Our connected future with the turn-key technologies that are reducing food waste and improving nutrition

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A generation has passed since the publication of *Our Common Future*, known as the Brundtland Report, which set out a requirement for sustainable development indicators so that policy makers could quantify the total value of all natural resources (Brundtland, 1987). This began a process of providing the global food system with a set of values that would provide baseline information or starting points for which future indicators and assessments of sustainable development could be made. It has provided sustainability route maps and recognised that new data tools were needed to implement solutions for sustainable development. The food systems role in achieving this was of importance because of the data held in supply chains concerned with the energy and materials used to manufacture and distribute food. An example of such a primary impact indicator is the use of nitrogen fertilisers that support high-yielding agriculture; their role in the food system is critical, with over a fifth of the nitrogen in all global protein being derived from industrially manufactured nitrogenous fertiliser (Smil, 2002). There are important outcomes for the use of energy and materials, such as the release of nitrous oxide greenhouse gases from organic and mineral nitrogen fertiliser use, that are identified as causal agents in environmental change. Characterising these materials and their associated processes has brought forward new methods of assessing nutrient flow, and the use of digital technologies has enabled improved traceability of information regarding their use. This has enabled the use of common frameworks and vocabularies to describe sustainable practices, which helps to provide incisive models, scenario generation and digital twins for food system activities.

One of the most recognisable of these common frameworks and vocabularies for industry and consumers in the food system is the value of nutrients whose production and consumption determines their impact on human nutrition. It has transformed not only how compliance and verification of foods is achieved with standards and certifications, but also how nutrient content is communicated through the labelling of products. There are important differences between nutrient content, which regulators can quantify on labels, and nutrition, which is far more complex to define and requires further consideration. The DELTA Model and the Sustainable Nutrition Initiative have both started to test the connection between nutrient content, nutrient availability and national nutritional requirements (Smith et al., 2021). It is the loss of nutrients through inefficient operational practices and food waste behaviours that will be built into such tools because each has important impacts on nutrient availability and it is reported that up to a third of food produced is wasted (Chen *et al.*, 2020). Nutrient loss and food waste must first be quantified so that meaningful food policy can be developed so that models such as DELTA can perform robustly enough to account for variations in waste between nations and different food groups or categories.

The relationship between supply chain nutrient losses and food waste is not straightforward, because the economic and nutritional value of different food categories varies. For example, the FAOStat Producer Price Index (typically the wholesale price) for New Zealand beef (deadweight, $USD 3247 per tonne in 2015) is lower than that of UK strawberries ($USD 3973 per tonne in 2015) even though their nutritional values are wildly different and their sustainability impacts have even less of a resemblance to each other. It is noteworthy at this point to consider that much environmental dialogue citing Life Cycle Assessment (LCA) data will still continue to compare the impact of plants and animal products without considering economic or consumer value. The strawberries and beef scenario indicates how tangled advice can get and it is further compounded by production systems between nations being very different because of available resources. New Zealand Producer Prices for beef,

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lamb, pork and, of course, whole milk are typically at least a third lower than in the UK, which is in large part due to geographic resources available. The complexity of assessing sustainability is clear and any assessment needs to consider how consumers value different food categories, because this certainly has impact with foods that are more expensive and preserved, which are rarely wasted (Martindale, 2016).

Improved accessibility to foods can provide a system of being able to afford to waste and eating more of what is enjoyable so that poor dietary choices can be made more often. The results are evident in the descriptive literature, where food waste is more prevalent in high-income countries, as are diseases such as diabetes and coronary heart disease (Swinburn *et al*., 2015). Food wastage is stifling efforts for developing a sustainable food system, because even if sustainability is achieved at least 20% of food products are currently wasted during preparation and consumption (Caldeira *et al*., 2021). What is the point of certificating products for sustainability if they are wasted? The issues of fair global access to food and the inequality of resource distribution in the global food system must be tackled if international policy frameworks such as the Sustainable Development Goals (SDGs) are to be met. One of the most visible demonstrators of this inequality is shown in Figure 1, where the number of Calories wasted per person per day for different nations globally shows high-income nations waste more nutrients than low- or middle-income countries. There are similar relationships for most nutrients; their loss is greatest in those nations that have access to nutrients and can afford to waste them. High-income countries waste 33 daily diets per person per year whereas low- and middle-income countries waste 4 daily diets per person per year (using the supplementary data of Chen *et al*., 2020). If sustainable outcomes are met, the global food system cannot seek to bring all citizens up to this level of high-income wastage, and there needs to be a re-thinking of policy and action that brings waste to a level where there is greater equality. Figure 1 demonstrates a universal principle that is often seen in sustainability research: failure is a result of resources being distributed on unequal terms through geography, income, or culture that creates inequality, and each must be tackled systemically.

Research demonstrates that food waste can be reduced to zero for each meal if preservation and cooking preparation are considered in achieving sustainable outcomes, with product development having an important role in delivering this (Martindale, 2016). Manufacturers are now reporting carbon zero product categories including whole milk and beef, where such improved understanding of how resources flow through food systems has made such baseline or zero targets a reality. Research developed at the National Centre for Food Manufacturing in the UK has provided an important start to reporting how a Digital Twin for Consumption (DTC) can be used to assess the utilisation of resources in food supply chains. The methodologies are being developed by co-creating delivery across Geographic Information Systems (GISs), LCAs, and demographic data science. The data shown in Table 1, are typical of the DTC projections for GHG emission and waste data for different diets when they are scaled to the UK population. It shows a greenhouse gas (GHG) emission and waste production scenario for the typical National Dietary and Nutrition Survey (NDNS) diet reported by the UK Government against the Livewell diet which generally provides a 10% reduction in livestock product consumption. The data reported by the DTC is compared to reported UK Office of National Statistics data including UK's 6th Carbon budget; Wrap's Food Waste Trends 2019; and UK's Family Food survey 2018/19. The DTC tests provide robust alignment between modelled data outcomes and actual reported data so that further analysis using the DTC methodology can be carried out with confidence.

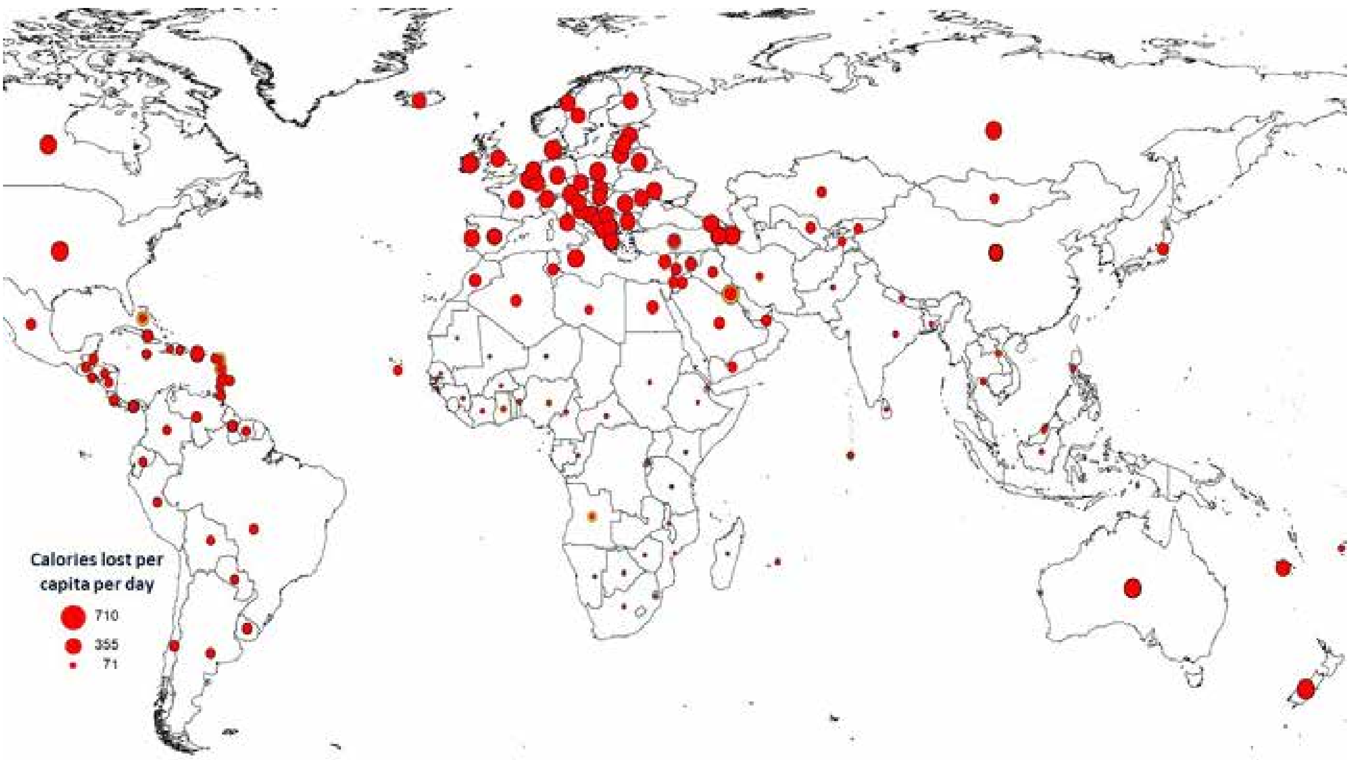

Figure 1. The number of Calories lost and wasted from diets globally. 40% of the Recommended Daily Amount of Calories are lost (as much as 710 Calories) using the supplementary data of Chen *et al*., 2020.

Table 1 shows that the DTC will provide robust projections of GHG emissions, waste production and expenditure based on population demographics reported by the UK National Census. The use of the DTC is being tested because the UK 6th Carbon Budget identifies some 60% of the currently achievable 20 million tonnes of GHG emission reduction from the UK agri-food system each year will be achieved through dietary change and reducing food waste. This means a change from livestock to plant proteins is not the only answer in achieving GHG emission targets, because such a transition will result in more food waste due to more fresh produce being wasted than livestock products (Table 1). The DTC demonstrates how sustainable dietary policy can be structured for the most realistic outcomes that consider eating behaviours and the agility of food choices made by consumers. Mapping how resources and nutrients move through supply chains is of use to reporting the risk of waste or losses, this has been tested and it will be developed further to include the impact of eating behaviours and choices (Martindale *et al*., 2020). The DTC and other risk models improve on those that use static 'peak resource' limits without considering innovation in product development, changes to manufacturing technologies, or the variance in consumer choices. These are important considerations, since changes in manufacturing and processing technologies will often reduce energy consumption and can improve product quality. This has been demonstrated at NCFM most recently with advanced steam infusion processing for soups, confectionery and dairy products (Brooks *et al*., 2021). The use of preservation techniques such as freezing and drying with storage interventions such as the use of fit-for-purpose packaging have also been shown to result in less food waste. Peak resource models can identify boundaries where technologies such as steam infusion can have greatest impact, but models need to be agile and construct future scenarios, and this is where digital twins become a more realistic option in providing risk reduction strategies.

Meeting sustainability and nutritional goals must also result in food being affordable, available, and assured, so New Product Development (NPD) strategy must take a concept-to-consumer approach for this to happen (Martindale, 2016). It is this insight that will provide total utilisation of foods by consumers and connect the sustainability attributes of nutritional improvement and waste reduction which are universally desirable impacts across supply chains. The impact that these GHG and waste reduction models have on NPD processes has also been tested for the UK food system with the DTC, and the research indicates that similar approaches to food and beverage NPD could be utilised in the food system for global impact.

Table 1. A Digital Twin for Consumption (DTC) demonstrator providing data on the relationship between dietary consumption, GHG emissions, and food waste. The DTC is developed by the author and reported by Martindale and Lucas (*in press, Springer Nature 2021*).

	Digital Twin projection (modelled data)	ONS (reported data)
GHG emissions livewell diet ($x\ 10^6$ tonnes. yr^{-1})	52.5	55
GHG emissions NDNS diet ($x\ 10^6$ tonnes. yr^{-1})	54.9	55
Domestic food waste livewell diet ($x\ 10^6$ tonnes. yr^{-1})	9.4	7.3
Domestic waste NDNS diet ($x\ 10^6$ tonnes. yr^{-1})	7.1	7.3
Consumer retail expenditure groceries ($x\ 10^9$ GBP. yr^{-1})	144.4	162.7

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