Biological Diversity,

[20] It is reported that approximately 90% of global cropland has no monitoring for agrochemicals.

2016) these plastics affect biodiversity and habitats in a variety of ways. The report has seven key messages, including that: over 800 marine and coastal species are impacted; the number of seabird and marine mammal species affected is increasing; microplastics are present in all marine habitats at all levels of the food web; and new microbial community habitats are being created with unknown consequences. This poisoning and pollution is a component of the current dietary pattern impact (beyond excess calories and meat consumption) - greater amounts of packaged foods are consumed (even more so because of the COVID-19 pandemic). For example, diet cola might replace regular cola to reduce calories, but does not impact the use of plastic packaging.

Destruction of biodiversity: The largest driver of biodiversity loss over the 21st century will be land and sea use change (Sala et al., 2000), most of which is driven by population growth crossed with dietary pattern shifts. The other top five causes will be/are direct organism exploitation, climate change, pollution and invasive alien species (IPBES, 2019) - with the rate of extinction accelerating. Dietary patterns are playing a major role in the destruction of biodiversity. And biodiversity is a critical driver of healthy ecosystem services.

An example of the effects of biodiversity loss on agriculture can be seen through the loss of native pollinators. A recent German study (Hallmann et al., 2017) reported a 76% seasonal decline and an 82% mid-summer decline of flying insect biomass over a 27-year period. An earlier study in California found that the proximity of native habitats and the production strategy, whether organic or conventionally produced, greatly affected the presence of native pollinators and their impact on field productivity (Kremen et al., 2002). It was reported that in farms producing organically, and with nearby natural habitat, native pollinators could fully pollinate the field – even crops with heavy pollination requirements such as watermelon – while all other farms showed greatly reduced diversity and abundance of native bees and an increased need for outside pollination services (i.e. managed honey bees). Other studies have described the importance of native pollinators in agriculture (Rader et al., 2016; Garibaldi, L. A. et al., 2013), as well as strategies to increase their abundance (Garibaldi, Lucas A. et al., 2014). Remembering that approximately a third of the world's crop production is animal pollinated, pollination is an important form of natural capital. Even managed honeybees are experiencing difficulty with procuring food. A recently published study (Jones et al., 2021) found that, compared to 1951 honey samples, honeybees in the UK now have a greatly altered and narrower range of food sources. This is primarily due to two things: (i) managed pastures contain much less white clover (they are now principally grasses); and (ii) there is less native habitat in hedgerows and native ecosystems. There are a wide array of other examples of biodiversity loss as outlined in a recent report of the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) (IPBES, 2019).

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Stratospheric ozone depletion: Originally, chlorofluorocarbons (CFCs) were identified as the primary culprit in stratospheric ozone depletion (especially the ozone hole above the Arctic). The 1985 Montreal Protocol phased out production of these chemicals so that by 2010 production of CFC-11 and CFC-12 had virtually stopped. However, there is a 'bank' of the compound in existing refrigerator and air conditioning units that stays in operation for quite a while. It has been estimated that a failure to recover this banked material could delay stratospheric ozone recovery by six years (Lickley et al., 2020). Beyond these banked compounds, dichloromethane is also a potent stratospheric ozone depleting chemical that is not bound by the Montreal Protocol and is used in a number of industrial processes. In the food industry it is used in tea and coffee decaffeination. The Swiss water process of non-chemical decaffeination[21] is a good alternative to the use of this chemical.

Human capital includes human health, education, skills, various types of knowledge and is defined as "The knowledge, skills, competencies and attributes embodied in individuals that facilitate the creation of personal, social and economic well-being." (OECD, 2001; TEEB, 2018b). This is often measured by determining how much is invested in areas as education

[21] https://coffeeconfidential.org/health/decaffeination/

and health care across countries. Parts of the social floor in Raworth's Doughnut Economics that relate to human health can be examined, given that food, dietary patterns and the food system are important components of determining human health. The full list of these includes food security, health, education, income, peace and justice, political voice, social equity, gender equity, housing, networks, energy security and water security. How these relate to the food system is explored in more depth using a couple of examples from this list.

Health and food security are the two most obvious relating to dietary patterns and the food system. Health is impacted in many ways, including includes toxic chemical residues on/in food as well as production and processing exposure, fertilizer contamination in air and water supplies, work related injuries, antibiotic-resistant bacterial exposure and contaminated food and worker food insecurity through low wages.

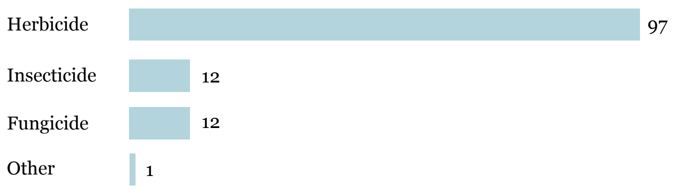

Figure 17: Pesticides Applied to Corn Planted Acres, 2016 Crop Year (% of planted acres). Adapted from United States Department of Agriculture. (2006). (Online) Available at: https://www.nass.usda.gov/Surveys/Guide_to_NASS_Surveys/Chemical_Use/2016_Corn_Potatoes/ChemUseHighlights_Corn_2016.

For example, a key dietary pattern is excess calorie consumption – which comes at an environmental cost. Assuming that all excess calories are consumed as 'corn equivalents' via corn oil and high fructose corn syrup, one analysis (Hamm, M. W. et al., 2018) calculated that excess global calorie consumption was approximately equivalent to 94% of US corn production (a conservative estimate based on US average corn yields, not global averages, and not considering crop losses/food wastage). Across 94 million acres of corn (2016 US production data), over 160 million pounds of pesticide were sprayed – nearly 2 pounds per acre total (National Agricultural Statistics Service, 2017) - herbicides being the most prevalent (Figure 17). In addition, about 12.2 billion pounds of nitrogen were applied to these acres. Recent analysis indicates approximately one-third of this nitrogen is used to make up for soil loss. Overall, about 24% of shallow wells (less than 30.5 meters deep) in the US have dangerous levels of nitrate contamination (Nolan et al., 1998) - a danger to human health. In other words, excess calorie consumption is itself a major contributor to environmental destruction and food system externalities.

Some pesticides have been linked to a range of diseases, especially certain cancers (Gillam, 2021). Atrazine is one of a long list of EDCs (Roy et al., 2009). Excess calorie consumption impacts human health directly because of the calories and also with respect to the way in which these calories are predominantly produced.[22] Since large amounts of corn acreage is utilized for animal feed production this same logic can be applied to high meat consumption.

Fresh water is also critical for human capital development and preservation. Nitrate contamination of groundwater is an issue in many areas while 50% of the world's population relies on wells for their daily water needs. There is also significant contamination of surface waters as indicated under 'natural capital'. It is estimated that by 2030 the world will face a 40% global water deficit with a 'business-as-usual' approach (United Nations World Water Assessment Programme, 2015).

It is also useful to consider ways in which altered dietary patterns, i.e. reduced meat consumption in this case, could contribute to improved human health. Recent research has demonstrated that a multi-species pasture rotation system could meet a number of environmental attributes (e.g. soil carbon sequestration, erosion control) while producing chicken, pork and beef (Rowntree et al., 2020). One can say that it is feasible to produce low-to-positive environmental impact meat for a dietary pattern with much lower average meat consumption. Also, pasturing systems for ruminant meat or dairy production use virtually no pesticides (if any). However, it took about 2.5 times as much land to produce the meat such that less would be produced overall on the same amount of land.

In addition to food production itself there are also social issues that come under scrutiny, along the supply chain. For example, the agricultural sector is one of the most hazardous workplaces worldwide (IPES-Food, 2015). In addition, many seasonal workers are migrants and have little to no health coverage – a particular crisis during the current COVID-19 pandemic (IOM UN Migration, 2020). Wages across the food system – from agricultural laborers to workers in the processing and transportation sectors, and to retail/restaurant workers, are mostly below the liveable wage in any given area. In one US survey only 13.5% of all food workers earned a liveable wage (Food Chain Workers Alliance, 2012) and they use US food stamps at twice the rate of the rest of the workforce. In addition, they typically get little-to-no benefits (such as retirement or health care). A similar situation exists globally. Studies of various supply chains have found little indication of a liveable wage – and, in fact, some were at the extreme poverty level (Wilshaw, 2014). Figure 18 illustrates the percentage of a liveable wage that is represented by the legal minimum wage for a variety of Eastern European and Asian countries. There are a broad range of other arenas that need addressing within human capital. These include gender equity, land ownership and housing for low-paid workers, among others. Finally, there is the area of food security, which has four dimensions: availability, access, utilization and stability.[23] All four dimensions must be present for a person, household or nation to consider itself food secure. At any given time a person could be chronically or transitorily food insecure – for example people in urban areas may be chronically food insecure if they lack the ability to purchase food and lack resources to produce their own. People in rural places are often transitorily food

[22] N.B. This paper recognizes this is vastly oversimplified and is more intended as an example of the links between high calorie consumption and human health, beyond direct health implications of the excess calories.

[23] http://www.fao.org/3/al936e/al936e.pdf

insecure in parts of the crop production off-season, yet this can turn to chronic insecurity for example during droughts, plagues or war. The TCA approach can consciously investigate these social and equity issues when valuing externalities so as to understand the implications for human health and well-being.

Produced capital inputs into the food system include farm equipment, community centres, food processing equipment, energy, fuel, fertilizers, pesticides, packaging, processing chemicals, etc. Fertilizers and pesticides have been discussed above, in the context of pollution, under 'natural capital'. Other aspects of produced capital discussed below include machinery and infrastructure, energy, fuel and packaging.

Machinery and infrastructure are an interesting agglomeration of a number of arenas. It is useful to recognize that no matter what the diet, 7.4 billion people require a large tonnage of food. While the global population is growing, more of those people are living in urbanized areas – an estimated 70% by 2050. This means a larger urban/rural population ratio which implies potential impacts on food production and sufficiency in several ways. While reducing food waste can move towards ensuring food sufficiency, it is unlikely to balance shifting population dynamics. Certainly shifting dietary patterns, as outlined earlier, will also greatly impact these population dynamics - less animal feed crops would be needed if people generally move to a more plant-based dietary pattern. It still may be true that the remaining rural farm population will need to be more productive (i.e. feed more people per farmer) due to population shifts to urban areas. It is possible, and even likely, that some food production will move more into the urbanized environment space as urban farming becomes more prolific. While there have been proposals (and pilot projects in some cases) for dairy cows on barges in Amsterdam (Frearson, 2019) and skyscrapers producing a city's total food supply (Despommier, 2015), these are not practical from a variety of sustainability and logistical viewpoints. A reality-based approach to food production will continue to see the predominance of protein and calorie production on rural and peri-urban landscapes even with greater emergence of alternative protein sources (Parodi et al., 2018; Hamm, Michael W., 2018). Also, the more excess calories and animal-based products are consumed, the more and bigger machinery will be needed for this production. 'Why is this important? Can environmental sustainability be addressed within produced capital while also increasing commitment towards human and social capital? Is it feasible for mechanization of production at various scales to contribute to net zero farming?' It is reasonable to assert that the more excess calories and animal products (based on corn/soybean feeding regimens, including aquaculture production) are consumed, the harder this will be.

At larger scales of food production, there are currently two options for carbon footprint reduction: electric and hydrogen fuel cell mechanization and (FuelCellsWorks, 2020) tractors

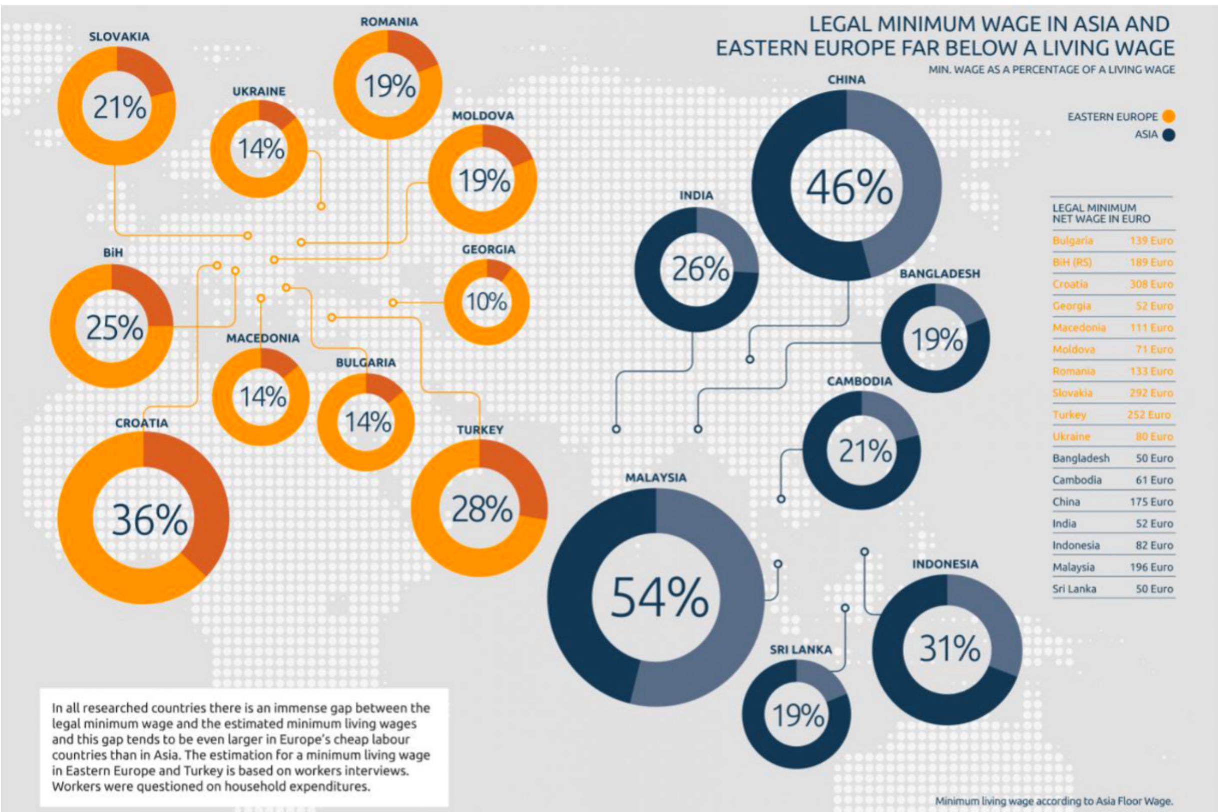

Figure 18: Minimum wages as a percentage of estimated living wages: garments. Reprinted from Wilshaw, R. (2014). Steps Towards a Living Wage in Global Supply Chains: Timms, B. (ed.) Oxfam Issue Briefing. Oxford, UK. Oxfam International. Oxfam. (Online) Available at: https://oxfamilibrary.openrepository.com/bitstream/handle/10546/336623/ib-steps-towards-living-wage-global-supply-chains-101214-en.pdf?sequence=1

(Van Leeuwen, 2020). They both have drawbacks and full calculations are beyond the scope of this report. It is more reasonable to consider the potential for hydrogen fuel cells due to weight and cost but also recognize that their efficiency of energy transfer relative to electric is deficient, requiring more solar panels or wind turbine capacity for their use. This implies yet a greater land mass requirement for energy production (space for the solar cells and wind turbines) and hence greater implications for land use and biodiversity, among others. In summary, excess calorie and high animal product consumption implies a greater need for equipment. This also implies both a higher environmental impact and more difficulty in becoming net-zero carbon in the near future.

An example of technological development that could improve the situation for farmers/ranchers regarding animal rearing is virtual fencing – a technology combining radio-collars, computer and Global Positioning System software, as well as animal warning cues and negative stimuli (Marini et al., 2018; Campbell et al., 2018). As cited earlier there is strong evidence for the value of intensively-managed pasture systems. This can be a time-consuming process given the frequency of paddock shifting. There is potential to both decrease some infrastructure (physical, movable fencing) and increase others (Anderson, D. M., 2007) as virtual fencing research and development advances.

Current global dietary patterns need modification relative to fruit, vegetable and nut consumption – per capita consumption needs to increase by almost double as part of a healthy diet. This has implications for machinery and physical infrastructure with respect to production machinery and technology (e.g. indoor production technology), harvest and post-harvest management technology and packaging materials. Again, scale of production is a necessary decision and discussion point. Minimum fruit and vegetable consumption recommendations are 500 grams a day or 182.5 kg a year. Ignoring all waste (both at the point of consumption/preparation and in the supply chain) means 1.35 billion metric tonnes of produce per year for 7.4 billion people (or 182 million kg/yr/million people). In 2013 there were 617 million tonnes of fruits and 794 million tonnes of vegetables produced globally – 1.411 billion tonnes total (European Fresh Produce Association, 2015). So not accounting for waste, enough food is produced for everyone to consume recommended levels. However, it is estimated 45% is wasted (FAO, 2011). Currently, the infrastructure to reduce wastage is insufficient for people to consume a healthy diet – or else, production needs to be almost doubled. By 2050, with a couple of billion more people, this situation will be exacerbated. The produced capital in the form of post-harvest management is currently insufficient and negatively impacts dietary pattern considerations.

There are also important developments in digitalization, precision agriculture and artificial intelligence that can be of great benefit depending on a number of conditions. These can have positive implications for such things as the application of fertilizer (Basso et al., 2019), herbicides and GHG release (Balafoutis et al., 2017). However, there are a range of social issues that need confronting, such as utility at smaller scales and intellectual property. The challenges in this arena include making technology available, worker dislocation and affordable at smaller scales, as well as ownership of the data generated and utilized (Wolfert et al., 2017; Rotz et al., 2019; Christiaensen et al., 2021).

Packaging is a continuing problem. On the one hand, packaging has improved – for example packaging that, allows CO_2 to escape but prevents O_2 in-migration – thus retarding spoilage. On the other hand, this packaging is also a serious waste issue (see above). Compostable and bioplastic packaging is not necessarily yet the answer. If they end up in landfills they still take a century or more to decompose and still produce methane (Kolstad et al., 2012). Bioplastics are often the same chemical building blocks for the oil-based plastic – the difference is that they are plant-based. Very few plastics today are able to break down to CO_2, water and compost in 80 days (Prokopanko, 2020). It can be argued that the most perishable items should be produced with less packaging required to transport them to market – in other words optimal post-harvest handling (internal temperature reduction as quickly as possible and then maintenance at optimal temperature through the supply chain) coupled with minimum time from production to final destination. This implies production closer to the point of consumption with technology in place for temperature/pest control to reduce the need for packaging. Thus it can be argued that the supply chain infrastructure should solve the simultaneous equations of temperature control, time-to-plate and environmental cost of production strategy (e.g. near rural production vs. vertical farm within a city) in order to optimize the dietary pattern for health (positive impact on human capital) while minimizing the environmental impact (negative impact on natural capital). Recent research indicates that technology currently exists to convert lower load, shorter distance truck shipments to all-electric (Liimatainen et al., 2019) – an argument in favour of shorter supply chains.

The above discussion on produced capital is not exhaustive nor is it intended to be. Rather, it provides snippets of how to think about impacts – the types of analysis needed – as well as the potential constraints on aspects of the current global food system. equality), social relationships and organizational systems as well as bringing all the capitals together. Defined by the OECD as “networks together with shared norms, values and understandings that facilitate co-operation within or among groups” (OECD, 2007), it is an enabling capital that holds the food system together and functioning (TEEB, 2018a), and should include a variety of social protection policies and programmes (Kangasniemi et al., 2020). In this section governmental laws and regulations, corporate norms and policies and societal/ community development will be discussed.

Government policy generally shows a bifurcation between 'agricultural policy' – targeted to producers and 'food policy' – targeted to consumers. In addition, there are a range of issues nestled within either agricultural or food policy that impact the supply chain (e.g. food safety). Agricultural policy is typically focused on production – usually with incentives/disincentives for yield, environmental characteristics and production practices and generally, the 'what is produced relative to dietary pattern and human health' is not a consideration. On the other hand, food policy is typically concerned with issues of food security and (at least in neo-liberal economics) is generally not accompanied by incentives for healthy dietary patterns. Government policy mostly is not oriented towards laws, regulations and policies that will both reduce the physical and environmental footprint of agriculture while simultaneously moving the average dietary pattern towards one that is healthier and more sustainable. In addition, it is mostly true that even countries with the strongest food security support programs tend to limit them and do not ensure food security for all their population. For example, the US the food stamp program (SNAP benefits) is only designed to cover 60% of the cost of food so that in winter many households are forced to choose between paying the heating bill and eating.

Food companies often are constrained by the level of choices they are able to make. For example, a company that is focused on bottled liquid products (soda, juice, water, etc.) is constrained by the product. They can shift from soda to water and encourage lower calorie consumption in this way - which may drive a set of environmental issues concerning ground/surface water depletion. They can shift from recyclable to compostable plastics or paper-based but the issue of ocean waste may persist. They can shift to smaller serving sizes and then need to see such a move across the sector to not be out-competed. Other food companies like vegetable wholesalers will have a goal to increase vegetable consumption. In this context, the degree to which positive externalities are maximized and negative ones minimized is entirely dependent on their decisions concerning human capital (e.g. ensuring a liveable wage across the supply chain), social capital (e.g. ability of workers to unionize) and natural capital (e.g. moving towards net zero carbon supply chains, encouraging pollinator friendly buffering areas, eliminating toxic pesticides). These are business plan decisions made within the context of their license to operate.

Societal and community development can be thought of as networks of relationships among people. In the context of TCA it includes political voice as illustrated by small-scale farmer protests in India over recently enacted agriculture laws. 'Are the policies and regulations functioning in a way that encourages relationships across the food system or does it, either directly or by neglect, discourage them? Do existing social norms encourage pathways to sustainability or do they encourage a continuing trend towards consolidation and uniformity?'

Overall, the analysis of these four capitals (natural, human, produced and social), their incorporation into national accounting statistics and their use in determining positive and negative externalities within the food system is critical at this juncture in human history. For example, the World Bank reported that for low-income countries 47% of their total assets (with some differences in their identification of 'capitals') is within natural capital (World Bank Group, 2018) - something not fully accounted for in GDP, and being constantly degraded.

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