Protective Foods for a Protected Planet: A Report on Food Production Impacts on Environmental Systems

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Contents

1. Introduction

The food system has a large impact on the environment, from greenhouse gas (GHG) emissions, land use change, nitrogen emissions, fertiliser runoff and soil degradation. For example, global food systems contribute between 19 and 29% of anthropogenic GHG emissions (Vermeulen et al, 2012). At the same time, rates of both obesity and malnutrition are high in both developed and developing nations (Godfray & Garnett, 2014; Popkin et al, 2012). "Protective food"-based diets offer a means of tackling obesity and malnutrition, as set out in the Conway & Burgman (2021) research for the Rockefeller Foundation. This report shows that protective diets also have a role to play in reducing the environmental impacts of the food system. Protective diets are defined as those foods "that significantly lower our risk of diseases, such as whole grains, fruits, vegetables, legumes, and nuts" (Flor, 2019).

This report demonstrates that protective diets are associated with lower emissions of greenhouse gases (GHGs) than alternative diets, particularly typical Western diets. It therefore argues that as well as having positive health impacts, incentivising protective diets will help to mitigate climate change and protect the environment. This report focuses on protective diets in Kenya, as one in a series of collaborative reports for the Rockefeller Foundation on protective diets and Smart Fresh Markets (SFMs) in Kenya.

Having established that dishes characterising a protective diet are relatively low in GHG emissions compared with existing Kenyan dishes and typical Western dishes, we next explore the options for incentivising adoption of protective diets in Kenya. One important factor is poverty alleviation, given the 'poor man's meal' referred to in the Kenya Markets Trust report (2016), while low in GHG emissions, does not exemplify a protective diet as it is deficient in protein and various macronutrients.

The report presents analysis of the GHG emissions associated with typical Kenyan and Western meals, as well as those of exemplar protective diet meals. Next, GHG emissions are assessed at the dietary scale, drawing upon the report of the EAT-Lancet Commission (2019). Section 4 provides analysis of the food sector's land use, Section 5 assesses water use, and Section 6 analyses pollution associated with different food products. We briefly discuss the implementation of a protective food-based diet in Section 7. Finally, we provide example scenarios of the potential impact of transitioning to a protective foods based diet, focusing in particular on GHG emissions.

2. Greenhouse Gas Emissions

In this section, CO_2 equivalent (CO_2eq) values for individual food products are used to explore the GHG emissions associated with different exemplar meals. The CO_2eq amounts are calculated using emissions factors from Clune et al (2017). First, we calculate the CO_2eq associated with four indicative Kenyan meals, taken from a Kenya Markets Trust (2016) report. We then show the CO_2eq values for some typical 'Western' dishes. Finally, we model some example meals which would more closely match a protective diet and calculate the CO_2eq values for these 'improved' meals.

Dish	Assumed food intake per meal	KgCO2eq, using Clune et al., 2017 median GWP values
Fish meal	100g fish, 250g refined grains, 300g vegetables, 20g unsaturated oils	0.349[fish]+0.125[grains]+0.0345[Sukuma wiki]+0.0135[onions]+0.02775[field-grown tomatoes] +0.0446[oil] =0.59435kgCO_2eq
Beef meal	100g beef, 250g refined grains, 300g vegetables, 20g unsaturated oils	2.661[beef]+0.125+0.0345+0.0135+0.02775+0.0446 =2.85635kgCO_2eq
Milk meal	100g dairy, 250g refined grains, 300g vegetables, 20g unsaturated oils	0.129[milk]+0.125+0.0345+0.0135+0.02775+0.0446 =0.37435kgCO_2eq
Ugali + Sukuma Wiki[1] only	250g refined grains, 100g vegetables	0.125+0.023 =0.148kgCO_2eq

[1] Ugali is a type of maize porridge that is consumed as a staple product in East and Central Africa. Sukuma wiki is an East African dish made primarily with collard greens, known as sukuma, and cooked with onions and spices. Sukuma comes from the same plant family as spinach.

The GHG emissions in the table above (see last page) were calculated using Kenya Markets Trust meal examples, and Clune et al (2017) emissions factors, as below:

Name	Median
Vegetables (all field grown vegetable)	0.37 kgCO_2eq/kg
Fruits (all field grown fruit)	0.42 kgCO_2eq/kg
Cereals	0.50 kgCO_2eq/kg
Legumes and pulses	0.51 kgCO_2eq/kg
Passive greenhouse fruit and vegetable	1.10 kgCO_2eq/kg
Tree nuts combined	1.20 kgCO_2eq/kg
Milk world average	1.29 kgCO_2eq/kg
Heated greenhouse fruit and vegetable	2.13 kgCO_2eq/kg
Rice	2.55 kgCO_2eq/kg
Eggs	3.46 kgCO_2eq/kg
Fish: all species combined	3.49 kgCO_2eq/kg
Chicken	3.65 kgCO_2eq/kg
Cream	5.64 kgCO_2eq/kg
Pork: world average	5.77 kgCO_2eq/kg
Prawns/shrimp	7.80 kgCO_2eq/kg
Cheese	8.55 kgCO_2eq/kg
Butter	9.25 kgCO_2eq/kg
Lamb: world average	25.58 kgCO_2eq/kg
Beef: world average	26.61 kgCO_2eq/kg

(Source: Clune et al., 2017.)

For comparison, the GHG emissions of four example Western-style meals are analysed below. The emissions are notably higher than in the four Kenyan example meals.

Dish	**Assumed food intake per meal**	**KgCO2eq**
Cheeseburger meal	113g beef, 100g refined grains, 20g tomato, 20g onions, 50g cheese, 150g potato, 50g oil	3.03+0.05+0.0426+0.4275+0.027+0.1115 = 3.6886 kgCO_2eq/kg

Fried chicken meal	150g chicken, 10g refined grains, 10g dairy milk, 150g potato, 50g oil	0.5475+0.005+0.0129+0.027+0.1115 = 0.7039 $kgCO_2eq/kg$
Steak meal	350g beef, 50g butter, 150g potato, 50g oil, 100g green vegetables	9.387+0.4625+0.027+0.037+0.1115 = 10.025 $kgCO_2eq/kg$
Spaghetti Bolognese meal	100g beef, 100g tomatoes, 50g onions, 10g garlic, 20g oil, 150g refined grains	2.682+0.213+0.009+0.0057+0.075 +0.0446= = 3.0293 $kgCO_2eq/kg$

Finally, we give four potential 'Improved' meals, based on the EAT-Lancet Commission's 'healthy reference diet' (EAT-Lancet Commission, 2019). The GHG emissions for these meals are also calculated below.

Dish	Assumed food intake per meal	KgCO2eq
Fish meal - Oily fish, Sukuma wiki, onions, tomatoes, wholegrain rice	100g fish, 300g vegetables, 150g wholegrain rice, 20g unsaturated oil	0.349+0.0345+0.0135+0.02775+0.3825 +0.0446= = 0.85235 $kgCO_2eq/kg$
Beans meal – Dried beans, Sukuma wiki, onions, green beans, peppers	100g beans, 300g vegetables, 100g cassava, 20g unsaturated oil	0.051+0.0345+0.0135+0.02775+0.037 +0.0446= = 0.20835 $kgCO_2eq/kg$
Groundnut stew meal – peanuts,	75g peanuts, 300g vegetables, 150g wholegrain	0.03825+0.0135+0.02775+0.0185+0.037 +0.0446=

onions, tomatoes, peppers, green beans, wholegrain bread	bread 20g unsaturated oil	= 0.1796 $kgCO_2eq/kg$
Lentil curry meal – lentils, onions, tomatoes, okra, wholegrain rice	100g lentils, 300g vegetables, 150g wholegrain rice, 20g unsaturated oil	0.051+0.0135+0.02775+0.0555+0.0446= = 0.19235 $kgCO_2eq/kg$

For easy comparison of the above calculations, Figure 1 shows all meals in the three categories. The Western meals are the most GHG intensive, with three out of the four example meals exceeding both existing Kenyan and 'improved' meals. Overall, the improved meals are the lowest in GHG emissions. It should be noted, furthermore, that while some of the existing Kenyan exemplar meals (and one Western meal) have lower GHG emissions than some of the Improved meals, these meals are also nutritionally improved compared to the Western and, to a lesser extent, Kenyan meals.

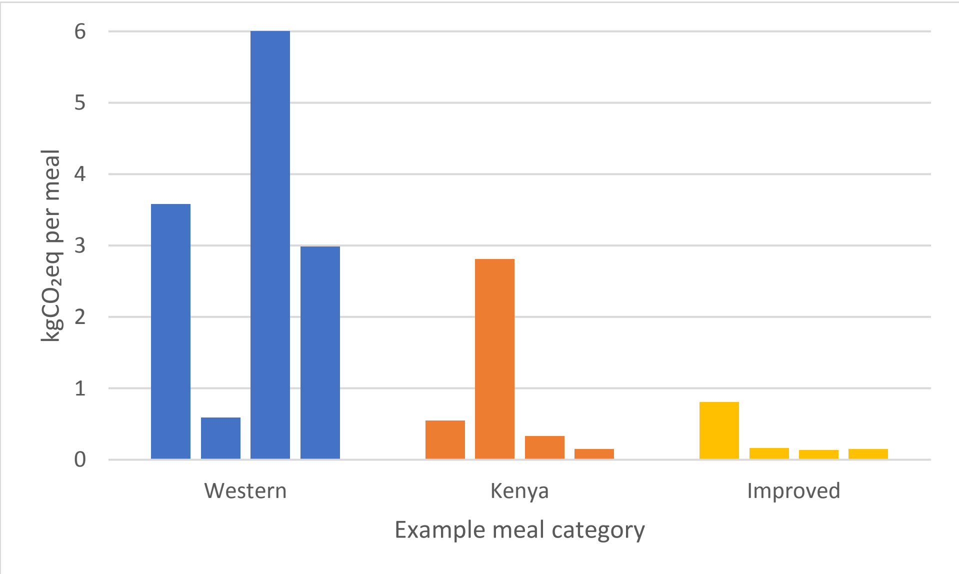

Figure 1: Western, Kenyan and Improved example meals, $kgCO_2eq$ per meal. Based on Clune et al, 2017.

3. Changes at the Dietary Scale

While our analysis of example meals provides some insight on the benefits of shifting toward protective diets for carbon reduction, it is at the dietary level that these benefits become most clear. The EAT-Lancet Commission published a reference diet that provided the required macronutrient intake while remaining within a 'safe operating space' defined by certain planetary boundaries – one of which is greenhouse gas emissions. This diet is therefore one that is characterized by protective foods that are also low in GHG emissions.

	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 vegetables Dark green vegetables Red and orange vegetables Other vegetables	300 (200-600) 100 100 100	- 23 30 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 Pork Chicken and other poultry Eggs Fish Legumes Dry beans, lentils and peas Soy foods Peanuts Tree nuts	7 (0-14) 7 (0-14) 29 (0-58) 13 (0-25) 28 (0-100) 50 (0-100) 25 (0-50) 25 (0-75) 25	15 15 62 19 40 172 112 142 149
Added fats		

Palm oil Unsaturated oils Dairy fats (included in milk) Lard or tallow	6.8 (0-6.8) 40 (20-80) 0 5 (0-5)	60 354 0 36
Added sugars All sweeteners	 31 (0-31)	 120

EAT-Lancet Commission 'Healthy Reference Diet, with possible ranges, for an intake of 2500 kcal/day'. Source: Eat-Lancet Commission, 2019.

Figure 2, below, gives the GHG emissions associated with major protein sources, using data collated in Poore & Nemecek (2018) from a review of studies on the impact of food. It shows the large impacts that beef and lamb have on GHG emissions, partly explaining why such protein sources comprise only a small proportion of the EAT-Lancet reference diet. Protective foods such as tofu, nuts, peas and pulses are associated with the lowest GHG emissions, as these protein sources are derived from plants which are largely grown from rain-fed agriculture (i.e., they are not grown in heated greenhouses which will have high CO_2 emissions (Poore & Nemecek, 2018), or through flooded agriculture such as rice paddies, which tend to have high methane emissions (Adhya et al., 2014)).

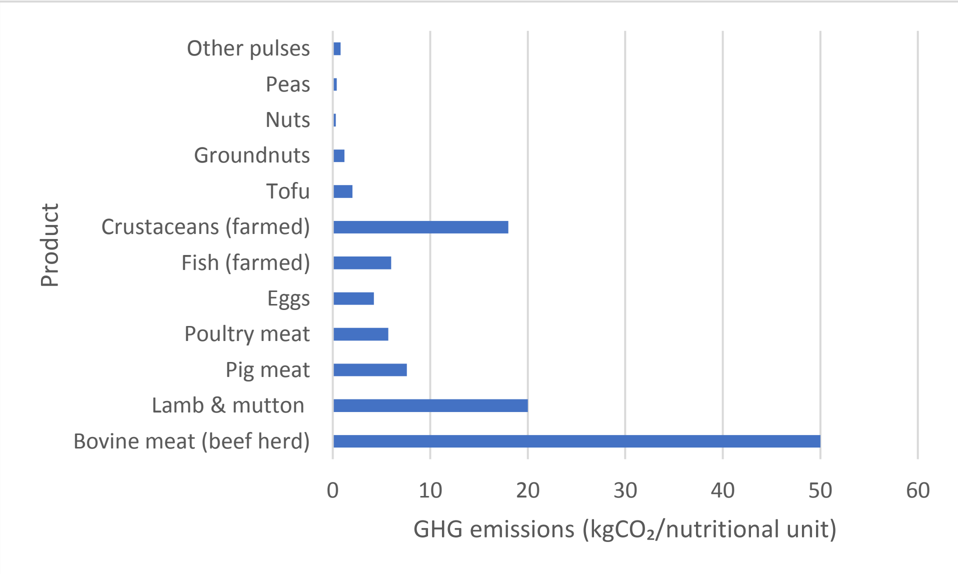

Figure 2: GHG emissions of major protein sources. Source: Poore & Nemecek, 2018.

In order to understand the reference diet presented above, we need to also appreciate where current diets are over- or under-consuming different food groups. Figure 3, below, shows that Sub-Saharan Africa is the only region to consume the 'correct' amount of red meat – i.e. neither over- nor under-consuming relative to the reference diet.

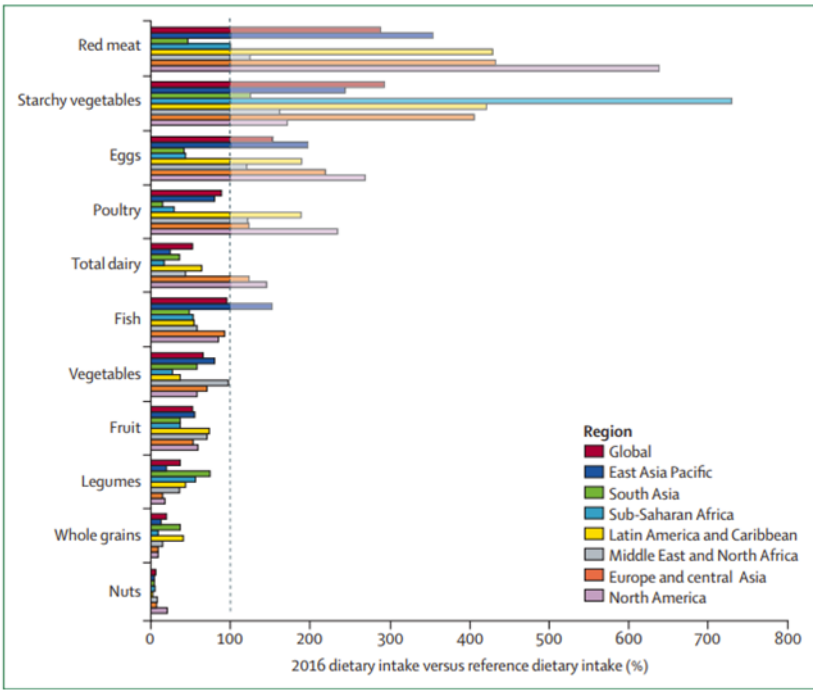

Figure 3: 2016 dietary intake of food types compared to the EAT-Lancet reference diet intake. Source: EAT-Lancet, 2019.

However, this regional scale result is likely to hide significant socioeconomic inequality among individuals in the consumption of red meat, with some people over-consuming red meat and many of them lacking in red meat consumption, relative to the reference diet.

Given that Sub-Saharan African inhabitants do not currently over-consume meat compared to the reference diet, and noting the continued severe burden of undernutrition and malnutrition, reductions in total meat consumption in the region are not recommended. Indeed, the EAT-Lancet report states that "…promotion of animal source foods for children, including livestock products, can improve dietary quality, micronutrient intake, nutrient status, and overall health" (EAT-Lancet, 2019).

Moreover, particularly in smallholder farms, livestock are often multifunctional – not just produced for their meat or milk, but also to fertilise land for crops and to provide draught power (Weiler et al, 2014). Accounting for this multifunctionality can cause estimates of farm carbon footprints to reduce, as Weiler et al (2014) show for Kenyan smallholder dairy farms. However, given that overall protein consumption needs to increase in Sub-Saharan Africa in order to meet the challenges of undernutrition and malnutrition (Godfray & Garnett, 2014; Tilman & Clark, 2014; Mensah et al, 2021), this does not preclude promotion of non-animal sources of protein. Rather, the increase in protein required to tackle undernutrition and malnutrition should be taken up by protective protein sources.

The Sub-Saharan Africa region under-consumes many protective foods, including fruits, vegetables, legumes, whole grains and nuts, in common with almost all other regions (EAT-Lancet, 2019). This therefore highlights a clear need to increase the consumption of alternative protein sources such as legumes and nuts, as well as to increase fruit and vegetable intake.

With consumption of meat currently expected to grow rapidly in Sub-Saharan Africa (Rockefeller Foundation, 2018), unhealthy and high carbon diets may become more commonplace unless action is taken (Tilman & Clark, 2014). The promotion of alternative protein sources is therefore vital to both the health and environment of Sub-Saharan Africa and the world. Some of these alternative protein sources may include so-called 'clean meat' – cultured cells that form meat without using animals (Rockefeller Foundation, 2017). However, it is likely that the majority of the protein shift will need to come from legumes and nuts, particularly in Sub-Saharan Africa given the high initial costs of 'clean meat'. It is also not clear that such 'clean meat' would in fact be deemed a protective food, in contrast to legumes and nuts.

4. Land Use

The amount of land required to produce a certain amount of a given food is an important environmental indicator given the competing demands on land (for example for energy supply, forestry etc.) This is particularly a problem where demand for a product is expanding such that the area of land used must also grow; this commonly necessitates land use change.

In the below, data from Poore & Nemecek's (2018) systematic review of literature on the environmental impact of food is used to understand the land use impact of different products within a food group. Protein sources were used as an example food group. Note that regional breakdowns were not provided, in part due to the lack of available data for the Africa region.

4.1 Protein Sources

Figure 4, below, shows that ruminant meat such as beef and lamb/mutton use significantly more land than other protein sources.

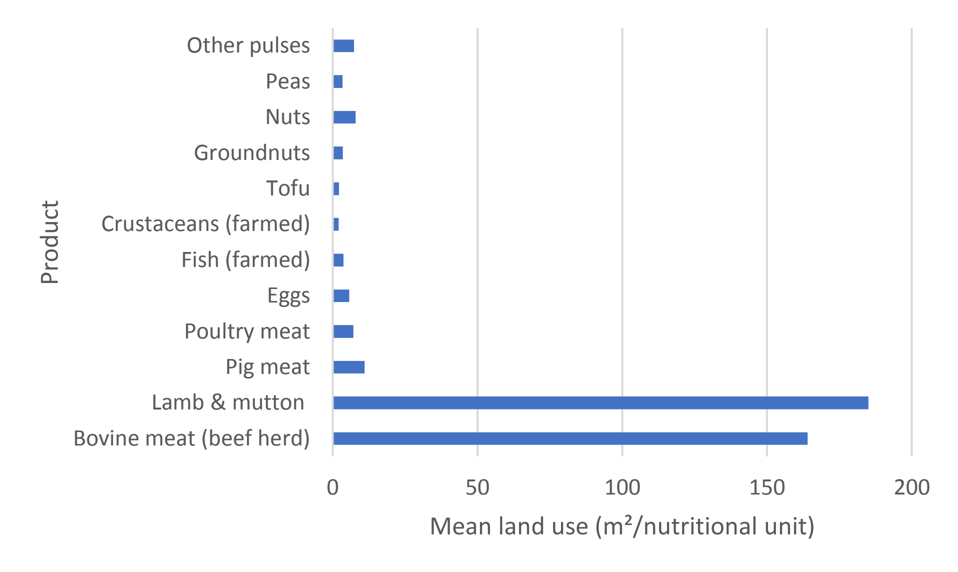

Figure 4: Mean land use of major protein sources. Source: Poore & Nemecek, 2018.

The above graph is dominated by the outsize effect of ruminants. In order to show more clearly the distinctions among other products, Figure 5, below (over page), shows the same graph but excludes beef and lamb/mutton to enable a clearer depiction of the remaining protein sources. From this graph we can see that pig meat, nuts, other pulses and poultry meats are the next highest land users of protein sources. This highlights that while protective foods such as nuts and pulses may have a low GHG emissions footprint, their use of land is high relative to farmed crustaceans and fish, or tofu and groundnuts. This does not take away, however, from the extreme land footprint taken up by ruminant agriculture – all other protein sources are significantly lower in mean land use.

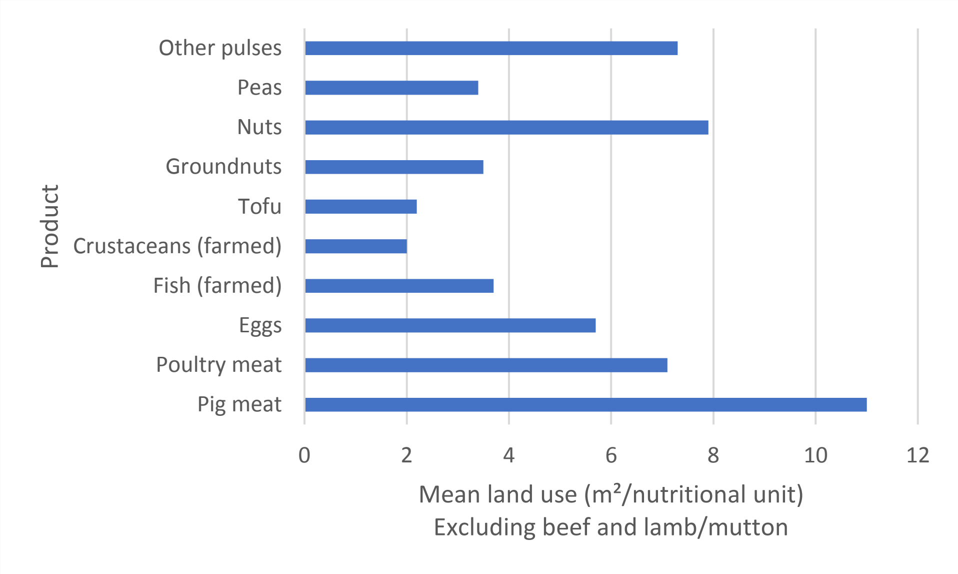

Figure 5: Mean land use of major protein sources, excluding beef and lamb/mutton for clarity. Source: Poore & Nemecek, 2018.

4.2 Example Meals

Data on land use is calculated per nutritional unit (i.e., the unit of primary nutritional benefit), meaning that amounts of land used for a single meal are not directly calculable. However, based on the ingredients presented for the example meals in the previous section, a traffic light system is presented below. For more information on the meal ingredients, see Section 2 above. Notably only the Kenyan and Improved meals receive any green lights, indicating a low land use impact for the meal. A red light indicates that the meal has a high or very high impact on land use, whereas an amber light denotes a meal that has a medium impact. The rationales for the category given each meal are included in the table.

Example Meal Category	**Example Meal**	**Land Use Traffic Light**	**Rationale**
Kenyan	Fish meal	🟢	Farmed fish has relatively low land use; it also only comprises 18% of aquatic animals produced in Africa (FAO, 2020) – wild caught fish has much lower land use and makes up a greater proportion of African fish consumption.
Kenyan	Beef meal	🔴	Beef has the second highest land use of any protein source.

Kenyan	Milk meal	●	Milk has median land use of $2.1m^2$ per functional unit, putting it on par with the lowest protein sources.
Kenyan	'Poor man's' meal	●	This meal relies on maize as the main component, the median land use of which is $1.8m^2$ per functional unit.
Western	Cheeseburger meal	●	Beef has the second highest land use of any protein source.
Western	Fried chicken meal	●	Chicken has relatively high land use, but is not as extensive as ruminant meat.
Western	Steak meal	●	Beef has the second highest land use of any protein source.
Western	Spaghetti Bolognese meal	●	Beef has the second highest land use of any protein source.
Improved	Oily fish meal	●	Farmed fish has relatively low land use; it also only comprises 18% of aquatic animals produced in Africa (FAO, 2020) – wild caught fish has much lower land use and makes up a greater proportion of African fish consumption.
Improved	Beans meal	●	Pulses have a relatively high land use, but are not as extensive as ruminant meat.
Improved	Groundnut stew meal	●	Groundnuts have a lower land use than other protein options.
Improved	Lentil curry meal	●	Pulses have a relatively high land use, but are not as extensive as ruminant meat.

5. Water Use

Water use is another important consideration when assessing food products' environmental impact. Data on the water use of protein sources is presented below.

Protein Sources

Figure 6, below, shows that nuts, and farmed crustaceans and fish use the most water per nutritional unit. It should be noted, however, that aquaculture comprises only about 18% of African production of aquatic animals, the majority of which is in North Africa (FAO, 2020). There is very little farming of crustaceans in the

Africa region (FAO, 2020). Tofu, peas and other pulses have the lowest water impact of these protein sources.

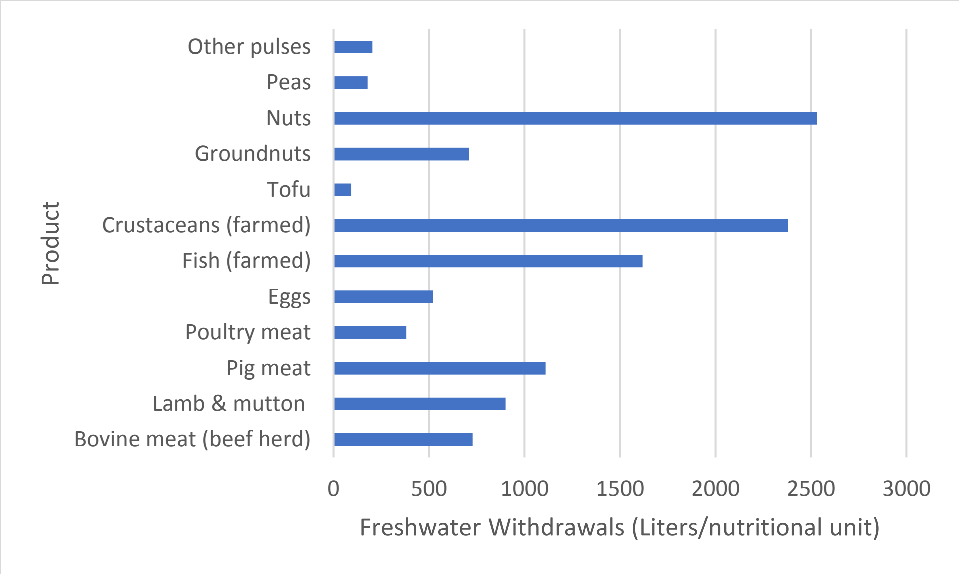

Figure 6: Freshwater withdrawals for major protein sources. Source: Poore & Nemecek, 2018.

However, while the overall amount of water used is important, the relative availability of water used should also be considered. Hence, Poore & Nemecek (2018) also provide water use data that is weighted by local water scarcity. Here, nuts and farmed crustaceans remain high water users, but farmed fish has a lower impact than implied from Figure 6, and lamb/mutton has higher water use when weighted by local water scarcity.

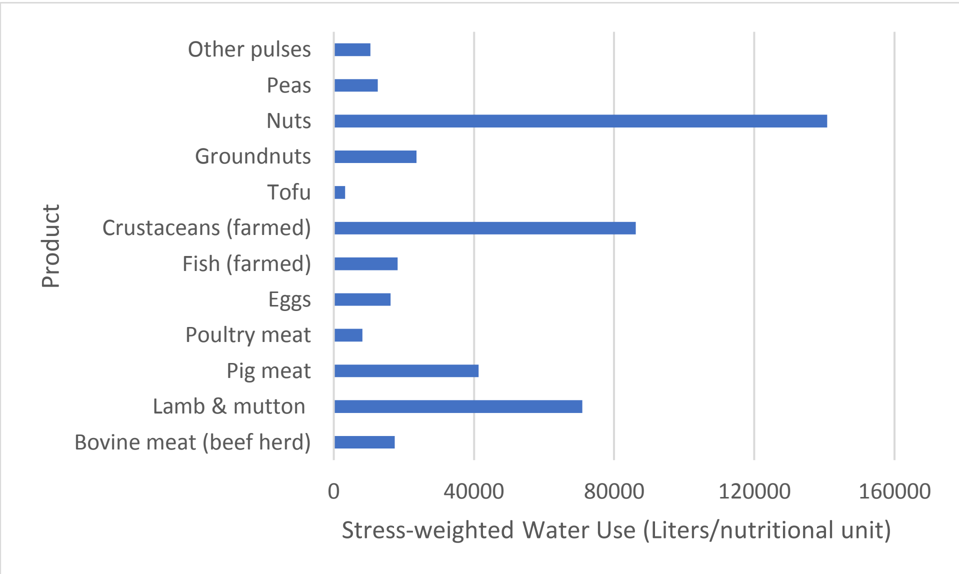

Figure 7: Freshwater withdrawals for major protein sources, weighted by water stress. Source: Nemecek & Poore, 2018.

Example Meals

As in the previous section, the table (below) presents a traffic light assessment of the example meals. Here, both the Kenyan and Improved example meals receive two green lights and two amber lights. However, the Kenyan meals that achieve green lights, indicating low water use impact for the meal, are nutritionally incomplete.

Example Meal Category	Example Meal	Water Use Traffic Light	Rationale
Kenyan	Fish meal	Amber	Farmed fish has relatively high water use in terms of liters per nutritional unit, but has low water use when stress-weighted. Note that a low proportion of fish consumed in Africa is from farmed sources (FAO, 2020).
Kenyan	Beef meal	Amber	Beef has relatively high water use in terms of liters per nutritional unit, but has low water use when stress-weighted.
Kenyan	Milk meal	Green	Milk has median freshwater withdrawals of 197 liters per nutritional unit and stress-weighted water use of 9,776 liters per nutritional unit, meaning it has low water use compared to the protein sources above.
Kenyan	'Poor man's' meal	Green	This meal relies on maize as its main component, which has median freshwater withdrawals of 44 liters per nutritional unit and stress-weighted water use of 350 liters per nutritional unit.
Western	Cheeseburger meal	Amber	Beef has relatively high water use in terms of liters per nutritional unit, but has low water use when stress-weighted.
Western	Fried chicken meal	Green	Chicken has low water use, both in terms of withdrawals and stress-weighted water use.
Western	Steak meal	Amber	Beef has relatively high water use in terms of liters per nutritional unit, but has low water use when stress-weighted.
Western	Spaghetti Bolognese meal	Amber	Beef has relatively high water use in terms of liters per nutritional unit, but has low water use when stress-weighted.

Improved	Oily fish meal		Farmed fish has relatively high water use in terms of liters per nutritional unit, but has low water use when stress-weighted. Note that a low proportion of fish consumed in Africa is from farmed sources (FAO, 2020).
Improved	Beans meal		Pulses have low water use, both in terms of withdrawals and stress-weighted water use.
Improved	Groundnut stew meal		Groundnuts have water use around average for the protein sources above in terms of liters per nutritional unit, and when stress-weighted.
Improved	Lentil curry meal		Pulses have low water use, both in terms of withdrawals and stress-weighted water use.

6. Pollution

Pollution from food production causes more than 30% of terrestrial acidification, and more than 70% of eutrophication. It is therefore important to understand the drivers of such pollution, particularly relating to protein sources.

Protein Sources

Poore & Nemecek (2017) present two datasets relating to pollution – on eutrophying and acidifying emissions. Beef and farmed crustaceans are the most impactful products on both counts. In terms of acidifying emissions (expressed as grams of sulphur dioxide-equivalent per nutritional unit), beef, crustaceans and pig meat are the highest polluters. In contrast, tofu, peas, groundnuts and other pulses all show very low acidifying emissions. Note that all these products are also protective foods.

Data on eutrophying emissions (expressed as grams of phosphate-equivalent per nutritional unit) show that farmed crustaceans, beef and farmed fish are associated with high levels of eutrophication. Again, protective foods such as tofu, peas, groundnuts, other pulses and nuts are associated with much lower impact on eutrophication.

Ewoukem et al (2012) report notably high eutrophying emissions in Cameroonian fish farms due to poor water and manure management. Hence, farmed fish may be of particular concern in terms of eutrophying emissions in the Sub-Saharan African region.

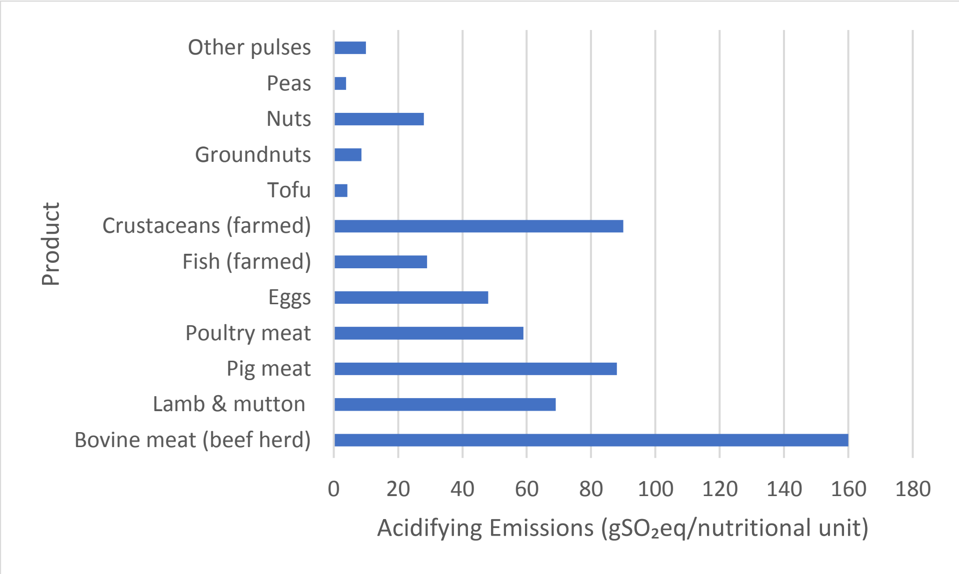

Figure 8: Acidifying emissions of major protein sources. Source: Poore & Nemecek, 2018.

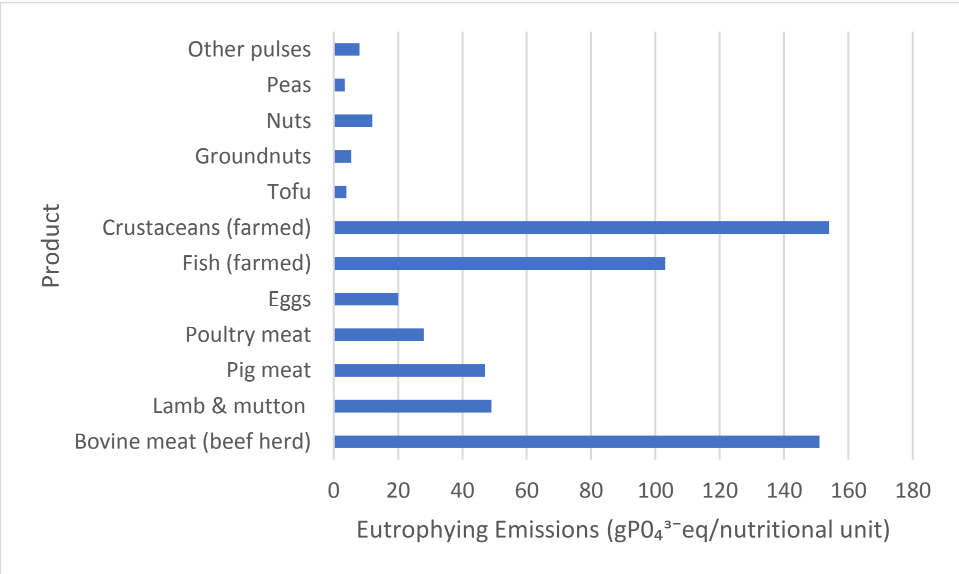

Figure 9: Eutrophying Emissions of major protein source. Source: Poore & Nemecek, 2018.

<u>Example Meals</u>

Acidifying and eutrophying emissions are considered jointly in the pollution traffic light assessment. The Improved example meals receive three green lights indicating low pollution impact from the meal, with the only other green lights for pollution coming from two Kenyan example meals which are lacking nutritionally.

Example Meal Category	Example Meal	Pollution Traffic Light	Rationale
Kenyan	Fish meal	● (orange)	Farmed fish is associated with low acidifying emissions, but high eutrophying emissions. Note that a low proportion of fish consumed in Africa is from farmed sources (FAO, 2020).
Kenyan	Beef meal	● (red)	Beef has very high acidifying and eutrophying emissions.
Kenyan	Milk meal	● (green)	Milk is associated with acidifying emissions of 20.6gSO_2eq per nutritional unit and eutrophying emissions of 10.7gPO_4^{3-}eq per nutritional unit. This means it is associated with low pollution compared to the protein sources above.
Kenyan	'Poor man's' meal	● (green)	This meal relies on maize as its main component, which has acidifying emissions of 10.2gSO_2eq per nutritional unit and eutrophying emissions of 2.4gPO_4^{3-}eq per nutritional unit. This means it is associated with low pollution compared to the protein sources above.
Western	Cheeseburger meal	● (red)	Beef has very high acidifying and eutrophying emissions.
Western	Fried chicken meal	● (orange)	Chicken is associated with average pollution for the protein sources above, in terms of acidifying and eutrophying emissions.
Western	Steak meal	● (red)	Beef has very high acidifying and eutrophying emissions.
Western	Spaghetti Bolognese meal	● (red)	Beef has very high acidifying and eutrophying emissions.
Improved	Oily fish meal	● (orange)	Farmed fish is associated with low acidifying emissions, but high eutrophying emissions. Note that a low proportion of fish consumed in Africa is from farmed sources (FAO, 2020).

Improved	Beans meal	●	Pulses are associated with low acidifying and eutrophying emissions.
Improved	Groundnut stew meal	●	Groundnuts are associated with low acidifying and eutrophying emissions.
Improved	Lentil curry meal	●	Pulses are associated with low acidifying and eutrophying emissions.

7. Transitioning to protective food diets

How easy will it be to transition to a society in which we all consume diets based on protective foods? Increasing consumption of protective foods, particularly alternative protein sources, will require increased production of those foods. This is likely to be accompanied by a transition period, as the food industry adjusts to producing less unhealthy foods and more protective foods. The agricultural shift will also be momentous; for example, much of the land currently used to produce beef and lamb/mutton will not be suitable for the growing of alternative proteins. However, large amounts of global arable land are currently used to produce animal feed, the demand for which would be reduced. The land freed up by the reduction in animal feed production may in part be converted to crops for direct human consumption. Sustainable intensification of existing cropland may also offer opportunities for increasing production of protective foods (Godfray & Garnett, 2014).

Policy and regulatory support will play a fundamental role in promoting necessary shifts in land use, upskill farmers to enable them to grow new crops, and provide financial support to transition buildings, capital and equipment to new uses.

Inevitably, however, much of the transition towards more protective food-based diets will depend upon informed consumer choices (Poore & Nemecek, 2018). The current trend worldwide, due to increasing urbanisation and income (unaccompanied by adequate nutritional education), is towards increased consumption of non-protective foods such as sugar, meat and refined fats (Tilman & Clark, 2014). Informing consumers about average product impacts, perhaps through product labelling and major marketing campaigns for a healthful life related to the foods that we eat, is an important means to promote consumer behaviour shifts (Roodenberg et al, 2011; Tan et al, 2014; Muller et al, 2019). But product labelling and marketing campaigns alone are unlikely to drive the level of consumer dietary change required. Governments will again need to intervene in order to shift consumer choices, including the use of regulation, intensive public advertising campaigns, subsidising protective foods and perhaps even introducing food carbon taxes and other means to internalise both environmental and public health costs (many of which are otherwise borne by the state as externalised costs).

8. The environment in a protective food diet world

If we were to achieve widespread adoption of a diet based on protective foods, what would the impacts be on the environment? Mensah et al (2021) conduct a systematic review of observational diet studies in Sub-Saharan Africa, finding that the average per capita intake of meat per day was 98g. However, this data was not broken down by meat type, so FAO data on production, imports and exports of meat types were used to calculate meat consumption per year for the most commonly consumed meats (FAOSTAT, 2018).

	Production (tonnes)	Imports (tonnes)	Exports (tonnes)	Consumption (tonnes)	Impact Factor	CO_2eq (MT)
Beef	6,925,000	527,000	96,000	7,356,000	26.61	195,743
Chicken	6,102,000	1,746,000	88,000	7,760,000	25.58	28,324
Pig	1,542,000	243,000	29,000	1,756,000	5.77	10,132
Mutton & Goat	3,024,000	22,000	30,000	3,016,000	3.65	77,149

Therefore, the total CO_2eq associated with the above major meat types is 311,349MT CO_2eq per year. Holding steady the total amount of protein, various options are compared below. Note that these are presented as an example only, as options for potential replacement of meat types. Alternative proteins are of course already consumed. However, they are not included here as this analysis only compares the options for replacement of meat protein.

Scenario	Protein Sources	Total CO_2eq (MT) per year
Option 1: Business as Usual	Beef: 7.356MT, Chicken: 7.76MT, Pig 1.76MT, Mutton & Goat: 3.02MT	311,349
Option 2: Replacing Beef with Chicken	Beef: 0, Chicken: 15.116MT, Pig: 1.76MT, Mutton & Goat: 3.02MT	142,455
Option 3: Vegetarian	Eggs: 5MT, Lentils & Pulses: 7MT, Tree Nuts: 3.5MT, Groundnuts: 3.5MT, Seeds: 1MT	29,945

Option 4: Flexitarian	Beef: 1MT, Chicken: 7.76MT, Pig: 1.76MT, Mutton & Goat: 1MT, Eggs: 2MT, Lentils & Pulses: 3MT, Tree Nuts: 1MT, Groundnuts: 2MT, Seeds: 0.5MT	103,004

The above CO_2eq values should be taken as exemplary rather than real world possibilities, especially given the protein sources are given by weight, and do not take in to account different nutrient values per gram across the different foods. Moreover, protein consumption will need to increase over time in Sub-Saharan Africa both to tackle malnutrition and to meet the needs of a growing population. Meat, including red meat, will of course have an important role to play. Indeed, ruminant meat production "can increase food security, dietary quality, and provide environmental benefits via nutrient cycling" (Tilman & Clark, 2014). However, as an example of the potential of shifts towards more protective food-based diets, the flexitarian option (Option 4) has a third of the CO_2eq of the 'business as usual' (Option 1) case with the vegetarian option (Option 3) constituting less than a tenth of "business as usual". Clearly, there are significant greenhouse gas emissions savings to be made by reforming our food consumption habits.

9. Conclusion

This report has found that, in addition to the health benefits of adopting a diet based on protective foods, there are also clear environmental benefits. Protective foods are associated with lower GHG emissions, lower land and water use, and less pollution, than alternative non-protective foods. The report first analysed the GHG emissions of exemplar meals – from Kenyan and Western diets, and three 'improved' meals – demonstrating that current Kenyan meals are lower in GHG emissions than their Western equivalents, and furthermore that improved meals with more protective foods exist that are both healthier and lower in GHG emissions than either Kenyan or Western example meals.

We then analysed the potential impacts of changes at a dietary scale, examining the GHG emissions, land use, water use, and pollution associated with common protein sources. Protein sources were used due to the outsize impact of some protein sources on key environmental indicators. Again, protective foods were shown to be associated with lower GHG emissions than other foods; in addition, protective foods tended to have lower land use, water use and pollution levels. There were important exceptions however: unless they are primarily rain fed, nuts are associated with very high water use, particularly when weighted by the water stress of the region they are grown in, and nuts and pulses use a large amount of land (though note that this remains low in comparison with red meat).

Overall, our findings provide a clear endorsement of the environmental benefits of a dietary transition towards protective foods. Such a transition will not be without challenges, particularly given the social prestige associated with eating meat, but awareness raising efforts such as product labelling offer an important start. On average, Sub-Saharan Africans currently eat approximately the appropriate amount of red meat compared with the EAT-Lancet (2019) reference diet, though with obvious inequalities across national populations. The total consumption of red meat must not rise. Instead the opportunity for improving dietary nutrient intakes in Sub-Saharan Africa for better health, a more stable climate and a sustainable environment is synonymous with growing and consuming protective foods.

References

Adhya, T. K. et al. 2014. "Wetting and Drying: Reducing Greenhouse Gas Emissions and Saving Water from Rice Production." Working Paper, Installment 8 of Creating a Sustainable Food Future. Washington, DC: World Resources Institute https://files.wri.org/d8/s3fs-public/wetting-drying-reducing-greenhouse-gas-emissions-saving-water-rice-production.pdf

Conway, G.R; Burgman, M., 2021. Better Diets, Better Health: Protective Diets. Briefing Paper 1. Centre for Environmental Policy, Imperial College London, UK: London.

Clune, S. et al., 2017. Systematic review of greenhouse gas emissions for different fresh food categories. *Journal of Cleaner Production.* Volume 140, Part 2, pp. 766-783. DOI: 10.1016/j.jclepro.2016.04.082.

EAT-Lancet Commission report, 2019. Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. *Lancet.* DOI: 10.1016/S0140-6736(18)31788-4.

Ewoukem, T.E. et al., 2012. Environmental impacts of farms integrating aquaculture and agriculture in Cameroon. *Journal of Cleaner Production*, Vol. 28, pp. 208-214. DOI:10.1016/j.jclepro.2011.11.039.

FAO, 2020. The State of World Fisheries and Aquaculture 2020. Sustainability in action. Rome. DOI:10.4060/ca9229en.

FAOSTAT, 2018. Food & Agriculture Organization. Rome. https://www.fao.org/faostat/en/#data/FBS

Flor, R., 2019. Focusing on "Protective Foods" to Reduce the Global Burden of Disease. https://www.rockefellerfoundation.org/blog/focusing-protective-foods-reduce-global-burden-disease/ Rockefeller Foundation.

Godfray, H.C.J. & Garnett, T., 2014. Food security and sustainable intensification. *Philosophical Transactions of the Royal Society B. Biological Sciences.* Volume 369, Issue 1639. DOI: 10.1098/rstb.2012.0273.

Kenya Markets Trust, 2016 https://www.kenyamarkets.org/wp-content/uploads/2019/10/Agri-Summary-Report-The-Burden-of-Produce-Cess-and-Other-Market-Charges-in-Kenya.pdf.

Mensah, D.O. et al., 2021. Meat, fruit, and vegetable consumption in sub-Saharan Africa: a systematic review and meta-regression analysis. *Nutrition Reviews*, Volume 79, Issue 6, pp.651-692. DOI: 10.1093/nutrit/nuaa032.

Muller, L. et al, 2019. Environmental Labelling and Consumption Changes: A Food Choice Experiment. *Environmental and Resource Economics.* 73, pp. 871–897. DOI: 10.1007/s10640-019-00328-9.

O'Neill, K., 2017. Is Protein a Key to Feeding 10 Billion? https://www.rockefellerfoundation.org/blog/protein-key-feeding-ten-billion/ Rockefeller Foundation.

Poore, J. & Nemecek, T., 2018. Reducing food's environmental impacts through producers and consumers. *Science*, Vol. 36, Issue 6392. DOI: 10.1126/science.aaq0216.

Popkin, B.M. et al, 2012. Global nutrition transition and the pandemic of obesity in developing countries. *Nutrition Reviews*, Volume 70, Issue 1, pp. 3-21. DOI: 10.1111/j.1753-4887.2011.00456.x.

Roodenberg, A.J.C., et al., 2011. Development of international criteria for a front of package food labelling system: the International Choices Programme. *European Journal of Clinical Nutrition*, Volume 65, pp. 1190–1200. DOI: 10.1038/ejcn.2011.101.

Shah, R.J. 2018. Rising Obesity in Africa Reflects a Broken Global Food System. https://www.rockefellerfoundation.org/blog/rising-obesity-africa-reflects-broken-global-food-system/ Rockefeller Foundation.

Tan, M.Q.B., 2014. Prospects of carbon labelling – a life cycle point of view. *Journal of Cleaner Production,* Volume 72, pp. 76-88. DOI: 10.1016/j.jclepro.2012.09.035.

Tilman, D. & Clark, M., 2014. Global diets link environmental sustainability and human health. *Nature*, Volume 515, pp.518–522. DOI: 10.1038/nature13959.

Vermeulen et al., 2012. Climate Change and Food Systems. *Annual Review of Environmental Resources*, 37:195-222. DOI: 10.1146/annurev-environ-020411-130608.

Weiler, V. et al., 2014. Handling multi-functionality of livestock in a life cycle assessment: the case of smallholder dairying in Kenya. Vol.8, pp. 29-38. DOI:10.1016/j.cosust.2014.07.009.