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Impacts of Reducing UK Beef Consumption Using a Revised Sustainable Diets Framework

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Abstract: The impact of beef consumption on sustainability is a complex and evolving area, as sustainability covers many areas from human nutrient adequacy to ecosystem stability. Three sustainability assessment frameworks have been created to help policy makers unpack the complexities of sustainable food systems and healthy sustainable dietary change. However, none of these frameworks have yet to be applied to a case study or individual policy issue. This paper uses a hybrid version of the sustainability assessment frameworks to investigate the impact of reducing beef consumption (with a concurrent increase in consumption of plant-based foods, with a focus on legumes) on sustainability at a UK level. The aim of this paper is to understand the applicability of these overarching frameworks at the scale of an individual policy. Such an assessment is important, as this application of previously high-level frameworks to individual policies makes it possible to summarise, at a glance, the various co-benefits and trade-offs associated with a given policy, which may be of particular value in terms of stakeholder decision-making. We find that many of the proposed metrics found within the sustainability assessment frameworks are difficult to implement at an individual issue level; however, overall they show that a reduction in beef consumption and an increase in consumption of general plant-based foods, with a focus around legumes production, would be expected to be strongly beneficial in five of the eight overarching measures which were assessed.

Keywords: UK; beef consumption; sustainability; revised indicators; traffic light model; evaluation; policy

1. Introduction

The definition of a sustainable diet as formulated by the 2010 Food and Agriculture Organization (FAO) International Scientific Symposium on Biodiversity and Sustainable Diets is: "Diets with low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable, nutritionally adequate, safe, and healthy, while optimizing natural and human resources." [1]. This definition covers many dimensions and associated metrics. The recent frameworks of Chaudhary et al. [2], Gustafson et al. [3], and Drewnowski [4] have provided sustainable diet assessment frameworks for assessing the impact of food consumption and production on sustainability. However, there are limited practical examples of these frameworks being put into use. This paper takes an applied case study approach to determine if these proposed frameworks can be applied to a specific issue or scenario, and assist policymakers in understanding the potential implications of individual policy options. This is in contrast to the nation-state or global level of application that the sustainable diet assessment frameworks have been used at up to now.

The recent EAT-Lancet Commission paper [5] highlighted the importance of sustainable diets in terms of diets which are low in animal derived products, yet—to the authors' knowledge—there are no studies which have applied the existing sustainable diet assessment frameworks to the impact of beef consumption. Beef consumption has been identified as causing high carbon emissions whilst also offering important nutrients, thus highlighting a potential trade-off in at least two sustainability dimensions [6].

Beef consumption is an historic part of the 'British' diet [7]. However, rates of beef consumption in the UK vary by income, geography, and other demographic factors. Historically (1900s onwards), industrialisation decreased beef consumption as other calorie-dense, cheaper, and processed foods became available [8]. In 1904, total butcher's meat (including pork, mutton, veal, and beef) consumption was between 450 g per week per person (skilled working class) to 260 g per week per person (Bowley Poor); by 1918, all classes were eating a similar amount of butchers meat, around 317 g per week per person [9–11]. By 1942, the average working person was consuming 230 g a week of beef and veal [12]; this decreased to an average consumption of 124 g per person per week by 2000, and by 2017/2018, the average amount purchased for in-home consumption was 99 g per person per week [13,14]. The price of beef has become cheaper with the advances in technology (and the decreasing in prices of other competing animal protein products such as chicken). The UK's current rate of meat consumption, at 84.2 kg per person per year, is relatively consistent with its neighbours in Ireland (87.9 kg), France (86.7 kg), and Germany (88.1 kg) [15]. Current UK dietary guidance—the Eatwell guide [16]—recommends that people who eat more than 90 g (cooked weight) of red and processed meat a day cut down to 70 g. Evidence from the National Diet and Nutrition Survey [17] indicates that current typical portion sizes are still in excess of this recommendation for men aged 19–64 years and 65–74 years (This indicates that beef might not be consumed every week, by every person, but when it is, it is in portions larger than 90 g). Recently, Reynolds et al. [18,19] found that thought there were some income-based differences to the proportion of beef purchased per day per person (between 26–28 g per person per day); these were not large differences (~6%). Furthermore, Reynolds et al. found that all income groups needed to reduce their meat consumption to 8–10 g per day per person (a ~65% reduction) (i.e., one portion per week to ten days) to deliver a healthy, low optimised diet.

This paper takes the innovative approach of assessing the impact of (reducing) beef consumption in the UK on the following interdisciplinary dimensions: (1) Food Nutrient Adequacy, (2) Ecosystem Stability, (3) Affordability and Availability, (4) Sociocultural Wellbeing, (5) Resilience, (6) Food Safety, (7) Waste and Loss Reduction, and (8) Cultural Acceptability. Overall scores for these dimensions are determined based on the metrics suggested in Chaudhary et al. [2], Gustafson et al. [3], and Drewnowski [4]. These scores are then used to provide a traffic light system, indicating which dimensions would be beneficially, neutrally, or negatively impacted by a reduction in beef consumption in the UK. This traffic light system allows for researchers, stakeholders, and policy makers to see the potential trade-offs and complexities inherent in any sustainability measurement of behaviour at a glance.

As there are multiple dietary and economic shifts that can accommodate a reduction in beef consumption in the UK (for example, see [19,20]), this will be substituted by increased consumption of general plant-based foods, with a focus around pulses and legumes (According to the FAO (http://www.fao.org/es/faodef/fdef04e.htm), the term 'pulses' refers to dried seeds of legumes, i.e., the plants whose fruit is enclosed in a pod, so it excludes green peas and fresh beans which are classified as vegetables. (Peanuts and soybeans are excluded from the group of pulses, as they are used mainly for processing: Soybeans for oil and fodder production, and peanuts for oil and peanut butter production). For this paper, we take a broader and inclusive grouping of pulses and legumes).

The research methodology used throughout this paper is to (1) review and use the macro measures or metrics (and the suggested databases and references) used by the three previous sustainability assessment frameworks to answer our specific research question. (2) If these previous sources are not enough, attempt to use additional literature and data to answer our specific research question. (3) Provide recommendations for future sustainable diets frameworks.

The structure of this paper is as follows: The next section explains the justification for a combined framework for sustainable diets. This is followed by a section detailing the application of the eight dimensions to beef consumption in the UK with an accompanying table of impact summarising the metrics involved. Where required for clarity, some of the eight dimensions have a 'Methods' and a 'Results and Discussion' sub-section. The final section is a conclusion detailing the overall impact of beef consumption on sustainability measures at the UK level.

2. The Need for a New Framework for Sustainable Diets That Can Be Practically Applied

Chaudhary et al. [2], Gustafson et al. [3], and Drewnowski [4] have proposed dimensions, measures, or metrics (see Table 1) for sustainable food and nutrition security. However, all three propose these without linking these dimensions, measures, or metrics through to practical application and methods to measure progress on a local or food-specific scale, making the uptake and deployment of these methods any lower than at the national scale difficult in practice. Instead, each lists specific generalised databases that can be used to measure progress against each indicator.

In this paper, we propose a hybrid of the previous dimensions, measures, or metrics for sustainable food and nutrition security, suggesting applied metrics and current real world (at a country-specific level) measures of progress towards reduced beef consumption in the UK. In practice, our hybrid is an aggregation of all the dimensions of Chaudhary et al. [2], Gustafson et al. [3], and Drewnowski [4], to allow for assessment of the usefulness of the three frameworks concurrently. In Section 3, we show how these macro measures or metrics may not be useable for specific food issues in this case a reduction of beef consumption in the UK.

One important dimension of sustainability which is not included in this paper or previous frameworks is "health". While the authors recognise that, in order for a diet to be sustainable, it must be healthy (see [19,21]), we also recognise the complexities surrounding the measurement and quantification of a healthy diet. The majority of evidence linking meat intake with diseases comes from observational studies which, while useful sources of information, can have problems with errors in epidemiology such as confounding bias relative to randomised controlled trials [22,23]. For this reason, we exclude "health" as a dimension and metric for the current study, and instead include health outcomes as a measure of sustainability through the inclusion of the Food Nutrient Adequacy dimension (measuring intake rather than outcome).

With regards to the application of beef consumption, a number of studies have linked the consumption of red and processed meat with a higher risk of cancer, cardiovascular mortality, and type two diabetes [21,24–27]. However, in addition, the importance of red meat in the diet can vary widely between genders, cultures, and religions, as well as across the lifespan, providing an important source of iron and readily accessible protein to some, while being relatively unimportant to others [28].

Table 1. Dimensions, measures, and metrics proposed in Chaudhary et al. [2], Gustafson et al. [3], and Drewnowski [4], compared with our "hybrid" metrics. *

Chaudhary et al. [2]	Drewnowski [4]	Gustafson et al. [3]	This study
(1) Food Nutrient Adequacy (2) Ecosystem Stability (3) Affordability and Availability (4) Sociocultural Wellbeing (5) Resilience (6) Food Safety (7) Waste and Loss Reduction	(1) Foods and food patterns need to be nutrient-dense (2) Affordable (3) Culturally acceptable (4) Sparing of the environment	(1) Food nutrient adequacy (2) Ecosystem stability (3) Food affordability and availability (4) Sociocultural wellbeing (5) Food Safety (6) Resilience (7) Waste and loss reduction	(1) Food Nutrient Adequacy (2) Ecosystem Stability (3) Affordability and Availability (4) Sociocultural Wellbeing (5) Resilience (6) Food Safety (7) Waste and Loss Reduction (8) Culturally acceptable

* In this paper, we use the following terminology in a hierarchy: 'Metric', 'indicator', 'sub-indicator'.

3. Impacts of Beef Consumption on the Dimensions of the Revised Framework of Sustainable Diet

This section details the application of our hybrid framework's eight dimensions (see Table 1) to beef consumption in the UK with an accompanying summary table of impact summarising the corresponding metrics involved.

3.1. Food Nutrient Adequacy

Consistent evidence indicates that, in general, a dietary pattern that is higher in plant-based foods, such as vegetables, fruits, whole grains, pulses, legumes, nuts, and seeds, and lower in animal-based foods is more health-promoting and is associated with lesser environmental impact [29]. However, few studies focus on indicators (such as greenhouse gas (GHG) emissions) and the overall nutritional adequacies.

3.1.1. Nutrient Composition of Meat

Red meat (red meat includes beef, veal, pork, or lamb) is rich in protein of a high biological value (containing the essential amino acids in the right proportion required by humans) and is a good source of B vitamins, iron, zinc, and selenium [30]. Red meat can contribute up to 15% of the daily protein intake. Red meat is a natural source of omega-3 fatty acids, contributing 8% to daily intakes in adults [31]. For micronutrients, red meat contains a range of essential vitamins and minerals that are important across the life course [32]. For some of these nutrients, meat is defined as a source or rich source using the cut-off points established in law by an EU (2008) directive, which are based on the recommended daily allowance (RDA). Red meat is a source of fat-soluble vitamins including vitamin A. Red meat is also one of the few foods that contain vitamin D in the form that is best absorbed or bioavailable [33].

3.1.2. Impact of Reducing Beef Consumption

Food Nutrient Adequacy is a food system metric proposed by Gustafson et al. [3] to quantitatively characterise the performance of the food systems. The influence of reducing beef consumption on food nutrient adequacy was assessed using the methods presented by Chaudhry et al. [2]. This has six nutritional indicators; however, only three are used in the current analysis, as the remaining four were not relevant to the research question. These were:

- Nutrient Balance Score (NBS)—The nutrition balance score is an indicator of the extent to which a food, meal, or diet can satisfy the daily requirements for all qualifying nutrients (nutrients that are known to be essential for maintaining health) present in a sample containing 2000 kcal [34]
- Disqualifying Nutrient Score (DNS)—A disqualifying nutrition score is an indicator assessed by comparing the total daily intake of four public health sensitive food nutrients (i.e., disqualifying nutrients—sugar, cholesterol, saturated fat, and total fat) with their maximal reference values [34]
- Population Share with Adequate Nutrients (PAN)—A country's population share with adequate nutrients was estimated by comparing the per capita daily food nutrient supply to a demographically weighted threshold for a population though the Estimated Average Requirement"cut-point" approach [35].

Disqualifying nutrient scores are calculated by comparing the total daily intake of four public health sensitive food nutrients (sugar, cholesterol, saturated fat, and total fat) with their maximal reference values [2], whilst the nutrient balance score compares national daily average intake amounts of 25 essential (qualifying) food nutrients with their reference daily intake values [34]. In order to explore the sustainability outcomes and potential trade-offs between different indicators, three alternative dietary scenarios were constructed by Springmann et al. that excluded food from animal sources. These were healthy global diets (HGD), lacto-ovo vegetarian (VGT), and vegan (VGN) [2]. HGD assumed that people consume just enough calories to maintain a healthy body weight, implying the implementation of global dietary guidelines on healthy eating. This included a minimum of five portions of fruits and vegetables, < 50 g of sugar, a maximum of 43 g of red meat, and an energy content of 2200–2300 kcal [36]. VGT assumed a healthy energy intake based on a vegetarian diet that includes eggs and dairy, six portions of fruits and vegetables, one portion of pulses with no red meat, poultry, or fish, whist VGN is a completely plant-based diet.

Within Chaudhary et al., there was limited discussion of the composition of these diets. However, it can be assumed that consumption of general plant-based foods—pulses and legumes in particular—would increase to fulfill the protein requirements of these diets.

3.1.3. Results

Overall, the analysis on reducing beef consumption on food nutrient adequacy is mixed. Analysis from Chaudhry et al. [2] indicates that changing diets towards more plant-based foods can result in significant reductions in disqualifying nutrient intake but small improvements in the nutrient balance scores. The PAN score may decrease for Europe and North America due to a decrease in caloric intake for these regions which currently have higher than the recommended caloric intake. The evidence further indicates that the HGD diet improves the % adequacy of almost all 17 essential nutrients in most countries, except for a few high income countries. The VGR diet, on the other hand, shows slight improvement in % adequacy of most nutrients—except for vitamin B12—as compared to the current diets of these countries, whilst the VGN diets improves the % adequacy of folate, magnesium, and vitamin C due to higher intake of fruits and vegetables, but leads to potential deficiencies in vitamin B12 and selenium [2].

Reducing beef consumption may require efforts such as supplementation and fortification of replacement foods to increase micronutrient intake. Scaling up of fruits, vegetables, or pulse crops consumed is currently insufficient to compensate for micronutrient requirements which are provided mainly by beef.

3.2. Ecosystem Stability

3.2.1. Methods

The influence of reducing beef consumption—following the baseline assumption of its replacement with plant food products, specifically pulses and legumes—on ecosystem stability in the UK was assessed using the methods presented by Chaudhury et al. This metric is broken down into six indicators. Ecosystem Status was defined by Chaudhury et al. as the Environmental Performance Index (EPI) score of a given country, as assessed by Hsu et al. [37]. The EPI itself is comprised of twenty-four sub-indicators, ranging from methane emissions intensity to water sanitation. Sub-indicators deemed not relevant to the question at hand—for example, lead exposure—were removed from the analysis. For those sub-indicators which remained, the impact of reducing beef consumption was assessed by following the original citations used in the EPI's calculations, and using these to determine whether the impact of reducing beef consumption would have a neutral, beneficial, or negative impact on the sub-indicator. Where this was not possible—for example, because the original references did not separate data or results into the necessary categories—impact was assessed through a broader literature review. The remaining five indicators used by Chaudhury et al. were assessed in the same way as the EPI.

3.2.2. Results and Discussion

Overall, the impact of reducing beef consumption on the UK's Ecosystem Stability is expected to be beneficial (see Table 2). One indicator was not assessed: Non-renewable energy use, due to a lack of data. Of the twenty-four sub-indicators comprising Ecosystem Status, seventeen were not assessed, as the impacts were either dependent upon decisions around what might be done with the additional land made available following moving from beef to legume production (such as tree cover loss), or were deemed only indirectly related to beef production and consumption (such as fish stock status).

While the potential benefits of reducing beef consumption were not quantified for each indicator, large reductions in greenhouse gas emissions are expected, as beef has one of the highest greenhouse gas emissions per kilo of any food in the UK: 12.14 kg CO_2e for UK-produced beef, as compared with 1 kg CO_2e for mushrooms [38]. Land-use benefits are also expected to be substantial, given that "animal products contribute disproportionately low amounts of energy and protein to human diets… relative to their land-use footprint" [39], and that approximately 38% of total UK crop supply goes towards animal products [40]. However, (1) as not all livestock feed is produced in the UK, some of these impacts would be shared with other countries, and (2) the data sources found did not specify the total UK crop supply going towards beef production/cattle farming, only all animal products. Thus, a greater resolution of data is needed.

The potential impact of reducing beef consumption on the UK's Ecosystem Stability will vary to some extent, depending on what land-use changes follow such a dietary shift; however, significant benefits are expected to accrue in terms of greenhouse gas emissions, blue water consumption, overall ecosystem status, and land use. There is potential for large benefits to be delivered in other areas which are currently excluded from the analysis, such as tree cover, if changes in beef consumption co-occur with carefully planned land-use changes.

Table 2. Assessment of reduction of UK beef consumption on Ecosystem Stability indicators.

Indicator	Data Source(s)	Impact of Reducing Beef Consumption**
Ecosystem Status *	Environmental Performance Index [41]	Beneficial
Greenhouse gas emissions	Chaudhury et al., see supplementary file of this paper [2]	Beneficial
Blue water consumption	Ercin et al.; Mekonnen and Hoekstra [42,43]	Beneficial
Land use	See supplementary file of Alexander et al. [39]	Beneficial
Non-renewable energy use	[44]	Not assessed
Biodiversity footprint	Stoll-Kleemann and Schmidt; Harwatt and Hayek [20,45]	Beneficial
Ecosystem Stability (total effect)		Beneficial

* Comprised of the following sub-indicators: $PM_{2.5}$ exposure, $PM_{2.5}$ exceedance, CO_2 emissions intensity, methane emissions intensity, N_2O emissions intensity, SO_2 emissions intensity, NOx emissions intensity. ** Note: where indicators are beneficial the colour Green is used to highlight. A neutral indicator is highlighted with a Yellow, and a negative indicator with Red. If the indicator is unassessed, Grey is used to highlight.

3.3. Affordability and Availability

3.3.1. Affordability

Chaudhary et al. [2] based their affordability metric on the work of the Economic Intelligence Unit (2015), which used six indicators of affordability. The first indicator of "Food consumption as a share of household expenditure" is the most applicable for this paper, as the UK government provides annual data for this area. The other indicators such as "Proportion of population under global poverty line" are not applicable within a UK context. This section will focus on "Relative affordability of food" and "UK food inflation", which feed into the area of "Food consumption as a share of household expenditure". There will also be a discussion regarding the situation of "Trading down", which is applicable to the issue of affordability.

The first sub-indicator for the indicator of "Food consumption as a share of household expenditure" is that of "Relative affordability" of food products which "can be measured by the share of the household budget going towards food, i.e., the percentage of total household spending that goes towards household food purchases" [46]. At the UK level, there has been an overall increase in household incomes, which has reduced the percentage of spending on food and non-alcoholic drinks from 16.4 percent in 2014 to 14.3 percent in 2016/2017 (Engel's law: "Income rises; the proportion of income spent on food falls") [46].

UK inflation regarding food prices: For meat (01.1.2 Meat), price increased by 1.4 percent from August 2017 to August 2018. However, when focusing on only beef, the situation is quite different, with a general price decrease of −1.1 per cent for these 12 months [47]. This implies that, overall, beef has become more affordable within a 12-month period (though the price changes are relatively small), though this clearly provides no indication of how the prices of individual beef products are changing, or how price changes affect quantities purchased by consumers. This is in contrast to the (01.1.7) vegetables group, which, during the same time period, experienced a 3 percent increase in prices. Unfortunately, due to the aggregated inflation data, it is not possible to describe how legume prices have changed over a 12-month period.

This is where the indicator of "trading down" is important, as this measures consumers' switching to purchases of less expensive products (when a price rise occurs) within a food group [46]. In a situation where households trade down, the assumption is that the subsequent product (e.g., trading down from beef steak to beef mince) is of less quality, which could be a result of brand name, nutrient content, taste, etc. [46]. The situation of trading down with regards to pulses and legumes could not be studied, as the groups were not available from the Revoredo-Giha et al. [48] study. Please also see [49–51] for additional discussion and modelling of similar topics.

With regards to the situation for beef/veal products for the period of 2007–2014, it was found that a "price increase of beef and veal implied increases in expenditure and decreases in quantities in all countries" of the UK [48]. However, Revoredo-Giha et al. found that Scotland was the only country within the UK which traded up with this price increase, whilst the others traded down. However, no statistically significant relationship was found between trading up/down and the effect on nutrient consumption for beef/veal [48]. It is difficult to compare this situation to pulses and legumes, given that there is not a pulses and legume group.

3.3.2. Availability

Chaudhary et al. [2] describe food availability as being related to "ease of physical access to food" and food affordability. de Roos et al. [52] found that: "Contrary to previous studies, purchase data show that access to and average prices of fresh foods generally, and F&V and fish specifically, are broadly similar between urban and rural areas". Therefore, with regards to the UK context, affordability of beef products is the issue, rather than availability.

3.4. Sociocultural Wellbeing

3.4.1. Methods

Chaudhary et al. [2] included this metric to represent societal factors. They proposed using four indicators: Gender Equity [53], Extent of Child Labour [54], Respect for Community Rights [55], and Animal Health and Welfare [56]. We performed a review on each of these nominated indicators/datasources, compiling relevant statistics for reducing beef consumption in the UK. The nominated 'global' databases had little subnational information provided.

3.4.2. Results

Three of the indicators were data scarce, due to this category's relating more to the Sociocultural Wellbeing of the production system rather than consumption of food products (i.e., beef).

Child labour and exploitation does occur in the UK, with 1026 cases reported in 2017 [57]. The Gangmasters and Labour Abuse Authority has conducted over 20 operations related to labour exploitation in the agriculture sector. However, there is no information on how many of the operations or child labour cases are linked to the beef industry.

There is no data available on the male–female employment rate within the UK meat industry's 75,000 employees; however, it is admitted that women are outnumbered by men in all areas of the meat industry, at senior levels and higher learning skills in particular [58]. This lack of Gender Equity can be further evidenced by the current gender pay gap in the UK meat industry being 12–16% lower than a man's hourly wage [59–62]. Changes to meat consumption would have effects on employment within the UK meat industry. However, it is unknown how this would relate to the male–female employment rate.

Respect for Community Rights is high in the UK, with it scoring 2.14 (5th highest) on the Environmental Democracy Index [63]. However, further use of this indicator was hampered by the lack of sectoral or product information on beef, livestock, or meat processing.

The Animal Protection Index gives the UK an 'A' ranking, indicative of high animal welfare standards [56]. However, there is no individual assessment of the beef industry for these indicators, so further determination by these indicators is not possible. Animal Health and Welfare is a rapidly developing issue in the UK, with an ongoing debate on grass-fed versus grain-fed beef [64,65], the developments of Brexit—a new Farm Bill and Non-EU trade (China lifted ban on British beef in the summer of 2018 for the first time since BSE (https://www.theguardian.com/environment/2018/jun/27/china-lifts-ban-on-british-beef), with larger-scale beef farms on the rise (https://www.thebureauinvestigates.com/stories/2018-05-29/inside-britains-new-intensive-agriculture-sector-beef-lots)). In addition, there has been a reduction of local abattoirs, which is affecting animal welfare by increasing journeys of live transits [66]. For these reasons, additional metrics to those proposed may be required to understand how beef reduction may impact Sociocultural Wellbeing.

3.5. Resilience

3.5.1. Methods

Resilience, as conceived by Chaudhury et al., is linked with the vulnerability of a given system to climate change; as reducing beef consumption is expected to reduce climate change impacts, we would expect an overall improvement in resilience from a shift in diets away from beef consumption. What is assessed here are further direct impacts that reducing beef consumption may have on resilience. The two components of resilience used by Chaudhury—the Notre Dame Global Adaptation Initiative (ND-GAIN) [67], and the Shannon Diversity of Food Production Index [68]—were used to assess the direct impact of reducing beef consumption on resilience. A total of 38 ND-

GAIN sub-indicators were considered not relevant (such as transport infrastructure). For the seven sub-indicators selected for further review, the original sources of data used in ND-GAIN or the Shannon Diversity of Food Production Index were consulted, in order to determine the likely impact of reducing beef consumption. Where this was not possible, indicators were assessed through a review of the literature.

3.5.2. Results and Discussion

Overall, the impact of reducing beef consumption on resilience is expected to be beneficial (see Table 3). A number of sub-indicators could not be fully assessed, as their outcomes were highly dependent on the type of land-use change which would follow a reduction in beef consumption. For example, likely changes in annual groundwater runoff and recharge vary with differing land-use change scenarios—moving to agroforestry, for example, may reduce groundwater recharge rates [69,70]—but these impacts vary with differing crop and tillage types [71]. Freshwater withdrawal rate and ecological footprint are both likely to be improved by a reduction in beef consumption, as discussed in more detail in the Ecosystem Stability section of this paper, due to the lower overall impacts of plant foods such as legumes (for example, the water footprint of pulses is 4055 L per kilogram, as opposed to 15,415 L per kilogram for bovine meat [42,43].

Resilience, both in terms of the direct impacts measured by the sub-indicators assessed in Table 3 and in the broader terms of vulnerability to climate change, is likely to be improved by reducing beef consumption, as climate change itself will be lessened, and immediate benefits will accrue in areas such as freshwater use and ecological footprint.

Table 3. Assessment of reduction of UK beef consumption on Resilience indicators.

	Indicators	Data Source(s)	Impact of Reducing Beef Consumption*
ND-GAIN	Food import dependency		Not assessed
	Rural population		Not assessed
	Projected change in annual groundwater runoff		Not assessed
	Projected change of annual groundwater recharge		Not assessed
	Fresh water withdrawal rate	Stoll-Kleemann and Schmidt; Harwatt and Hayek [20,45]	Beneficial
	Natural Capital Dependency		Not assessed
	Ecological footprint	Galli and Mailhes [72]	Beneficial
Shannon Diversity of Food Production			Not assessed
Resilience (total effect)			Beneficial

* Note: where indicators are beneficial the colour Green is used to highlight. A neutral indicator is highlighted with a Yellow, and a negative indicator with Red. If the indicator is unassessed, Grey is used to highlight.

3.6. Food Safety

3.6.1. Methods

Food safety has been assessed by Chaudhary et al. [2] and Gustafson et al. [3] by using two broad indicators, namely the Global Burden of Foodborne Illness and the Food Safety Score proposed by the WHO and the GFSI (Global Food Security index 2015), respectively. The Global Burden of Foodborne Illness indicator as reported by the WHO did not contain country-specific data; hence, the impact on the UK level could not be assessed from the WHO report itself. Data specific to England and Wales on foodborne illnesses as reported by Adak et al. [73] was used to fill this gap. A literature search was performed to determine if the pathogenic agents listed by Adak et al. [73] were identified as being present in beef consumed in the UK. Association between microbes in the food chain and antibiotic resistance has previously been widely reported. To capture this connection, a literature search was conducted to check if the pathogens reported in Adak et al. [73] were associated with anti-microbial resistance in the UK. The three sub-indicators (agency to ensure the safety and health of food, percentage of population with access to potable water, and presence of formal grocery sector) of the Food Safety score were used for the assessment in our study.

3.6.2. Results and Discussion

The safety of foods and consumables is an important aspect of public health. The relationships between the food safety indicators and the effect of reduced beef consumption on the indicators are shown in Table 4. The three sub-indicators of the Food Safety Score have not yet been assessed in a UK context and hence could not be used to draw any conclusions. However, with regard to the "burden of foodborne illness" indicator, as measured by the presence of the pathogens (as reported in Adak et al. [73]) in beef consumed in the UK, as well as the association of pathogens to anti-microbial resistance, the reduced consumption of beef is expected to have a beneficial effect. Among the 25 defined pathogenic agents listed by Adak et al. [73], ten were found to be present in UK beef (see our Supplementary Table S1). Seven unique pathogenic agents were both present in UK beef and associated with anti-microbial resistance in UK. However, it must be mentioned that the indicators do not completely capture all the risks associated with the consumption of beef. Notably, the indicators do not consider the risks and impacts of prominent additives and conditioning agents in beef and beef products. Due to the non-pathogenic nature of such additives, they were not included in Adak et al. [73]. Hence, work needs to be performed to design better indicators which capture the other food safety aspects of beef consumption.

Table 4. Assessment of reduction of UK beef consumption on Food Safety indicators.

Indicator	Sub-Indicator	Data Source(s)	Impact of Reducing Beef Consumption*
Burden of foodborne illness	Presence of pathogen in beef consumed in the UK	Adak et al., see Supplementary file 1 [73]	Beneficial
Burden of foodborne illness	Association of pathogen to antibiotic resistance in the UK	Adak et al., see Supplementary file 1 [73]	Beneficial
Food Safety Score	Agency to ensure safety and health of food		Not assessed
	Percentage of population with access to potable water		Not assessed
	Presence of formal grocery sector		Not assessed
Food Safety (total effect)			Beneficial

* Note: where indicators are beneficial the colour Green is used to highlight. A neutral indicator is highlighted with a Yellow, and a negative indicator with Red. If the indicator is unassessed, Grey is used to highlight.

3.7. Waste and Loss Reduction

3.7.1. Methods

Reducing food loss and waste (FL&W) has been identified as an essential requirement in achieving global food security [74], and is a key objective of Sustainable Development Goal (SDG) 12.3 (halve food waste and reduce food loss by 2030). The measurement of Food waste and loss is becoming standardised, thanks to the creation of the food loss and waste accounting and reporting standard [75] and the Food Waste Atlas [76,77]. However, there is a lack of product-specific information due to a variety of factors, including the cost and time intensity of survey methods [19,78], with differences of up to 40% being returned by different measurement methods [79,80].

Food waste and loss has been assessed by Chaudhary et al. [2] and Gustafson et al. [3] as a metric that quantifies the portion of the produced food that is not either lost (pre-consumer) or wasted (post-consumer) in a country. Both use an aggregated measure from the FAO [81] to report country-wide food loss and waste proportions. However, to investigate product-specific food loss and waste, greater detail is required.

After reviewing the UK FL&W literature, it was found that the information that can be readily accessed include on-farm food loss, post-farm food loss, food waste and loss in the processing and manufacture, food loss and waste in retail, in-home food waste, and out-of-home food waste. Additionally, food loss and waste should be categorised into edibility and inedibility [82].

Overconsumption of food can also be regarded as a waste, and this can be calculated by estimating what proportion of consumption is in excess of that needed to provide the level of nutrition required to maintain good health [83–86]. Measurement, however, is problematic: Data on food intake at the population level (from estimates of gross food consumption) and from surveys of individual consumption (and purchase) behaviour can be used to measure the level of overconsumption, although the consumption of certain foods is often incorrectly reported [87].

3.7.2. Results

On a global scale, food loss and waste is estimated by the FAO and other groups [81,88,89] (see Table 5). UK beef loss and waste statistics are available for the supply chain, retail, out of home, and at home (see Table 3). Comparison between the FAO and other sources is possible between the consumer and retail estimates. However, due to issues of scope, no such comparison is possible with industrial or manufacturing estimates. From the tonnages provided in Table 6, we calculated that household beef waste alone embodies 1,479,168 tonnes of CO_2e per year [90].

Table 7 presents 2012 UK household food purchase and waste as well as the percentage of purchase wasted for beef, total fresh vegetables and salads, and beans. Overall, total fresh vegetables and salads have a higher amount of purchase wasted (66% wasted, with 14% inedible) than beef (11% wasted, 8% inedible). However, beans have a much lower percentage of wastage to purchase, but a high rate of inedible waste due to discards from fresh beans [91,92]. This indicates that a decrease in beef and an increase in the consumption of general plant-based foods, as well as pulses and legumes, would have a mixed effect on household food waste due to the increased inedible waste per tonne of purchase and consumption. However, the carbon impacts and cost of this waste would be drastically reduced.

Overconsumption of beef was estimated using the National Diet and Nutrition Survey (wave 7 and 8 of 2014 to 2015 and 2015 to 2016), which provides high quality data on dietary intake and nutritional status in a representative sample of the UK population. A total of 3–4% of the sampled population were found to have a level of beef consumption that contributed towards overconsumption or was comprised entirely of overconsumption (increasing caloric consumption above 2500 kcal/day). The average portion size of beef partly or totally overconsumed per day was 80–100 g—meaning that 29.2 to 36.5 kg per year is potentially over-consumed for 3%–4% of the UK population. Scaled up to the total UK population, this would mean that 91 tonnes of beef are partly or totally overconsumed in the UK every year out of an estimated total beef consumption of between 416,000–460,000 tonnes. This embodies 2639 tonnes of CO_2e per year [90].

A reduction in purchases of beef (and thus a reduction in the waste and consumption of beef) would reduce direct waste and overconsumption. We have not been able to assess the systemic waste and overconsumption effects of the food that is consumed to replace the portions of beef avoided.

Table 5. Regional estimates of Food Loss and Waste (%) by food system stage; data from: Food and Agriculture Organization (FAO) [81], see also [88].

Waste Category	Region	Crop-Region	Waste (%) by Food System Stage				
			Agricultural Production	Postharvest Handling and Storage	Processing and Packaging	Distribution	Consumption
Meat	South and Southeast Asia	Meat, South and Southeast Asia	5.1	0.3	5	7	4
	Europe incl Russia	Meat, Europe incl Russia	3.1	0.7	5	4	11
	North Africa, West and Central Asia	Meat, North Africa, West and Central Asia	6.6	0.2	5	5	8
	sub-Saharan Africa	Meat, sub-Saharan Africa	15	0.7	5	7	2
	Latin America	Meat, Latin America	5.3	1.1	5	5	6
	North America & Oceania	Meat, North America & Oceania	3.5	1	5	4	11
	Industrialised Asia	Meat, Industrialised Asia	2.9	0.6	5	6	8

Table 6. UK statistics on beef food loss and waste at different stages of the supply chain.

Year	Source	Food System Stage	Tonnage of Waste (Beef)	Tonnage of Total Production/Consumption of Foodstuff (Beef)	% of Total Waste Relative to Food System Stage
2010–2011	WRAP [93]	Slaughtering and processing	614,147 (inc cat 1,2,3 and blood waste)	1,061,000	57.8% (beef)
2015	WRAP [94]	Manufacturing	160,000	-	(18% of all manufacturing food waste was meat, poultry and fish)
2010–2011	WRAP [93]	Retail	14,572	379,000	3.8% (beef)
2014	Moult et al. [95]	Retail	-	-	13% (meat)
2011	WRAP [96–98]	Out of Home	55,158	-	(6% of all OOH waste was meat/fish)
2012	WRAP [92]	Household	47,000 (Edible), 4000 (Inedible), £400 million	449,000	11.3% (beef)

Table 7. Selected foods, total purchased, household waste in 2012 by type, split by wasted food/inedible parts. Data from WRAP [92] and Office for National Statistics [14].

	Wasted Food (Edible Parts), Tonnes	Inedible Parts, Tonnes	Total Food Waste, Tonnes	% of Wasted Edible Parts in Total Food Waste	% of Wasted Inedible Parts in Total Food Waste	Total Purchases, Tonnes	% of Total Purchases Wasted
Beef	47,000	4000	51,000	92%	8%	449,000	11.3%
Total fresh vegetables and salads	1,300,000	230,000	1,600,000	81%	14%	2,439,000	66%
Bean (all varieties, (fresh and tinned, not including baked beans)	8000	4000	13,000	62%	31%	344,000	4%

3.8. Culturally Acceptable

3.8.1. Methods

Incorporating consumer preferences is one means to account for cultural acceptability. Cultural acceptability has been identified by Drewnowski [4] as representing one of the four domains of sustainable food and nutrition security (the Drewnowski paper from which we draw our terms of reference measured cultural acceptance only in terms of frequency of consumption by population subgroups. However, we acknowledge that cultural acceptability of diets can also consider much broader and harder to quantify factors including ethnicity, food history, religious preferences, social aspects, etc.). Measuring consumer preferences encompasses different disciplines; this subsection focuses on Economics. Economics can measure consumer preferences using price elasticities. Price elasticities measure the responsiveness of quantity demanded of a good to a change in the price of the good in question (called own price elasticities) or other goods (cross price elasticity and either a substitution effect or complement effect). It should be emphasised that there are other methods for eliciting preferences, such as choice experiments. Other disciplines may opt for a focus group approach; for reasons of brevity, only price elasticities will be studied within this paper.

These price elasticities are estimated using demand systems which impose various constraints in order to model consumer behaviour. Therefore, consumer preferences in Economics require modelling, which some other disciplines may view as a limitation. These price elasticities can be incorporated into diet models in order to estimate more sustainable diets, which also take into account the potential substitution and complement relationships amongst foods (economic demand systems which are based on purchasing data will help capture the consumer preferences via our purchasing patterns. However, the data will be aggregated, which means that we cannot estimate individual preferences using these price elasticities. Nevertheless, capturing consumer preferences via elasticities is one approach for measuring cultural acceptability with regards to different food groups. There are other approaches which would elicit preferences, such as qualitative studies). Irz et al. [99] and Green et al. [21] both devised diet models (which used optimisation) which incorporated price elasticities, with the former incorporating both substitution and complement relationships whilst the latter only incorporates own price elasticities.

3.8.2. Results and Discussion

Irz et al. [99] and Green et al. [21] have studied the change in all major food groups as a result of optimising the diets to incorporate consumer preferences, nutritional constraints, low carbon emissions, and price effects. This subsection will briefly detail the main results of the two aforementioned studies which are applicable to this paper.

Green et al. [21] ran their quadratic diet model with a 10 percent reduction in GHG (relative to the baseline) for each run; for 10, 20, 30, and 40 percent reductions (for adult males), some red meats still existed in the diet. The baseline diet for processed beef was 25.1 grams for adult males, and this changed to 16.3 grams under the 40 percent reduction scenario, but the beef group was zero grams [21]. Green et al. [21] show a similar situation for adult females where processed beef remains (also partially explained by the same price elasticities being used). The Irz et al. [99] paper, which incorporates both substitution and complement effects (unlike Green et al. [21]), found that a 5 percent reduction in GHG emissions would reduce red meat consumption (it is not disaggregated into beef products) by approximately 36 percent for the four income groups.

The criticism of Green et al. [21] would be that their underlying price elasticities are estimated at household level, but their demand systems assume that these household elasticities are representative of males or females (in addition, Green et al. is an example of using own price elasticities which do not capture substitutions). Whilst Irz et al. [99] appears to use a common set of dietary reference values to represent households, but given that a household could contain a mix of age groups, this may be a strong assumption.

4. Conclusions

This paper has shown that the process of fitting specific policy questions to prescribed sustainable diets frameworks can be challenging. However, we are able to use our hybrid sustainable diets framework to detail the overall impact of beef consumption on sustainability measures at the UK level. To summarise this papers findings we have provided provide a summary table (Table 8).

The impact of reducing beef consumption is expected to be strongly beneficial to all aspects of ecosystem stability which were assessed in this study. Further benefits could be expected regarding a range of indicators, such as biodiversity footprint and land use, depending on whether land used to produce beef is turned over to monoculture arable cropping, biodiverse agroforestry, industrial use, etc.

With regards to affordability of beef products, most countries in the UK reacted to price increases from 2007 to 2014 by trading down (except Scotland) and reducing quantities purchased. Therefore, fewer beef products are being purchased, which is related to this paper's topic of reducing beef consumption. Physical access is not considered applicable within a UK context.

While the overall impact on resilience has been classed as beneficial, the majority of indicators for this metric were unable to be assessed. This is largely due to the fact that impacts will depend on which land-use change scenarios take place following a reduction of beef consumption.

The culturally acceptable dimension is important to consider, given that sustainable diet estimation whereby preferences are incorporated via price elasticities can still (depending on the relative emission reductions required) include beef products (grouped as red meats), but at a lower quantity than what is currently being consumed in baseline diets.

This is study is novel and useful to policy practitioners as it highlights a practical method of policy assessment. It considers how to assess and monitor the sustainability of dietary changes and other aspects of diets, particularly the unintended consequences. There is no doubt that the previous sustainable diets frameworks have the strength of giving quantified feedback on changes to diets and the food system. However, using the example policy question of decreasing beef consumption in the UK, we highlight that the previously developed 'global' indicators are not always granular enough to be useful for assessing specific in-country and policy issues. To improve future sustainable diets frameworks, the selection of indicators, dimensions, measures, and metrics must be granular and flexible enough to allow for the investigation of national or sub-regional policy change. The number of indicators not able to be assessed in our example also highlights the need for a greater number of higher quality interoperable datasets both at global and sub-regional levels.

One possible source of additional data for sustainable diets frameworks is the in-progress assessment of the sustainable development goals—17 global goals designed to be a blueprint to achieve a better and more sustainable future for all (see https://sustainabledevelopment.un.org). Set in 2015 by the United Nations General Assembly, the goals are intended to be achieved by the year

2030. Each goal has multiple subgoals, on which each UN member state will report their progress throughout the 2020s. The sustainable development goals map well onto this study's (and previous) sustainable diets frameworks. Future research could further examine if this data could help provide additional databases to perform assessment.

Table 8. Summary of assessment of reduction of UK beef consumption on all metrics and indicators.

Metrics	Indicators	Indicator Outcome *	Overall Outcome *
(1) Food Nutrient Adequacy	1.Population Share with Adequate Nutrients 2. Nutrient Balance Score 3. Disqualifying Nutrient score 4. Shannon Diversity of Food Supply 5.Non-Staple Food Energy 6.Modified Functional Attribute Diversity	1.Beneficial 2. Beneficial (slight improvement) 3. Beneficial 4 Not assessed 5. Not assessed 6. Not assessed	Beneficial
(2) Ecosystem Stability	1.Ecosystem status 2.GHG emissions 3.Blue water consumption 4.Land use 5.Non-renewable energy use 6.Biodiversity footprint	1.Beneficial 2.Beneficial 3.Beneficial 4.Beneficial 5.Not assessed 6.Not assessed	Beneficial
(3) Affordability and Availability	1. Affordability: Share of the household budget going on food 2. Trading down and reducing quantities purchased 3. Availability: Ease of physical access to food	1. Beneficial 2. Beneficial 3. Not applicable in UK context	Beneficial
(4) Sociocultural Wellbeing	1. Gender Equity 2. Extent of Child Labor 3. Respect for Community Rights 4. Animal Health and Welfare	1. Not assessed 2. Not assessed 3. Not assessed 4. Beneficial	Over 50% of indicators not assessed
(5) Resilience	1. Food import dependency 2. Rural population 3. Project change in annual groundwater runoff 4. Projected change of annual groundwater recharge 5. Fresh water withdrawal rate 6. Natural capital dependency 7. Ecological footprint	1.Not assessed 2.Not assessed 3.Not assessed 4.Not assessed 5.Beneficial 6.Not assessed 7.Beneficial	Over 50% of indicators not assessed
(6) Food Safety	1. Burden of foodborne illness 2. Food safety score	1. Beneficial 2. Not assessed	Beneficial
(7) Waste and Loss Reduction	1. Avoidable and unavoidable waste 2. Overconsumption	1. Beneficial (decrease in avoidable/edible waste) and Negative (increase in unavoidable/inedible waste) 2. Beneficial	Beneficial
(8) Culturally Acceptable	1. Price elasticities (can incorporate product substitution and complements)	1. Neutral	Neutral

* Note: where 50% or more of the indicators are beneficial: The colour Green is used to highlight. A neutral indicator is highlighted with a Yellow, and a negative indicator with Red. If the indicator is unassessed, Grey is used to highlight.

Supplementary Material: The following is available online at www.mdpi.com/xxx/s1, Table S1: Summary of studies reporting antimicrobial resistance in pathogens found in UK beef. We have provided a spreadsheet with references (PubMed IDs) for (1) the presence of pathogen in UK beef and (2) association between pathogen and AMR in the UK.

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