PROJECT ACRONYM	ENOUGH
PROJECT TITLE	European Food Chain Supply to reduce GHG emissions by 2050
PROJECT COORDINATOR	SINTEF OCEAN
PROJECT DURATION	2021-2025

D1.1

A model for calculating emissions from food

PROJECT NO: 101036588

TYPE OF ACTION: IA (INNOVATION ACTION)

CALL: H2020-LC-GD-2020-4

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101036588

DOCUMENT INFORMATION

DELIVERABLE NO.	D1.1 A model for calculating emissions from food
DISSEMINATION LEVEL [1]	PU
WORK PACKAGE	WP1
TASK	T1.1 Framework
LEAD BENEFICIARY	UoB
CONTRIBUTING BENEFICIARY(IES)	LSBU, IIR, SO
DUE DATE OF DELIVERABLE	31/03/2023
ACTUAL SUBMISSION DATE	31/03/2023

[1] PU = Public
PP = Restricted to other program participants (including the Commission Services)
RE = Restricted to a group specified by the consortium (including the Commission Services)
CO = Confidential, only for members of the consortium (including the Commission Services)

DOCUMENT HISTORY

Version	DATE	CHANGE HISTORY	AUTHOR	BENEFICIARY
1.0	26/03/2023		Prof. Toby Peters, Dr. Hameed Al-Muhammedawi, Dr. Leyla Sayin, Dr. Xinfang Wang (University of Birmingham), Prof. Judith Evans, Dr. Alan Foster (London South Bank University), Dr. Yosr Allouche (IIR)	UoB, LSBU, IIR
1.1	28/06/2023	Added clarifications after review meeting	Hameed Al-Muhammedawi, Yosr Allouche	

QUALITY ASSURANCE, STATUS OF DELIVERABLE		
ACTION	PERFORMED BY	DATE
Reviewed	Yosr Allouche (IIR), Judith Evans (LSBU), Alan Foster (LSBU), Shraddha Mehta (SO), Cristina Maria Iordan (SO), Andrea Viken Strand (SO)	30/03/2023
Approved (WP leader)	Yosr Allouche (IIR)	31/03/2023
Uploaded to SyGMa (Coordinator)	Kristina N. Widell (SINTEF O)	31/03/2023

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Nomenclature

D_{OC}	Degradable organic carbon
D_{OCF}	Fraction of degradable organic carbon dissimilated
EF	Emissions factor
F	Fraction of CH4 in landfill gas
gm	Grams
h	Hour
L	Methane generation potential
M_{SW}	Municipal solid waste, sent to landfill
mcf	Methane correction factor
OX	Oxidation factor, which reflects the amount of CH_4 from SWDS that is oxidised in the soil or other material covering the waste
H/S	Harvest/slaughter
IPCC	Intergovernmental Panel on Climate Change
R	Amount of CH_4 generated at SWDS that is recovered and burned in a flare or energy recovery device
RDC	Regional distribution centre
RoE	Rest of Europe
RoW	Rest of World
TRU	Transport refrigerated unit
WRAP	Waste and Resources Action Programme
y	Year
*	Sub-sub-driver

EXECUTIVE SUMMARY

This document is divided into the following sections:

1. Section 1: Introduction
2. Section 2: WP1 boundaries
3. Section 3: Horizon Scanning Model (Drivers model)
4. Section 4: The description of the 3 models used to estimate emissions from the food supply chain.

Section 2 and 3 provide details of the boundaries applied and the Horizon Scanning Model (Drivers model), respectively, which are required to estimate the greenhouse gas emissions (GHG) from the food supply chain of the EU, EEA countries and the UK. The methodology will be applied within the European boundaries for the food supply chain. Different food supply chain sectors, i.e., agriculture, aquaculture and fishing, manufacture of food products and beverages, packaging, warehousing and storage, transport, retail, food and beverage service and hospitality, domestic and food loss and waste are included for both perishable (those needing refrigeration) and non-perishable food (those which can be stored at ambient temperature). The model assesses the impact that varied drivers will have on the food chain through to 2050. This will be used to identify scenarios that will affect carbon emissions in the future. The most significant drivers can then be quantified or estimated and applied into the models described in section 4.

Section 4 presents a methodology for 3 models that can be used to estimate emissions from the European food supply chain from 2019 to 2050. The aim was to develop several models based on different assumptions and inputs to enable the results to be compared. In addition, the different models may be better placed to assess different driver impacts. The following models were developed:

a. A top-down model based on available Government statistics on emissions from the food chain for a country.

b. A bottom-up model that calculates the emission based on mass of food produced in a country.

c. A hybrid top-down/bottom-up model that uses a combination of Government statistics, stock data, physical heat transfer models and other published information.

Deliverable D1.1

1 INTRODUCTION

Food and agriculture are responsible for about 34% of global greenhouse gas emissions (GHG) (Crippa et al, 2021). The food supply chain, however, accounts for about 18-29% of these emissions, while the rest is related to land use, crop and animal production (Poore and Nemecek, 2018). Emissions from the food supply chain emanate from energy consumption (fuel and electricity), the leakage of the high global warming potential (GWP) refrigerants and methane from the wasted food in landfill.

The purpose of the models developed in WP1 are to estimate the greenhouse gas (GHG) emissions from the food supply chain (from farm to fork) for the EU and UK for the baseline years 1990 and 2019 and predict emissions for 2030 and 2050. To do so, an initial task was to define the boundaries for the assessment (section 2). A horizon scanning tool was then developed to identify the drivers that significantly impact emissions and whether they decrease or increase emissions from the food supply chain (section 3 horizon scanning's (sub-drivers') model). Three models are elaborated to calculate the emissions using different approaches with different levels of complexity (section 4).

Horizon scanning model

Six main drivers; climate change, demographics, business and economics, social and behavioural, policy and technology and infrastructure were first identified. These were then further categorised into sub-drivers and sub-sub-drivers (where necessary), and their expected impact on the food supply chain was determined. Overall, 62 sub-drivers and 36 sub-sub-drivers have been included. An intensive literature review and a well-organised multi-step process (model) using MS Excel was designed to select the most impactful sub-drivers. This included, for the first time, the direct and indirect influence of a sub-driver on the future emissions of the food supply chain by estimating the primary scoring index and the weighted impact of the roadmap matrix, respectively.

The goal of the primary scoring index (direct impact) was to quantify the sub-drivers' level of influence based on data gathered from data sources. The primary scoring index was estimated using a suitable mathematical expression involving the primary weighted impact, impact linkage of a sub-driver to each stage of the food chain and the likelihood of occurrence.

The indirect impact of the sub-drivers was developed to consider all possible influences by quantifying the hidden relationships among the sub-drivers, which the primary scoring index cannot capture. The dependency relationships were first identified and quantified using the gathered data from different data sources.

Accordingly, the top 20 sub-drivers, so far, for the UK and a number of EU countries, which have the greatest impact on the emissions of the food supply chain, (either decreasing or increasing the emissions) were identified. These qualified sub-drivers will be implemented in the prediction of the future emissions of the food chain, which will be estimated in Part II, using the scenarios approach.

Finally, the present model can be edited to accommodate changes such as adding or eliminating new sub-drivers if required. It is also possible to change various input scorings on the Excel sheet according to their importance in different countries. The model will calculate and show a bespoke list of the win and risk sub-drivers accordingly.

Emission calculation models

The results from the horizon scanning model will be used in 3 models which will calculate current and future emissions from the food chain. The aim of this work is to test different approaches in order to establish a solid and detailed database related to current and future emissions from the food supply chain sectors. Each model has varied attributes and assessment methodologies that can be used to cross check total emission calculation accuracy. Also, each model has specific features that best align to the questions generated from the horizon scanning model.

The 3 models are as follows:

- Top-down (high-level) model: this model has been completed and tested for the UK and several EU countries. The model uses data from the governmental statistics to calculate emissions.
- Production based bottom-up model based: In progress and tested only for the UK. This is based on mass of food (production base) that passes though the food chain.
- Hybrid model a combination of Government statistics, stock data, physical heat transfer models and other published information.

All the developed models consider ambient and refrigerated food and include – cereals, meat, poultry, fish, milk, fruits, and vegetables. The food supply chain is divided into stages from agriculture and fishing (on-farm energy use through to household consumption. Food loss and waste and packaging emission are also taken into account (see Fig. 1).

The models estimate the emissions for the baseline year (2019) with the ability to change inputs to project emissions though to 2030 and 2050 for a number of representative European countries including the UK, Norway, France, Italy, Germany, Poland, Lithuania, Hungary, Austria and Belgium. Emissions are divided into Scope 1, Scope 2 and Scope 3 emissions

In ENOUGH Scopes 1, 2 and 3 emissions are calculated. The Scopes definitions was introduced by the Green gas House Protocol. Scope 1 include the emissions from the owned or controlled sources of the entity (direct). These come from fuels used for onsite combustion for generation of electricity, heating (e.g. food processing), manufacture or processing of chemicals and materials (e.g. food packaging) and also for driving machines, primarily vehicles (e.g. transport), but also include fugitive emissions, which for the food sector are primarily leakage from refrigerants. Scope 2 emissions include the emissions from the purchased electricity which is generated offsite and consumed by the sector. Scope 3 include emissions from other sources identified to be as a consequence of the activity of the sector (e.g. waste disposal).

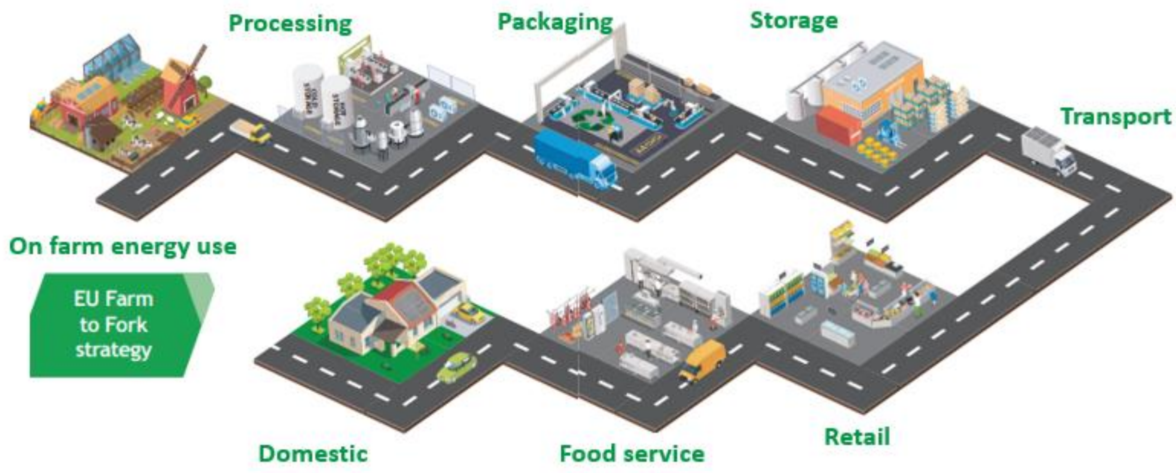

Figure 1ENOUGH food supply chain sectors.

2 WP1 BOUNDARIES

In ENOUGH, the emissions for the food supply chain within the European boundaries are calculated. The following representative countries have been selected based on the consortium affiliated countries: the UK, Norway, France, Italy, Germany, Austria, Lithuania, Poland, Hungary and Belgium. The food supply chain includes sectors from agriculture and fisheries to the consumer including waste). Emissions are calculated for both perishable and non-perishable food and beverages supply chains. Perishable food is that needing to be kept cold and is defined as either chilled or frozen food (e.g. meat, fish, dairy, fruits and vegetables). Non-perishable food can be preserved at ambient temperature (e.g. canned food, baking, cereals etc).

In ENOUGH, the food supply chain includes the following sectors: Agriculture and fishing, manufacture of food products and beverages, packaging, warehousing and storage, transport, retail, service and hospitality, domestic and food loss and waste.

In ENOUGH, at all stages, we are looking at Scope 1 emissions are those from on-site fuel combustion and fugitive emissions, which for the food sector are refrigerant (f-gas) leakage from the refrigeration equipment. Scope 2 emissions are the indirect GHG emissions from the generation of electricity purchased by the investigated sectors. For each EU country, a carbon intensity factor of the grid is applied to convert grid electricity to GHG emissions. For the emissions calculations only those from processes are calculated. Except for manufacturing of packaging materials and end of life of refrigerants we are excluding emissions from the manufacture and end-of-life (EOL) of all primary materials for the food supply chain, such as (energy, fuel, building materials for food chain infrastructure…).

The agricultural emissions are those associated to the energy use in agriculture (e.g. cooling and heating needs, transportation of off-road vehicles, fishing vessels and other machinery). Emissions from fertilisers and farm waste, chemicals added to the land and from the animals and food are excluded.

In packaging, emissions from raw materials (e.g. glass, plastic, paper…) are calculated and as possible, emissions from packaging manufacturing.

In transport, we are mapping emissions from fuel consumption in all food refrigerated and non-refrigerated transportation (land, maritime, air) within any food production country. Transport within an intermediate country located between an import and export country are also considered. In transport, we are also including the domestic food transport as we want to quantify the impact on home delivery and energy systems.

In domestic, we are calculating the emissions from energy consumption for cooking and refrigeration in the kitchen, we are also looking at the fugitive emissions from refrigerants leakage.

Food loss and waste: the food loss is defined as the reduction in the mass of food (due to poor food handling, lack of cold chain..) as it passes along the chain until the retail stage. Food waste is defined as the food that is still good for consumption but sent to landfill because of some regulations (expiry date in the supermarket) or bad consumption habits (at the consumer/food service point). In ENOUGH, we are calculating CH_4 emissions from solid food loss and waste resulting from the decomposition of the food in the landfill. We are excluding emissions from the waste treatment.

3 HORIZON SCANNING MODEL (SUB-DRIVERS MODEL)

Horizon scanning model (sub-drivers' model) is the main novelty of our work. It is a mathematical tool used to understand changes in the food supply chain and what the food supply chain shape might look like in the future (2050) and estimate future emissions by considering impactful drivers (i.e. transformative issues. Six main areas for transformative changes have been identified: demographics; climate change; business and economics; social and behavioural; policy; technology and infrastructure. Further, these main have been disaggregated into 100 (100+) sub-(sub)-drivers, following the IPCC 2006 guideline instructions. The likelihood and potential impact of all these sub-drivers and sub-sub-drivers have been quantified based on an extensive literature review and expert opinions. Direct and indirect impacts have been considered in the model to ensure that each sub-driver's impact on the food supply chain – including the impact on other sub-drivers - is fully assessed and fairly scored when developing the shortlist of qualified key sub-drivers likely to have the most transformative impact (positive or negative).

As part of this, the drivers that could change the nature and size of the food supply chain provision and demand out to 2050, their likelihood of occurrence, and impact on energy consumption and GHG emissions are identified. The procedure used is outlined in the following section. The top 20 (sub-) drivers expected to have the most significant impact in the UK have been identified from the overall (100+) (sub)-drivers collected from the literature. The horizon scanning's model can be replicated for other countries/regions and can also be expanded globally. The model outcomes will then be used to predict future GHG emissions from the food supply chain in 2050 based on the quantified impact of selected (sub)-drivers with data gathered from data sources and literature, using separate models (part II). This will be achieved by developing several scenarios using the model outcomes. These scenarios will then be used to estimate future energy consumption and GHG emissions from the food supply chain using the hybrid model.

Finally, in addition to above, the merit of this model can be summarized as follows:

- This model offers, for the first time, a systematic mathematical-based process (model) to select the most impactful, transformative drivers on the future energy demand and emissions from the food supply change. Previous studies only consider a small number of drivers that often include the grid emission factor, technological progress and demographics (such as population and urbanisation) and do not take into account wider drivers such as changes in consumption patterns, behaviour, exports and imports, or business models that could have a major impact on food chain. Furthermore, they do not provide a prioritization process to select the most impactful drivers.

- The model allows the inclusion of an infinite number of drivers through an easy-to-use process with input-output windows. At the same time, the model can be easily updated by adding new drivers or eliminating ones that are no longer relevant.
  The model also considers, for the first time, the direct and indirect impact of the drivers of change through the primary scoring index and road map matrix. This gives the ability to understand the hidden relationship among the sub-drivers and how it can influence the emissions of the food supply chain. It also allows us to assess them in an aggregated, consequential and systematic process.

3.1 Main and Sub-drivers

3.1.1 Identify Main Driver Categories

Identifying the main drivers is one of the most critical steps in estimating the future energy consumption and GHG emissions. An intensive literature review has been conducted to determine the main drivers that would impact the level and trend of future GHG emissions. Six main driver categories identified are as follows:

1. Climate change
2. Demographic
3. Business and economics
4. Social and behavioural
5. Policy
6. Technology and infrastructure

It is worth mentioning here that “biodiversity” as a main driver will be discussed and assessed as a potential sub-driver to be added to the current list. We will update the list of sub-drivers in D1.2.

3.1.2 Identify Sub-Drivers & Sub-Sub-Drivers

The six main drivers were then further categorised into sub-drivers and sub-sub-drivers (where necessary), and their expected impact on the food supply chain was identified. Overall, 62 sub-drivers and 36 sub-sub-drivers have been included, as shown in Fig. 2. The complete list of sub-drivers and sub-sub-drivers can be found in Appendix 1 and 2, respectively.

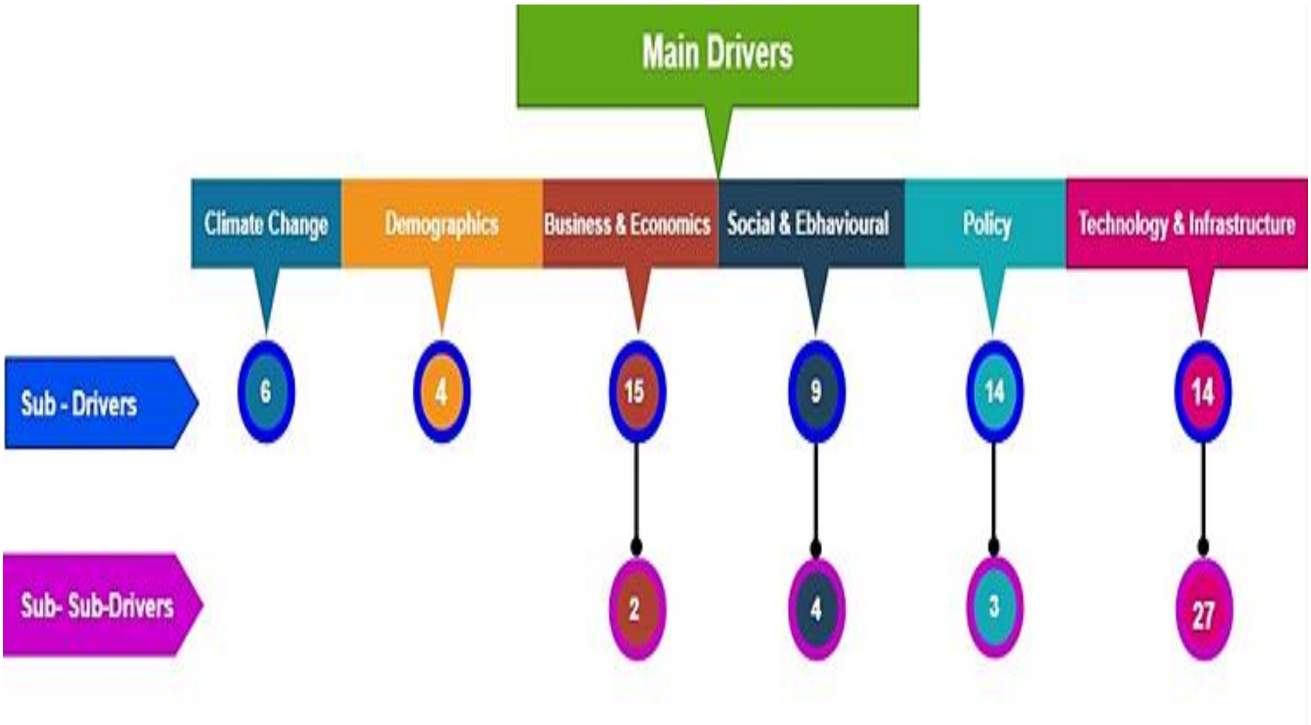

Figure 2. Distribution of sub-drivers and sub-sub-drivers over the main drivers.

3.2 Modelling Approach

The first step to achieving the most impactful sub-drivers on the future GHG emissions (2050) from the food supply chain is to develop the primary scoring index. Two different impacts of sub-drivers on future emissions from the food supply chain were identified and quantified.

A primary scoring index was developed to quantify the sub-drivers' level of impact, as outlined below. The quantification was based on data gathered from sources, academic literature, and expert knowledge.

The direct impacts of sub-drivers on food chain emissions were estimated using the:

- **Primary Weighted Impact:** Defines the significance and nature of the impact.
- **Impact Linkage:** Accounts for impacts of sub-drivers along the food value chain.
- **Likelihood of Occurrence:** Likelihood of occurrence of sub-drivers' based on the level of intervention.

3.2.1 Primary Weighted Impact

This is to define the nature and significance of the impact (increase (+)/decrease (-); High (H) =3, Medium (M) =2, Low (L) =1) of an individual sub-driver on the energy demand and emissions from food supply chain stages. 70% weight has been assigned to this element in developing the primary scoring index.

The three levels were weighted using the methodology (Fig. 3) as follows:

- **Small Impact:** $(\boldsymbol{H} = \pm\mathbf{1})$
- **Medium Impact:** $(\boldsymbol{M} = \pm\mathbf{2})$
- **High Impact:** $(\boldsymbol{L} = \pm\mathbf{3})$

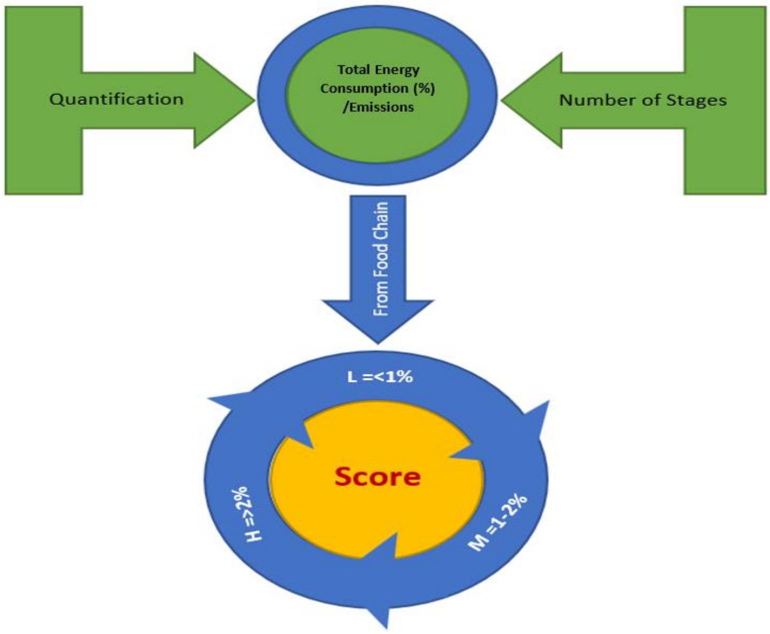

Figure 3. The methodology of primary weighted impact.

3.2.2 Likelihood of Occurrence

This is to identify and consider whether an individual sub-driver will occur without any intervention (strong or weak). For example, the future ambient temperature increase should occur naturally without intervention; on the other hand, improve the efficiency of cooling equipment, and decarbonisation of the grid cannot. Further, the intervention required to implement to improve the efficiency of refrigeration equipment by optimised their control systems, could be more straightforward compared to the electrification of the heavy goods vehicle (HGV).

Three different levels were assigned depending on whether a sub-driver will occur naturally or need some level of intervention:

- **Small Impact:** $(\mathbf{1})$ Occur naturally/ no intervention
- **Medium Impact:** $(\mathbf{2})$ Need weak intervention
- **High Impact:** $(\mathbf{3})$ Need strong intervention

3.2.3 Primary Scoring Index

The scoring index of the direct impact of the sub-drivers was calculated using the following expression:

$$\boldsymbol{Scoring\ Index} = \boldsymbol{Primary\ Weighted\ Impact}\ [\boldsymbol{i.e.\ 0.7} \times \boldsymbol{Weighted\ Imapct} + \boldsymbol{0.3} \times \boldsymbol{Impact\ Linkage}] \times \boldsymbol{Likelihood\ of\ Occurrence}$$

Finally, the direct sub-drivers' impact (primary scoring index) was assigned 75% of the total impact, while the rest was given to the indirect sub-drivers' effect.

The summary of the procedure used can be illustrated below (Fig. 4):

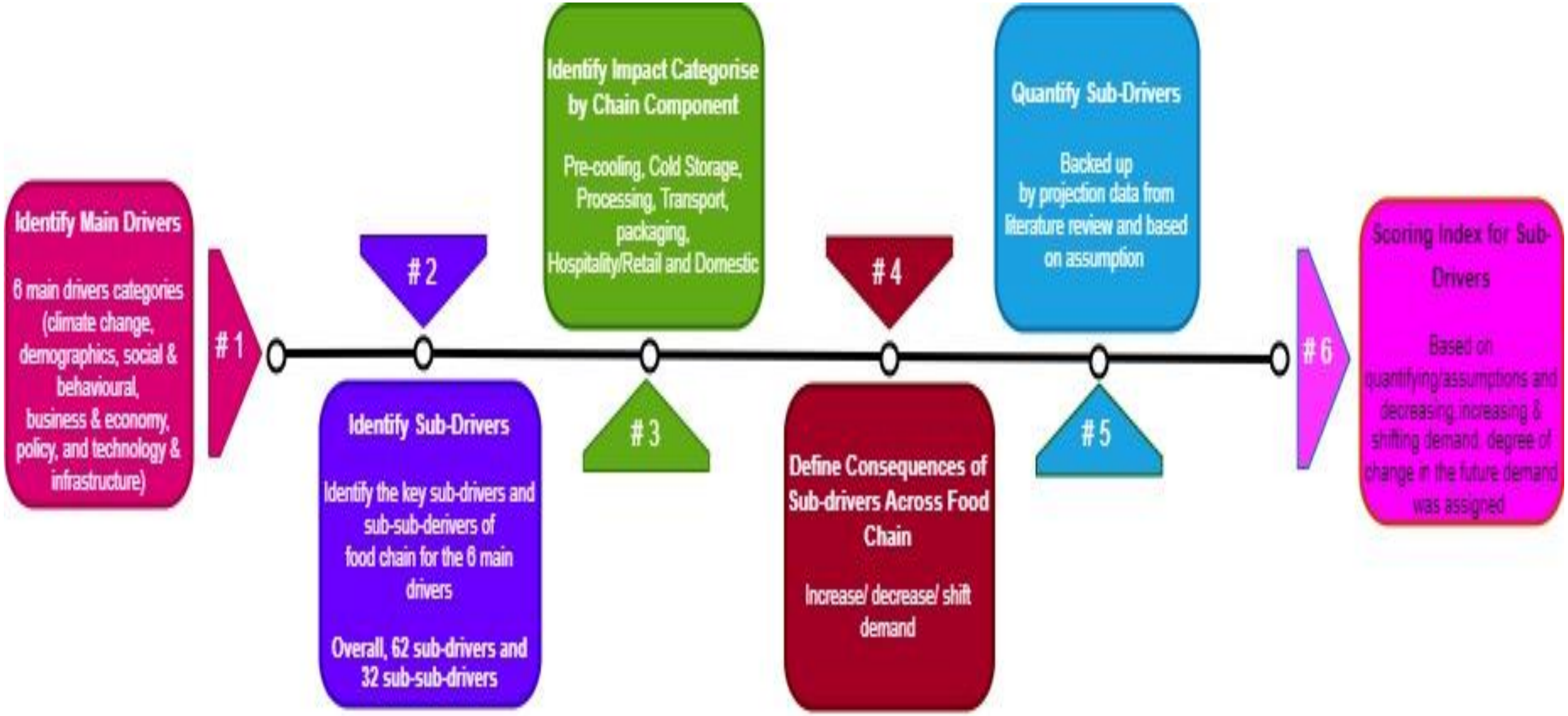

Figure 4. The whole process was used to develop the scoring index of the direct impact of the sub- drivers.

3.3 Indirect Impact

This is developed to consider the hidden impacts arising from dependency relationships among the sub-drivers, which the primary scoring index cannot capture. The relationships were identified based on data gathered from data sources and academic literature, and expert knowledge. 30% of the total sub-drivers' impact is allocated to the indirect impact.

3.3.1 Road Map Matrix

A road map matrix of the sub-drivers was constructed to identify the dependency relationship among the sub-drivers. Overall, a matrix of 62 by 62 was developed (see Fig. 5), and three different dependency relationships were considered:

- **Parallel:** when there is no relationship between the sub-drivers
- **Sequential:** when only one sub-driver (say in Y-axis) impacts another (say in X-axis).
- **Coupled:** when there is a reciprocal impact between any pair of sub-drivers

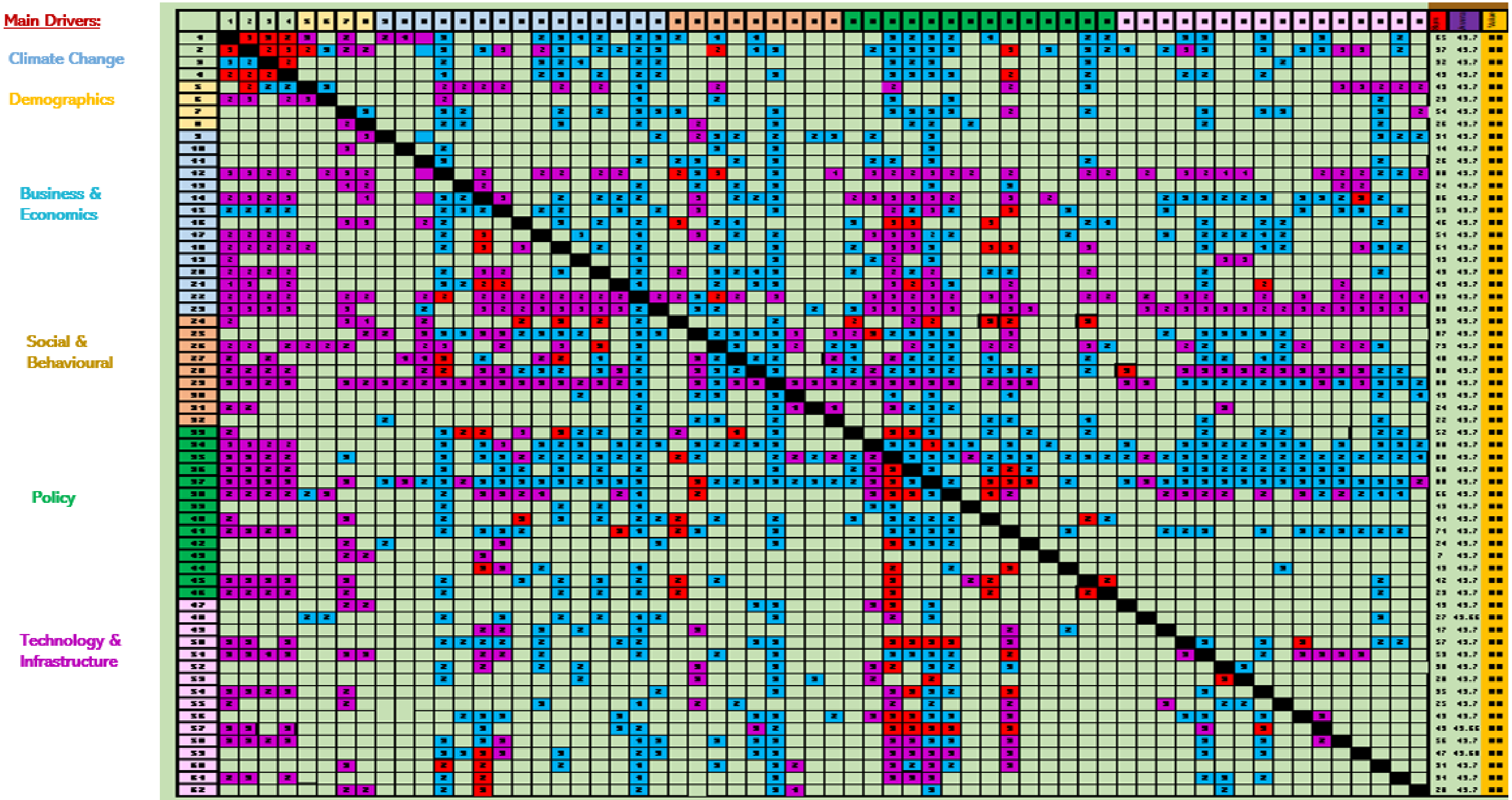

Figure 5.Roadmap matrix with the identification of the dependency relationships among the sub-drives

3.3.2 Dependency Relationships of Road Map Matrix

The dependency relationship among all sub-drivers was determined and then quantified. Three different levels were assigned depending on the dependency relationship:

- **High = 3** strong relationships between the sub-driver pair
- **Medium = 2** medium relationship between the sub-driver pair
- **Low = 1** weak relationship between the sub-driver pair

The whole process used to evaluate the indirect sub-drivers' impact can be illustrated in Figure 6 below:

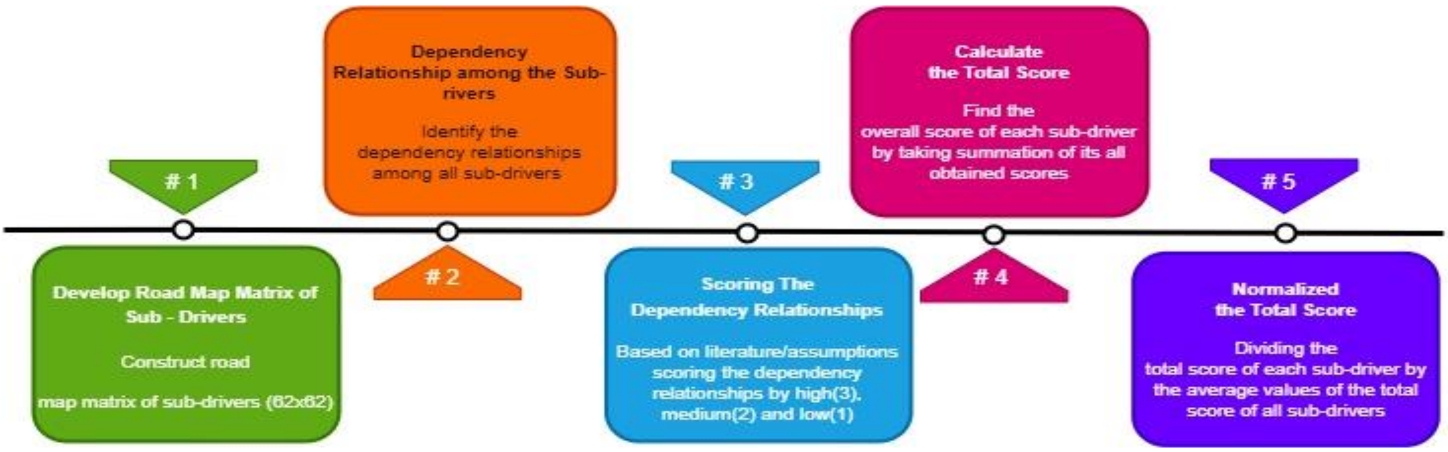

Figure 6. The method used to identify the indirect sub-drivers' impact.

3.4 Calculate the Final Score (Win & Risk Sub-Drivers)

The shortlist of the qualified sub-drivers which have a significant impact on the future emissions from the food supply chain (2050) was determined depending on their final score, which was calculated using the following expression:

$$\begin{aligned}&\boldsymbol{Final\ Score\ of\ Sub-Drivers}\\ &\qquad = \mathbf{0.75} \times \boldsymbol{Primary\ Scoring\ Index}\\ &\qquad + \mathbf{0.25} \times \boldsymbol{Score\ of\ Dependancy\ Relationship}\end{aligned}$$

The process used to find the final list of the most effective sub-drivers is illustrated in Figure 7.

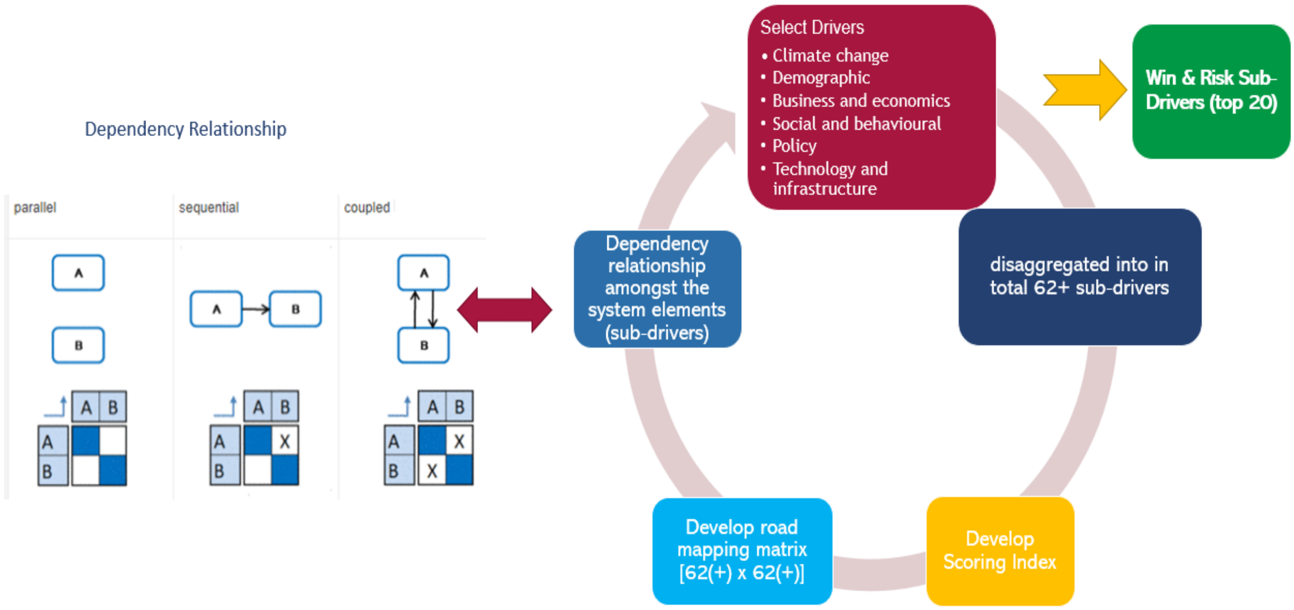

Figure 7. The whole process is used to develop the model.

3.5 Short-Listed Sub-drivers

Based on the final scores, the wins (i.e., the sub-drivers that are expected to reduce the energy demand/emissions from the food supply chain) and the risks (i.e., the sub-drivers that are expected to increase the energy demand/emissions from the food supply chain) are sorted. The top 20 sub-drivers expected to have the most significant impact on the UK's future emissions from the food supply chain were identified. In the present case study, the model gave seven risk sub-drivers and thirteen-win sub-drivers, according to their scores. However, the number of the win and risk sub-drivers can be determined according to the user's order.

As mentioned above, the present model outcome will be used to predict the emissions of the food supply chain (2050) using scenarios approach. A dependency matrix for the short-listed sub-drivers was developed to identify how sub-drivers influenced each other. This will reduce the number of scenarios that need to be developed to estimate the future food chain emissions by selecting the most impactable scenarios.

Figure 8 shows the roadmap matrix of the win and risk sub-drivers. In this figure, red, blue, and yellow refer to strong, medium and weak dependency relationships among the short-listed sub-drivers. The whole list of the qualified sub-drivers can be seen in Appendix 3.

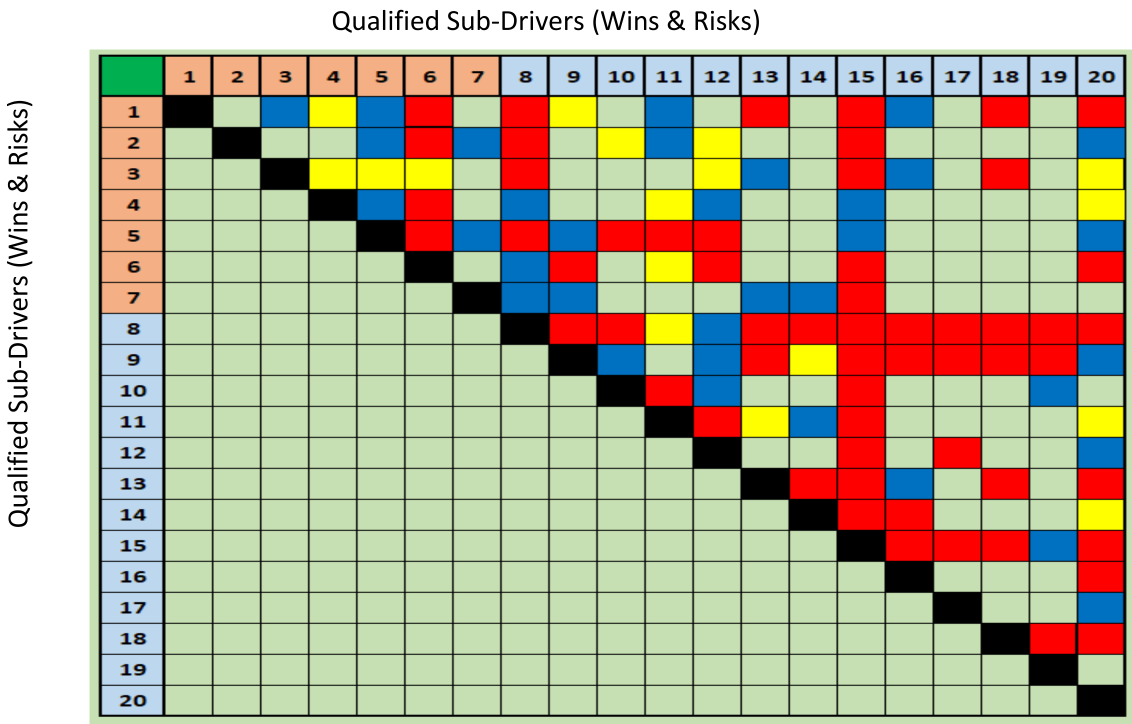

Figure 8.The road map matrix of the win and risk sub-drivers.

3.6 Input and Output

The present model was built using Microsoft Excel, and the main steps are illustrated in Figure 9 below. The model can be edited if required to accommodate changes, such as adding or eliminating new sub-drivers. It is also possible to change various input scorings on the input sheet according to their importance in different countries. The model will calculate and show a bespoke list of the win and risk sub-drivers accordingly. To test different inputs for various countries, an input sheet is created. This sheet contains the three input parameters - weighted impact (∓1 to ∓3), impact linkage (1 to 3) and the likelihood of occurrence (1 to 3), which are used to calculate the scoring index. The user can change the values of these three parameters, which will be reflected in the win and risk sub-drivers list.

Figure 9. The steps used to build the Excel model.

3.7 Model Framework/ Future Quantifying Impact

Once the final list of sub-drivers (wins & risks) is identified, their impact on the food supply chain's future emissions will be quantified. As shown in the figure below, this process starts with defining the system boundaries, food supply chain and food categories. Then the horizon scanning, and the food chain's future requirement can be identified. The projection of emissions will be developed using a scenarios approach. One of these scenarios will be the business as usual (BAU) scenario, which is used as a reference that other scenarios will compare with. Once the obtained results of any set of scenarios reach net-zero emissions, the results will be tested against 'black-swan' events to ensure whether they are resilient. If so, these results will be reported. Otherwise, a new set of scenarios should be developed and tested until reaching minimum (i.e., net-zero emissions) emissions produced by the food chain whilst being resilient. Figure 10 illustrates the summary of the whole process.

Note:

Model Stage	Status
Define Boundary Conditions	Done
Define Food/cold-chain categories	Done
Define food categories	Done
Horizon scanning	Done

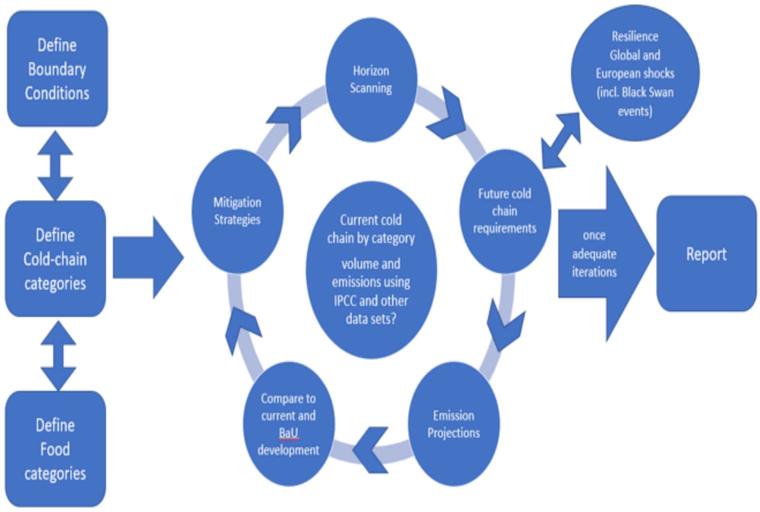

Figure 10. Model future framework.

4 MODEL DESCRIPTION

4.1 Top-Down Model

The methodology provided below is for UK as an example. All WP1 EU representative countries will follow the same procedure. Food chain was split into the following sectors. They were also classified into UK Standard Industrial Classification (SIC, 2007) codes. The SIC codes do not mirror the cold chain sectors. For example, there are likely to be many SIC codes in agriculture, food and fisheries which do not have cold chain emissions and food service. These including canteens which may operate in many different SIC code industries.

- Agriculture and Fishing (SIC Code 01 and 03)
- Manufacture of food products and beverages (SIC Code 10-11)
- Warehousing and storage (SIC Code 52.10)
- Transport (SIC Code 49.2 and 49.4)
- Retail (SIC Code 47.11 and 47.2)
- Food and beverage service and hospitality (SIC Code 56)
- Domestic (SIC code N/A)
- Waste
- Packaging

An example is below given for the UK, the same procedure is followed by all representative countries. The data sources from national statistics for all countries is given in appendix 4. Scope 1, 2 and 3 were used as follows:

Scope 1 are those emissions form on-site burning of fuels and also include fugitive emissions, which for the food sector are primarily leakage from refrigerants.

Scope 2 emissions are the indirect GHG emissions from the generation of electricity purchased by the Sectors. A carbon intensity of the grid of 0.22 kgCO2e/kWh was used to convert grid electricity to GHG emissions. This was the grid average consumption-based domestic electricity emission factor for 2019.

Scope 3 emissions are those from packaging raw materials (e.g. glass, plastic, paper…) as well as from packaging manufacturing. These also include emissions from food waste i.e. CH_4 emissions from the decomposition of food in (landfill).

For the UK, sources for these emissions were from the UK Digest of UK Energy Statistics (DUKES) for 2019. This data is compiled by the Department for Business, Energy & Industrial Strategy (BEIS) and contains data for many years up until the current year. The UK Statistics Authority has designated these statistics as National Statistics, in accordance with the Statistics and Registration Service Act 2007 and therefore they were considered as the most accurate data available.

Fugitive emissions were taken from Foster et al (2022) and were initially from UK Greenhouse Gas Inventory (NAEI, 2021). Waste emissions were taken from UK Greenhouse Gas Inventory (NAEI, 2021) and other sources were used to calculate the proportion of waste from food.

4.2 Production Based Model

A production-based model was developed for basic food types. The model was initially developed using sources from within the UK. Similar sources of data need to be identified and applied for the various ENOUGH countries who will use the model.

The model calculates total carbon emissions from the food chain and emissions for each sector and food type. The initial aim is to calculate baseline emissions for the current food chain, but also to apply changes and interventions to allow calculation of the impact of these changes on the food chain in the future.

The model assesses carbon emissions throughout the different stages of the food chain based on mass of product produced, imported and exported from a country. Only the emissions within the country boundaries are considered. The model considers basic food types (the 83 foods listed in Appendix 5) and does not consider how food may be mixed throughout the chain and processed into varied products. For example, the model considers beef, tomatoes, cheese and wheat as individual commodities and not when processed to produce a product such as a lasagne. The model was developed in MS Excel. A general schematic of the model is shown in **Error! Reference source not found.**1.

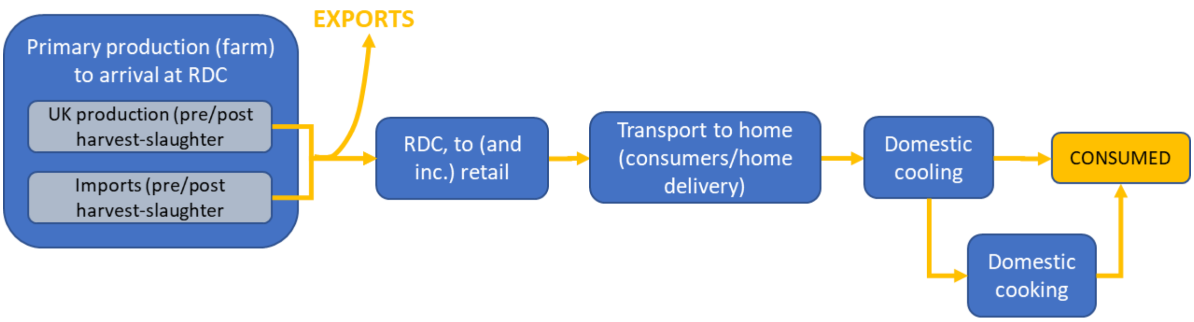

Figure 11. Sectors covered by the model.

The model boundaries were defined as including scope 1 and 2 emissions:

Scope 1:

- Fugitive emissions from refrigerants in all sectors of the food chain.
- Fuels.

Scope 2:

- Electricity used in the food chain that was directly related to the food process and directly associated buildings (except in domestic homes).
- Currently district heating/cooling is not included in the model. It could potentially be included it if there is a need to model such impacts when assessing future food chain emissions.

Scope 3 emissions were not included in the model.

The model covers the following sectors (Figure 12):

1. Energy used on the farm and any refrigerant emissions from refrigeration on the farm.
2. Primary production to arrival at the regional distribution centre (RDC). This includes carbon emissions vehicles, food processing/storage and other energy using equipment related directly to the food chain. (e.g., pumps, lights).
3. Food service. This includes food catering in restaurants, cafes, pubs, fast food outlets hospitals, schools and other establishments that have catering. It included cooking and cooling and other energy related devices at these sites.
4. Regional distribution centre (RDC) to retail. This includes all emissions from the point that the food reached the RDC until it exits the retail store.
5. Transport to the home by the consumer. This encompasses fuel used by the consumer to transport food from the supermarket to the home.
6. Domestic cooling. This included domestic refrigeration (chilling and freezing storage).
7. Domestic cooking. This includes all food cooking (and re-heating) in the home.

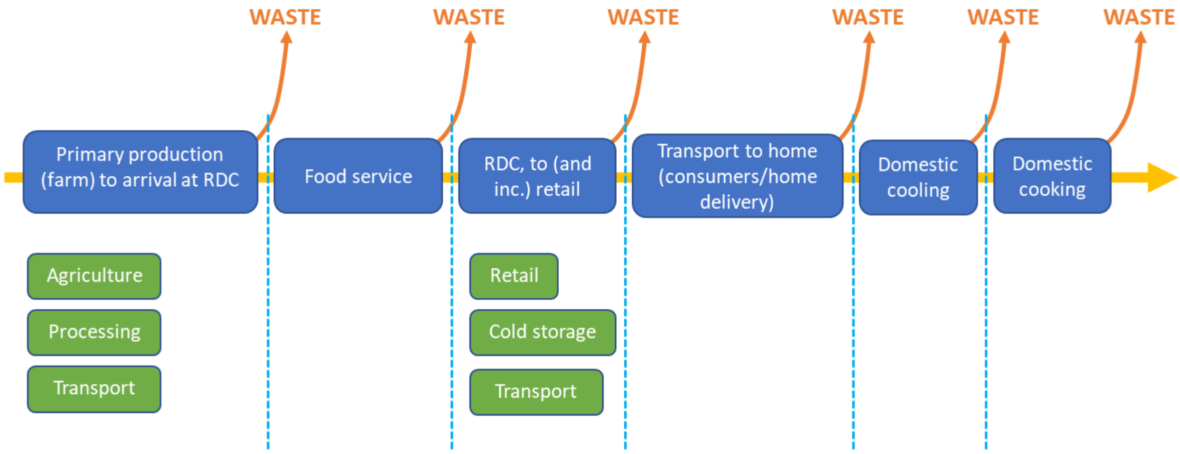

Figure 12. Sectors covered by the model.

Table 1. Emissions sources from each sector that the model considers.

Sector	Emission sources
Primary production (farm) to arrival at RDC	Oil, electricity, gas and other fuels, refrigerant loss
RDC, to (and inc.) retail	Oil, electricity, gas and other fuels, refrigerant loss
Transport to home (consumers/home delivery)	Petrol/diesel or electricity, refrigerant loss (for home delivery)
Food service (all emissions)	Gas or electric and other fuels, refrigerant loss (negligible as all systems apply R290 and have low leakage)
Domestic cooking	Gas or electric and other fuels (e.g., oil)
Domestic cooling	All electrical (refrigerant loss considered to be zero as R600a used)

The model outputs are presented in Appendix 2 as examples of the data that is produced.

4.3 Basis for the model

The model was based around work by (Audsley, et al., 2009) which divided the food chain as shown in Figure 12. The publication provided carbon emissions per mass of food per year for a variety of food types and for most of the sectors described in Figure 12.

Data from Audsley et al (2009) did not:

1. Differentiate between the emissions from primary production (on the farm) to arrival at the RDC into emissions pre- and post-harvest/slaughter as defined in the WP1 boundaries: post-harvest/slaughter but to include on-farm cooling.	To divide the emissions pre harvest slaughter from those post-harvest/slaughter to the RDC information from Hoolohan et al (2013) was applied.
2. Divide emissions from national production with those from imports.	To determine food that was imported and exported, a range of sources was applied including Statista, Government production figures (as presented below) and information from trade associate web sites.
3. Divide foods between food service and retail.	Food was divided into that used for food service and that for retail, using information from (IRI GIRA Foodservice, 2017).

Food that was wasted as it passed along the food chain was taken from Jeswani et al (2021), with supporting information from WRAP (2013a) (2013b).

No account was taken of what happened to the food after it was wasted unless it was used directly to produce energy on the site of a food process.

It should be noted that these references applied broadly to the UK where the model was initially developed. For other countries specific references that apply to that country may be applied.

4.4 Co_{2e} for UK, rest of Europe (RoE) and rest of World (RoW)

Information was initially taken from (Audsley, et al., 2009). Where unavailable similar products were substituted. Ongoing work is continuing to develop an extensive database of information to update the CO_{2e}/kg figures to be applied in the model. Non-juice beverage emissions were calculated from (Defra, 2013).

4.5 Checks within model

A number of internal checks were applied in the model. These were:

Waste from food calculated using the above method was compared to that calculated from Family food datasets (https://www.gov.uk/government/statistical-data-sets/family-food-datasets). The food consumed in the home and in food service was compared to the baseline food production figures to calculate levels of waste (UKEOcons-27Jan2022 and UKHHcons-27Jan2022 for food eaten in home and outside the home). This information may not be available in all countries and although of general use in the UK was not always considered reliable, as waste calculated using family food datasets was not realistic (for example more food was wasted than was produced in one food type). This is probably due to the data having been self-reported.

1. The calories contained in the food eaten by the consumer were obtained from McCance and Widdowsons, Composition of Foods Integrated Dataset 2021 (downloaded from: https://www.gov.uk/government/publications/composition-of-foods-integrated-dataset-cofid). The calories per person were calculated and compared to the calories reported to be consumed per person. Calories consumed were obtained from: https://www.gov.uk/government/publications/calorie-reduction-the-scope-and-ambition-for-action and an average for the UK population calculated using indexmundi: https://www.indexmundi.com/united_kingdom/age_structure.html. The calories consumed per head of population calculated by the model and that from independent figures could then be compared.
2. UK Household consumption figures provided the mass of food eaten per head of population per year and this could then be compared to the mass calculated in the model.
3. Using the food constituents information, the mas of protein consumed per day could be calculated. This was compared to protein needed per person from: https://www.nutrition.org.uk/healthy-sustainable-diets/protein/?level=Health%20professional. An average figure of 50 g/person/day was applied.
4. A check was added to ensure that the food constituents (water, protein, fat, carbohydrate, other/ mineral) used in the model added up to 100%.
5. The food passing into the food service sector and that flowing into the retail-home sector was calculated using family food datasets and comparted to the figures applied above.

4.6 Hybrid Model

4.6.1 Data Collection Framework

Data collection is an integral part of developing and updating a greenhouse gas inventory. This guideline aims to create a data collection methodology for GHG emissions from the food and beverage supply chain (from farm to fork) for the EU countries and the UK in line with the boundaries agreed under the ENOUGH Programme WP1. The data collected will be used for quantifying different emissions sources along the food chain (stages). To achieve this, we aim to collect the data required for each country primarily from their national resources and complement it with the data from the literature, and data bodies, such United Nations, Eurostat or the International Energy Agency, where necessary.

Our proposed framework considers two main food types in terms of the refrigeration requirements in the supply chain: refrigerated and non-refrigerated food and the food that may move between them. We further categorise the refrigerated food as chilled and frozen to capture the variation in the energy requirements to preserve products of each one:

- **Refrigerated food: chilled or frozen food**, where:
    - Chilled food: food which has been subjected to cooling (without freezing)
    - Frozen food: food which has been subjected to a freezing process
- **Non-refrigerated food:** food that can be handled at ambient temperature

For the refrigerated (perishable) food, we consider five food categories, which all demand different temperatures and ambient conditions: red meat (including beef, pork, lamb and other (e.g. goat, rabbit and venison)), poultry, fish, dairy, fruits and vegetables. On the other hand, we considered five categories for non-refrigerated (non-perishable) food: cereals, canned food, baking, confectionary and beverages.

For each country, the guideline starts with general information about demographic and climate data (which will help us to analyse the bigger picture better), total food mass and type (including production and import/export data) and the type and number of equipment in use today (i.e., vehicles, technologies/distribution centres etc.) along the food supply chain. To this end, the food chain is broken down into seven stages (see below, Fig. 1)

- **Agriculture, aquaculture and fisheries (on-farm)**
- **Food processing**
- **Packaging**
- **Cold storage**
- **Transport**
- **Retail and Food Services**
- **Household Consumption (including last-mile transport and delivery)**

Where possible, data should be collected from the country's national statistics agencies; otherwise, it can be obtained from reliable international data sources, such as United Nations, Eurostat or the International Energy Agency. In addition, it is crucial to include the most recent data available and to report the sources and year of all data.

Furthermore, we aim to collect data on food loss and waste at each stage of the food supply chain (as a percentage of the total amount of food in the country's supply chain). Furthermore, GHG emissions from food loss and waste (landfill) will be considered. Figure 2 shows the energy consumption and source of emissions from each stage of the food cold supply chain.

A brief description and detailed data required for each stage are mentioned throughout the guideline. A boundaries document has been produced and should be read in conjunction with the document.

It is worth indicating the differences in the terminology used in this model and the aforementioned top-down model regarding the food supply chain sectors. However, the first sector in the present model is "Agriculture, aquaculture and fisheries", which corresponds to "Agriculture and fishing in the to-down model". The "food processing" sector in the present model corresponds to the "Manufacture of food products and beverages". At the same time, the "cold storage" sector in the current model corresponds to the "warehousing and storage" in the top-down model. The "retail and food service" in the present model corresponds to "retail" in the top-down model. Finally, the "household consumption" sector corresponds to "domestic" in the top-down model.

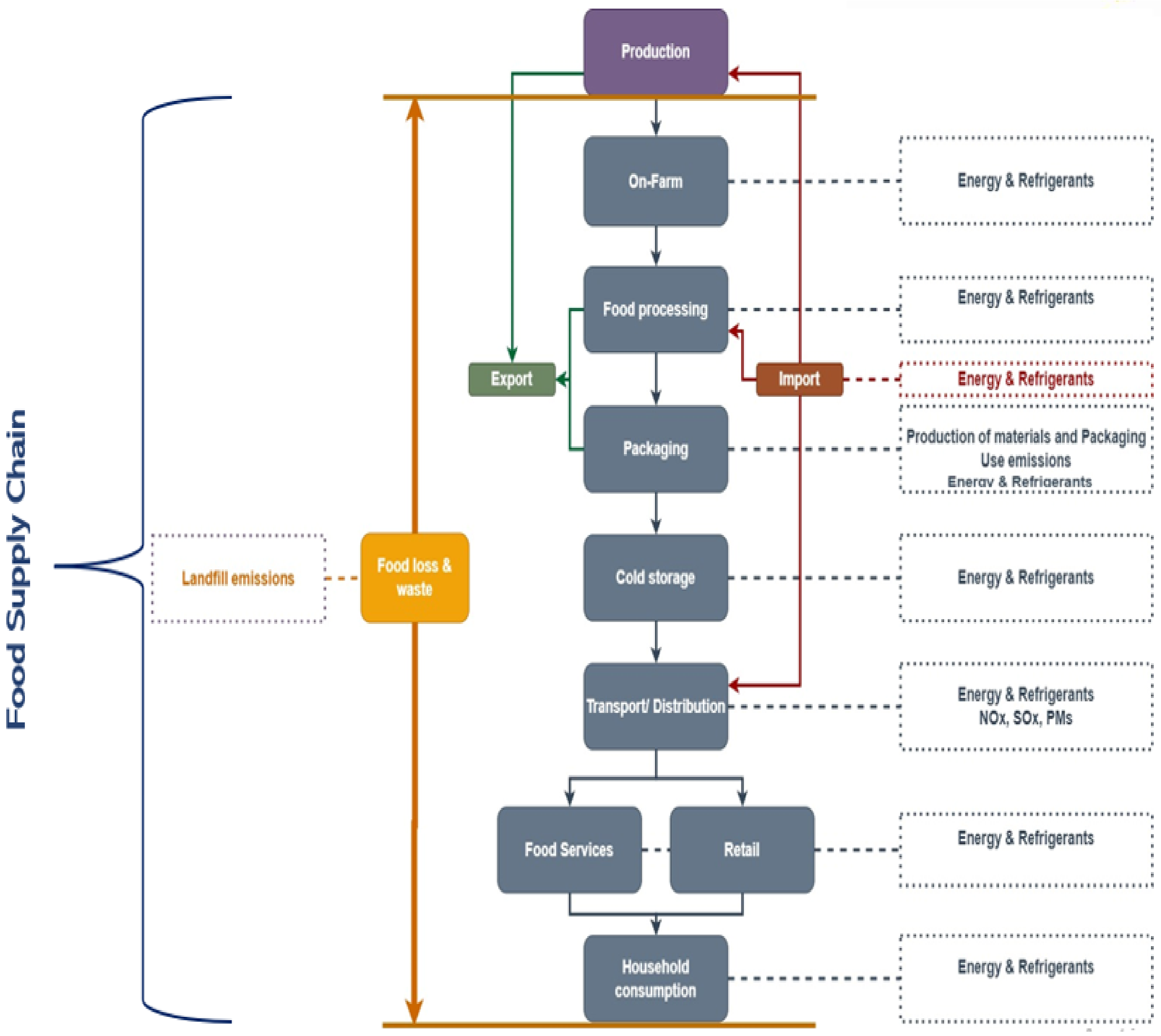

Figure 13. Energy consumption and source of emissions from the food supply change.

4.6.1.1 General Requirements

The following information (see table 3 and 4) are required for all countries.

Table 2. General Requirements (for each country)

Food	Food Type	Technology/ Distribution Centre/ Others
Total mass of food	**Refrigerated Food:**	Total number of vehicles and fishing vessels
Mass of each type of food	Meat: beef, pork, lamb, cattle and others, e.g., goat and veal & venison.	Total number of transport refrigerated units (TRUs)
Mass of food produced in the country		Number of refrigerated and non-refrigerated vehicles
Mass of food exported	Poultry	Types of refrigerated and non-refrigerated vehicles
Mass of food imported	Fish	Type of fishing vessels (by size)
Share of non-refrigerated food	Milk and Dairy	Number and size of cold storage/ warehouses
Share of refrigerated food	Fruits	Total volume of all/ each type (size) of cold storage
Share of chilled food	Vegetables	Share of chilled, frozen and mixed stores in terms of number and capacity
Share of frozen food	**Non-Refrigerated Food:**	Total number and the sale area of supermarkets
Share of packaged food	Cereals, baking, confectionary and beverages	Total number and floor area of food services
Share of unpackaged food		Number (stock)of refrigeration equipment used in:
		On-farm (Pre-cooling), cold storage, retail, food processing, and food service
		Number, type and capacity of domestic refrigeration appliances

4.6.1.2 Food Statistics

Table 3. The overall statistics required for food flowing in the food supply chain

															Food Loss and Waste							
	Type of Food	Produced in Country (kg)	Exported (kg)	% Exported	Imported (kg)	% Imported	Eaten (kg)	% Eaten	% Chilled	% Frozen	% Dried	% Canned	% Processed	% Packaged	% On-Farm	% Cold Storge	% Processing	% Packaging	% Transport	% Retail	% Food Service	% Domestic
1- Meat:	Beef																					
	Pork																					
	Lamb																					
2- Ploutry:	Poultry																					
3- Fish:	Cod																					
	Haddock																					
	Mackerel																					
	Pollack																					
	Salmon																					
	Tuna																					
	Other Fish																					
	Shrimps and Prawns																					
	Other shellfish																					
4- Milk and Dairy	Milk (liquid)																					
	Butter																					
	Cheese																					
	Cream																					
	Yoghurt																					
	Condensed milk																					
	Milk powders																					
	Other milk products																					

Table2 continue…

5- Fruits:	Apple																					
	Pears																					
	Figs																					
	Plums																					
	Cherries																					
	Other stone fruit																					
	Strawberries																					
	Raspberries																					
	Blackcurrants																					
	Other Soft Fruit																					
	Peaches And Nectarines																					
	Lemons and Limes																					
	Oranges																					
	Small Citrus Fruit																					
	Other Citrus Fruit																					
	Avocados																					
	Bananas																					
	Dates and Figs																					
	Melons																					
	Pineapples																					
	Other Exotic fruit																					
	Grapes																					
	Blueberry																					
	Apricots																					
	Kiwi																					
	Other fruit not elsewhere classified																					

Table2 continue…

6- Vegs.:	Turnips and Swedes																					
	Onions, Dry Bulb																					
	Potatoes																					
	Cucumber																					
	Onions, Spring																					
	Brussels Sprouts																					
	Cabbage																					
	Cauliflower+broccoli																					
	Beans																					
	Peas																					
	Asparagus																					
	Celery																					
	Courgettes																					
	Leeks																					
	Rhubarb																					
	Watercress																					
	Tomatoes																					
	Lettuce																					
	Mushrooms																					
	Sweet Peppers																					
	Garlic																					
	Aubergines																					
	Sweetcorn																					
	Carrots																					
	Parsnips																					
	Other vegs.																					

Table2 continue…

	Other vegs.																					
7- Grains:	Wheat																					
	Barley																					
	Oats																					
	Oilseed rape																					
	Linseed																					
	Rice																					
8- Other:	Sugar Beet+cane																					
	Eggs																					
	Non juice beverage																					
	Nuts																					
	Alcohol																					
	Cider & perry juice																					
	Tea/coffee																					

4.7 Data Collection for Each Stage of the Food Supply Chain

4.7.1 Agriculture and fisheries (On-farm):

This refers to emissions from on-farm (including aquaculture and fishing) energy consumption. Electricity used for both heating and cooling (only chilling), whether purchased from the grid or produced locally (on-site power generation), were included. In addition, fuel consumption for power generation and for different on-farm machines, such as tractors, air compressors, generators, etc., were included. Both Scope 1 and 2 emissions were included. **To estimate the GHG emissions associated with this stage of the food chain, the following data are required:**

Table 4. The collected data requires for estimating on-farm (including fishing) emissions due to electricity. The type of food involves all food listed in Table. 4.

	Energy Consumption per kg for:					
Type of Food	Heating (MJ/kg)	Cooling (MJ/kg)	% From Grid	% On-Site Generated	EF (kgCO2e/kWh)	Reference

Table 5. The collected data required for estimating on-farm (including fishing) emissions due to fuel use

Machine	Total Stock (units)	Working Hours (h/y)	Type of Fuel	Fuel Consumption (gm-fuel/h)	Energy Content (kWh/gm-fuel)	Fuel EF (kgCO2e/kWh)	Reference
Tractor							
Generator 5-100 kW							
Generator 100 - 1000 kW							
Rigid dump truck							
Articulated dump trucks							
Cranes							
Bulldozers							
Tracked Loaders							
Air Compressors							
Fishing Vessels/ only fishing							

Table 6. The collected data required for estimating on-farm (including fishing) emissions due to fugitive (refrigerant leakage)

Source of Refrigerant Leakage	Total Stock (units)	Category (if available)	Lifetime (years)	Charge (kg)	Refrigerant	GWP	Operational Loss Rate %	Disposal Loss Rate %	Reference

Note:

- Type of food refers to all food that is given in Table 2.

4.7.2 Cold Storage/Ambient Storage

The GHG emissions of the cold storage stage are associated to the electricity consumption of equipment to store the products at the required temperature, the fuel consumption and refrigerant leaks. In this stage, among the quantity of products subjected to refrigeration, one part is chilled while the other is frozen.

To estimate the GHG emissions associated with this stage of the food chain, the following data are required:

Table 7. The collected data required for estimating cold storage emissions due to energy consumption (electricity & fuel)

		Electricity Consumption						Fossil Fuel Consumption			
		Chilled	Frozen	Mixed	Heating	Lighting					
Storage Volume (m3)	Type (chilled, Frozen, Mixed)	kWh/m3	kWh/m3	kWh/m3	kWh/m3	kWh/m3	Electricity EF (kgCO2e/kWh)	Type of Fuel (gas, oil,.....)	kWh/m3	Fuel EF (kgCO2e/kWh)	Reference

Table 8. The collected data required for estimating cold storage emissions due to fugitive (refrigerant leakage)

Total Stock (units)	Category (if available)	Lifetime (years)	Charge (kg)	Refrigerant	GWP	Operational Loss Rate %	Disposal Loss Rate %	Reference

Note:

- Category refers to the type of refrigeration equipment

4.7.3 Food processing

In this stage the emissions from energy consumption (electricity and fuel) were included. The fugitive emissions from refrigerant leakage from chilled and frozen food products included.

To estimate the GHG emissions associated with this stage of the food chain, the following data are required:

Table 9. The collected data required for estimating food processing emissions due to energy consumption (electricity & fuel

						Energy Consumption per kg of Food (MJ/kg)					Fossil Fuel			
		Product	Amount (kg, t, Mt)	Details	Process	Electricity	% Cooling	% Heating	% Lighting	EF (kgCO2e/kWh	Type of Fuel	EF (kgCO2e/	Comments	Reference
1-	Grains and oilseed:	Breakfast Cereal		NA										
		Cooking oils		NA										
		Flour		NA										
		Oats		Oat Flakes										
		Rice		NA										
		Barley		NA										
		Other												
2-	Confectionery:	Caramel		NA										
		Chocolate		Chocolate Candy										
				Chocolate Bar										
		Coca Butter		NA										
		Candy		Hard Candy										
				Hard Candy raw sugar, corn syrup										
		Pralines		NA										
		Other												
3-	Sugar:	Sugar		Crystals, refined from raw sugar										
				Crystals, refined from										
				From sugar cane										
				Glucose, from corn										

Table 8 Continue ……..

			Glucose, from corn										
4- Fruits and Vegs	Apple		Apple sauce										
			Fresh										
			Juice										
			Canned										
			Frozen										
			Dehydrated										
	Beans		Brown Beans										
			Soy Bean										
	Beet Pulp		NA										
	Carrot		Frozen Carrot Cubs										
			Canned										
			Frozen										
			Dehydrated										
	Corn		Can, sweet corn										
			Frozen package, Sweet Corn										
			Canned Frozen										
			Canned, Sweet Corn										
			Dehydrated										
	Cucumber		Pickling										
	Jams and marmalade		NA										
	Juice		Tomato juice										
			Orange juice										
			From fresh citrus fruit										
			Canned orange juice										
			Lemon juice										
	Mushroom		Preserved										
	Peas		Yellow peas										
			Green, canned										
			Green, froze										
	Potato		French fries										
			Frozen chips										
			Dehydrated										
			Mashed potato										
			Frozen										
			Potato flakes										
	Tomato		Canned, peeled tomatoes										
			Ketchup										
			Paste										
			Puree										
			Chopped										
			Peeled, canned										
	Other												

Table 8 Continue ……..

5-	Dairy:	Butter		NA										
		Cheese		NA										
		Cream		NA										
		Ice Cream		NA										
		Milk		Powder										
				Concentrated milk										
				Whey Powder										
				Fresh Milk										
		Yoghurt		NA										
6-	Bakery:	Bread		Rolls										
				Wheat										
				Rye										
				Frozen wheat										
				Crispy rolls										
				Others										
		Biscuits		NA										
		Baked goods		Cake										
				Cake, sponge or sand										
				Frozen cakes, pies and other pastries										
		Other												
7-	Meat:	Beef, veal & she		Whole Frozen										
				Whole Chilled										
		Pork		Whole Frozen										
				Whole Chilled										
		Lamb		Whole Frozen										
				Whole Chilled										
		Poultry		Whole Frozen										
				Whole Chilled										
8-	Fish:	Fish		Fresh										
				Frozen										
				Canned										
9-	Other Food & Drink:	Soft Drink & Juice		NA										
		Distilled spirits		NA										
		Pasta		NA										
		Salad dressing		NA										
		Wine		NA										
		Beer		NA										
		Other		NA										

Table 10. The collected data required for estimating food processing emissions due to fugitive (refrigerant leakage)

Total Stock (units)	Category (if available)	Lifetime (years)	Charge (kg)	Refrigerant	GWP	Operational Loss Rate %	Disposal Loss Rate %	Reference

4.7.4 Packaging

The emissions from manufacturing of packaging materials and the emissions from energy consumption during packaging were considered. In addition, the fugitive emissions (refrigerant leakage) from the raw materials and packaging manufacturing were included

To estimate the GHG emissions associated with this stage of the food chain, the following data are required:

4.7.4.1 Raw Materials

Table 11. The collected data required for estimating emissions of raw materials of packaging due to energy consumption (electricity & fuel)

		Electricity Consumption			Fossil Fuel			
Materials	Amount(kg, t, Mt)	Cooling (MJ/kg)	Heating (MJ/kg)	EF (kgCO2e/kWh)	Type of Fuel	Energy Consumption (MJ/kg)	EF (kgCO2e/kWh)	Reference
Plastic								
Glass								
Steel & Al								
Paper								

4.7.4.2 Packaging Manufacturing

Table 12. The collected data required for estimating emissions of packaging manufacturing due to energy consumption (electricity & fuel)

		Electricity Consumption			Fossil Fuel			
Materials	Amount(kg, t, Mt)	Cooling (MJ/kg)	Heating (MJ/kg)	EF (kgCO2e/kWh)	Type of Fuel	Energy Consumption (MJ/kg)	EF (kgCO2e/kWh)	Reference
Plastic								
Glass								
Steel & Al								
Paper								

Table 13. The collected data required for estimating emissions from packaging raw materials and packaging manufacturing due to fugitive (refrigerant leakage)

Total Stock (units)	Category (if available)	Lifetime (years)	Charge (kg)	Refrigerant	GWP	Operational Loss Rate %	Disposal Loss Rate %	Reference

4.7.4.3 Packaging Use

This can be estimated by taking the fraction of energy (electricity for cooling) consumed by packing from the total consumed by refrigerated food.

4.7.5 Transport (Ambient & Refrigerated)

The GHG emissions of the transport stage (ambient and temperature–controlled) are considered to come from:

- The fuel consumption of the road transport vehicles (and TRUs) carrying food and refrigerant leakage from refrigerated vehicles.
- The fuel consumption from the fishing vessels used for transporting the captured fish and from refrigerant leakage associated with hauling it.
- There are no differences between chilled and frozen food transport logistics at this stage.

4.7.5.1 Road Transport

To estimate the GHG emissions associated with this stage of the food chain, the following data are required:

Table 14. The collected data required for estimating emissions of road transport due to fuel consumption

	Stocks (Vehicle)				km - Travelled (km/y)		Fuel Consumption (gm-fuel/km)						
Type of Vehicles	Stocks (Total)	Refrigerated	TRUs	Ambient	Refrigerated	Ambient	Refrigerated	TRUs	Ambient	Total Fuel Consumption (gm-fuel/km)	Energy Content (kWh/gm-fuel)	EF (kgCO2e/kWh)	Reference
Van													
HGVs Rigid													
HGVs Articulated													

4.7.5.2 Fishing Vessels

Table 15. The collected data required for estimating emissions of fishing vessels transport due to fuel consumption

	Number of Days at Sea				Fuel Consumption (L/day)						
Type of Vessel by Length (L(m))	Total	Catching	Hauling	Cooling	Catching	Hauling	Cooling	Total Fuel Consumption (L/day)	Fuel Energy Content (kWh/L)	EF (kgCO2e/kWh)	Reference
< 10											
10 to 24											
> 24											

Table 16. The collected data required for estimating refrigerator transport emissions due to fugitive (refrigerant leakage)

Total Stock (units) of TRUs & Vessels	Category (if available)	Lifetime (years)	Charge (kg)	Refrigerant	GWP	Operational Loss Rate %	Disposal Loss Rate %	Reference

4.7.6 Retail

The considered GHG emissions associated with the retail stage are due to the energy (electricity) consumption by equipment such as temperature-controlled rooms, refrigerated sales cabinets (RSCs), lighting and others and fuel consumption for heating and hot water production. These carbon emissions come from the energy consumption required to keep the products at the required temperature and refrigerant leaks from the corresponding refrigeration circuit. Both chilled and frozen products are considered in this stage. To estimate the GHG emissions associated with this stage of the food chain, the following data are required:

Table 17. The collected data required for estimating emissions of retail due to energy consumption

		Electricity				Fuel				
Type of Retail	Average Sell Area Size (m2)	Cooling (kWh/m2)	Heating (kWh/m2)	Lighting (kWh/m2)	Electricity EF (kgCO2e/kWh)	Heating (kWh/m2)	Hot Water (kWh/m2)	Fuel EF (kgCO2e/kWh)	Type of Fuel	Reference
Convenience <280 m2										
Supermarket <1400 m2										
Superstore > 1400 m2										

Table 18. The collected data required for estimating retail emissions due to fugitive (refrigerant leakage)

Total Stock (units)	Category (if available)	Lifetime (years)	Charge (kg)	Refrigerant	GWP	Operational Loss Rate %	Disposal Loss Rate %	Reference

4.7.7 Food Service

The GHG emissions considered in this stage come from the energy (electricity) consumed by different activities, such as refrigerators and freezers, heating (only the part relevant to the food), also from refrigerant leaks from these appliances. In addition, the emissions from energy (fuel) consumption for food preparation processes, such as cooking are included. Both chilled and frozen products are considered in this stage.

To estimate the GHG emissions associated with this stage of the food chain, the following data are required:

Table 19. The collected data required for estimating emissions of food service due to energy consumption

		Electricity (Specific Heat Consumption)								Fuel				
Non-Domestic Building	Total Floor Area (m2)	Heating (kWh/m2)	Hot Water (kWh/m2)	Cooking &Humedification (kWh/m2)	Fans (kWh/m2)	Lighting (kWh/m2)	Catering (kWh/m2)	Other (Pump, ICT equpments,...)	Electricity EF (kgCO2e/kWh)	Heating (kWh/m2)	Hot Water (kWh/m2)	Catering (kWh/m2)	Fuel EF (kgCO2e/kWh)	Reference
Eduction														
Health														
Hospitality														
Leisure Centre														

Table 20. The collected data required for estimating food service emissions due to fugitive (refrigerant leakage)

Total Stock (units)	Category (if available)	Lifetime (years)	Charge (kg)	Refrigerant	GWP	Operational Loss Rate %	Disposal Loss Rate %	Reference

4.7.8 Domestic

4.7.8.1 Household

The GHG emissions in this stage come from the energy consumed by domestic cooking appliances, refrigerators and freezers, as well as the emissions due to the refrigerant leaks from the refrigeration appliances. Both chilled and frozen products are considered in this stage.

Table 21. The collected data required for estimating emissions of domestic (from refrigeration appliances) due to energy consumption

Type of Refrigeration Appliances	Number of Refrigeration Appliance	Average Volume (L)	Energy Consumption (kWh/L)	Electricity EF (kgCO2e/kWh)	Reference
Chest Freezer					
Fridge-freezer					
Refrigerator					
Upright Freezer					

Table 22. The collected data required for estimating emissions of domestic (from cooking appliances) due to energy consumption

Cooking Appliance	Number of Cooking Appliances	Electric	Gas	Number of Use/ year	Energy Consumption (kWh/use)	Electricity EF (kgCO2e/kWh)	Gas EF (kgCO2e/kWh)	Reference
Oven/ electric								
Oven/ gas								
Hobs/ Electric								
Hobs/gas								
Microwave								
Kettle								
Toaster								
Fryer								
Electrical Grill								

Table 23. The collected data required for estimating food service emissions due to fugitive (refrigerant leakage from refrigeration appliances)

Total Stock (units)	Category (if available)	Lifetime (years)	Charge (kg)	Refrigerant	GWP	Operational Loss Rate %	Disposal Loss Rate %	Reference
Chest Freezer								
Fridge-freezer								
Refrigerator								
Upright Freezer								

4.7.8.2 Last–Mile Transport

The GHG emissions in this stage come from the energy consumed (fuel) by last-mile transport (shopping). To estimate the GHG emissions associated with this stage of the food chain, the following data are required:

Table 24. The collected data required for estimating emissions of domestic (from last-mile transport) due to energy (fuel) consumption

Last Mile Transport:
Cars and Taxi % =
Buses % =

		Population						
Age category (year)	Distance travelled on shopping trips per person (km/Person/y)	Men	Women	Type of Fuel	Fuel Consumption (gm-fuel/km)	Fuel Energy Content (kWh/km)	Fuel EF (kgCO2e/kWh)	Reference
0-16								
17-20								
21-29								
30-39								
40-49								
50-59								
60-69								
70+								

4.7.8.3 Last-Mile Deliveries

The GHG emissions in this stage come from the energy consumed (fuel) by last-mile delivery of both ready-to-eat food and grocery.

To estimate the GHG emissions associated with this stage of the food chain, the following data are required:

Table 25. The collected data required for estimating emissions of domestic (from delivery) due to energy (fuel) consumption

	Delivery							
Type of Vehicles	Ready to Eat Food	Glocery	Total Distance Travelled	Fuel Consumption	Energy Content (kWh/gm-fuel)	Type of Fuel	Fuel EF (kgCO2e/kWh)	Reference
Car								
Van								
Motorcycle								

Table 26. The collected data required for estimating emissions due to fugitive (refrigerant leakage from vehicles used in delivery)

Total Stock (units)	Category (if available)	Lifetime (years)	Charge (kg)	Refrigerant	GWP	Operational Loss Rate %	Disposal Loss Rate %	Reference

4.7.9 Waste/ Solid food waste disposal/ landfills

In UK and some EU countries, some proportion of solid municipal waste consisting of food waste ends up in landfills and open dumps where the anaerobic decomposition of organic material releases methane (CH4) gas. Emissions of CO_2 from landfills are not estimated as they are considered entirely biogenic in origin and, therefore, not counted towards the national total. Hence, he only significant GHG from landfill to be included is methane CH_4.

The following information is required to estimate the emissions of food waste (IPCC methodology):

Table 27. The collected data required for estimating emissions of food waste

	L					
Msf (Mt)	mcf	Doc	Docf	F	R	OX

Where:

Msf = the municipal solid waste sent to the landfill (kg, Mt)

L = the methane generation potential

R = the amount of CH_4 generated at a solid waste disposal site (SWDS) that is recovered and burned in a flare or energy recovery device

OX = the oxidation factor, which reflects the amount of CH4 from SWDS that is oxidised in the soil or other material, covering the waste

mcf = the CH_4 correction factor

Doc = the degradable organic carbon

Docf = the fraction of degradable organic carbon dissimilated

F = the fraction of CH_4 in landfill gas

4.7.10 Hybrid Model

A comprehensive bottom-up model was developed to estimate the GHG emissions from the EU and UK food supply chain in line with the boundaries and the data collection framework developed and agreed upon under the ENOUGH Programme Work Package (WP1). The model used a combination of Government statistics, stock data, physical heat transfer models and other published information. It considers all types of food (ambient, refrigerated and processed), including- grains, meat, poultry, fish, milk, fruits, vegetables, bakery, confessionary and beverage. In addition, refrigerated food was categorised into chilled and frozen to capture the difference in the energy consumed by each one. Meanwhile, the food supply chain is broken into seven stages: Agriculture and fishing (on-farm), cold storage, processing, packaging, transportation, food service (retail and food service), and household consumption (see Fig. 1 &2 above).

The model has been developed on MS Excel and aims to (1) estimate the historical emissions from the food supply chain (baseline year) based on the energy consumption by each stage and the leakage of refrigerants used by the refrigeration units, and (2) estimate the future emissions on a yearly basis until 2050 using the horizon scanning model outcome and scenarios approach as described in detail in the data collection framework document. Food produced in the country (both exported and consumed within country) as well as food imported are included. In addition, the GHG emissions from food waste along the food supply chain were considered.

The model estimates Scope 1, Scope 2, and, where relevant, Scope 3 GHG emissions. Scope 1 includes the GHG emissions from refrigerant leakage from all food supply chain sectors, and that produced from on-site fuel consumption. Scope 2 includes the indirect GHG emissions from generating electricity the sectors purchase. Finally, Scope 3 was used where relevant, i.e., the GHG emissions from the manufacturing of packaging raw materials and emissions from waste treatment.

4.8 Model Description

Figure 14 illustrates the general schematic diagram of the model. The model covers the following:

- **Agriculture, aquaculture and fisheries (On-farm):** this includes the emissions from different sources, such as the electricity consumption for food storage and pre-cooling, pumps, light, fuel consumption for driving on-farm machines, (e.g. tractors, generators etc.) refrigerant leakage etc. The model considered this sector's direct energy consumption (emissions) as a whole because of the lack of relevant data and the difficulty splitting it into pre- and post-harvest. However, only slaughterhouses' energy consumption is separated so far from the overall on-farm energy consumption. Meanwhile, work is ongoing following up on the scientific publication to find an appropriate formula to estimate the pre- and post-harvest energy consumption separately.
- **Cold storage and other stores:** this includes the emissions due to the energy consumption by refrigeration equipment, hot water, lighting, emissions due to refrigerant leakage, etc.
- **Processing:** this includes the emissions due to the energy (electricity and fuel) consumption in different industrial and thermal processes and the emissions from refrigerant leakage.
- **Packaging:** this includes, where possible, the emissions from the packaging of raw materials, manufacturing packaging and the use of packaging.

- **Transport:** this includes the emissions from road transport and fishing vessels. In addition, road transport involves ambient and refrigerated transport, including the emissions from refrigerant leakages from TRUs.
- **Retail & Food Service:** This includes the emissions from the overall energy consumption (i.e., for heating, cooking, etc.) and refrigerants leakage from refrigeration units used. However, the food service involves restaurants, coffee shops, fast food, schools, hospitals, health care centers, education, and pubs etc.
- **Domestic (Household):** This includes the emissions produced, from cooking and refrigeration appliances. In addition, the emissions from last-mile transport (shopping) and last-mile delivery.
- Finally, the emissions from **food waste** were considered.

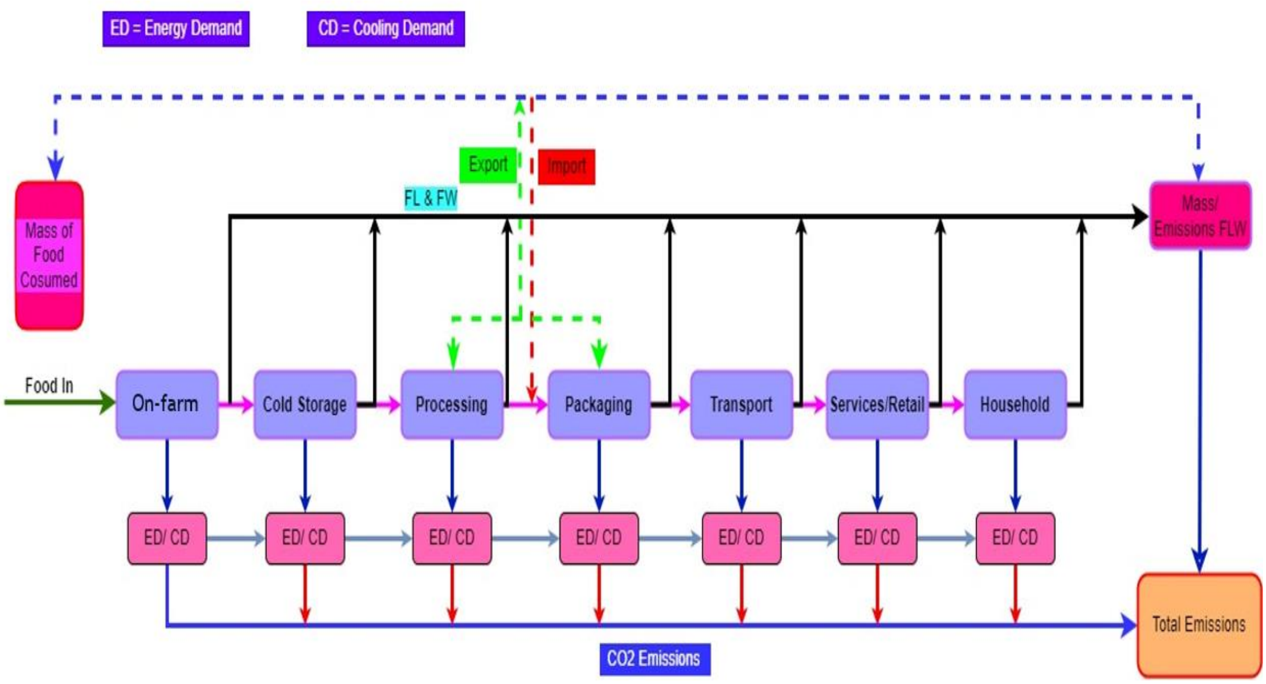

Figure 14. Schematic diagram of the food supply chain sectors considered in the model.

4.9 Model Structure

As mentioned above, the model aims to estimate the GHG emissions from the representative countries in the EU and UK food supply chain for the baseline year and predict future emissions (2050) using the drivers of changes provided by the horizon scanning model described in section 1.

Figure 15 shows the schematic diagram of the process used to estimate the GHG emissions of each stage of the food supply chain. The process starts with data collection and the data needed varies depending on the supply chain sector. For example, we need to know the total volume of the cold storage and the stock of refrigeration units to estimate the emissions of the cold storage produced by refrigeration equipment. On the other hand, to estimate the emissions from the transport sector, the amount of fuel consumption, the number of vehicles, the number of TRUs as well as the fuel consumed, and the stock of fishing vessels are required. However, whatever input data is needed, the general procedure to estimate emissions was based on the energy consumption and the refrigerant leakage in each stage, as explained in Figure 15.

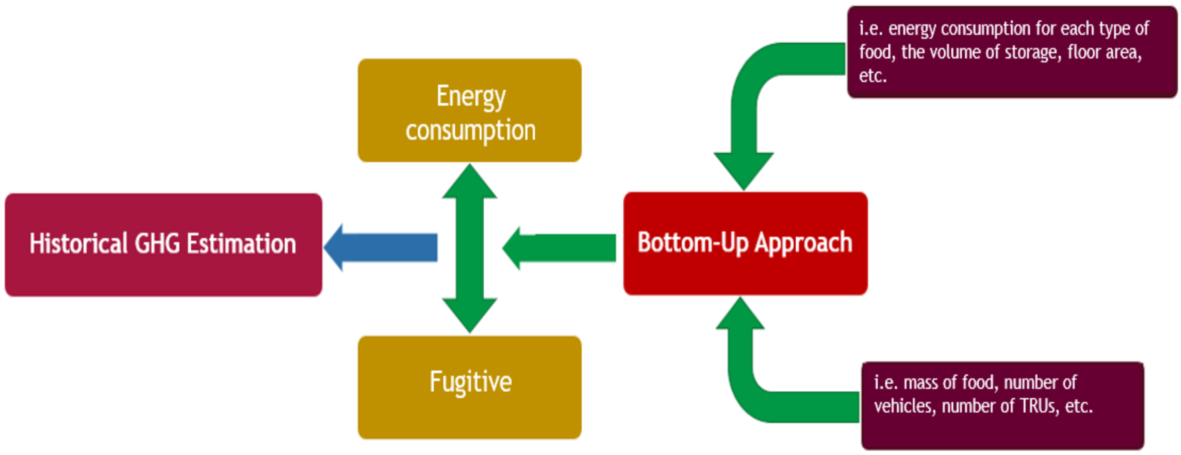

Figure 15. Procedure used to estimate emissions from each food supply chain sector.

In the present model, the prediction of future emissions (2050) was based on the baseline year (2019) emissions by using a number of scenarios. These scenarios have been developed based on the highest impact drivers identified through the horizon scanning model. One of these scenarios was the business-as-usual scenario (BAU), which is used as a reference to compare other scenarios. Multiple scenarios will be tested to identify the ones which will provide the lowest GHG emissions in 2050. These scenarios will then be tested against black swan events to ensure whether they are sustainable and resilient. If so, these results will be reported. Otherwise, a new set of scenarios will be developed and tested until reaching minimum emissions produced by the food chain meanwhile remaining resilient. Figure 15 shows the general schematic diagram of the model used to predict future emissions.

It is very useful to mention here the importance of testing our model against the black swan events. In a world which is seeing a trend from globalisation to nationalism, expansionism, population growth, new viruses, uncertainty and climate change, the food systems are threatened by many factors, and their dynamic capacity to continue to deliver against food and health security goals despite changes to the system as well as disturbances and shocks (**i.e., black swan events**) will be critical. Hence, while we aim for strategies to deliver net zero food supply chains, it is imperative to consider the risk and response to such events to ensure resilience and sustainability.

Therefore, designing a sustainable and resilient food supply chain requires a responsive, future-oriented approach to understanding how the cold-chain needs, climate, technologies, policies and regulations, social norms, food, and health systems will change or might need to change. And equally important, it requires understanding and minimising risks and planning for future disruptions to the system, which are likely to happen more frequently.

One recent example of black swan events is the Ukraine war. Before the war, Russia and Ukraine's combined wheat production accounted for about a third of global needs. The two nations are also important for the supply of fertiliser, cooking oil and feed grains such as corn. And they are particularly important suppliers to numerous countries in the Middle East and Africa. So, when Russia invaded Ukraine, all of a sudden, the concern was that both countries were potentially being knocked out of the global market.

Adding to the challenge was the fact that global food prices were already at record highs due to a spate of previous droughts and poor harvests in other countries that are also important suppliers – including the United States. With food stocks being tight, there was not going to be a cushion to deal with a sudden drop in supply from Russia and Ukraine.

The result is that in the first couple of months after Russia invaded, "food prices were quite high and quite volatile. Wheat futures jumped almost 60%. Corn and soybeans were up 15 to 20% in the first week or so."

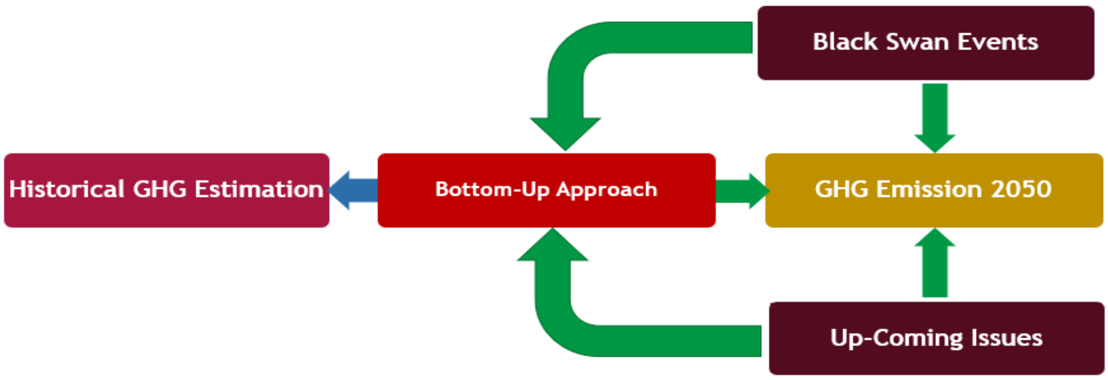

Figure 16. General model structure

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Appendices: Horizon Scanning Model

6 APPENDIX 1: LIST OF SUB-DRIVERS

Climate Change 1. Extreme weather events (heat waves, flooding, flash flooding, drought, and storms) 2. Temperature change 3. Rainfall pattern 4. Increase humidity	20. Increase in seasonal fruits and vegetables 21. Reduction in cost of efficient equipment, GWP or environmentally friendly equipment (Purchasing power of new energy efficient) 22. Dynamic pricing 23. Reduction in food loss- post-harvest loss

5. Increase CO2 level 6. A warmer, more acidic ocean **Demographics** 7. Population growth 8. Urbanisation- increase in urban population 9. Impact of education level on mitigation of human source emissions 10. Impact of the age groups on emissions from food **Business & Economics** 11. GDP growth, increased household income and rise middle income population 12. Increased food prices and food insecurity 13. Increased in support for local business 14. Change towards servitisation business models (cooling as a service, reducing initial cost and increasing access to cooling services etc.) 15. Green Finance Mechanisms 16. Increase imported food 17. Optimisation of logistics -third party logistics (3PL)/ optimum sizing and velocity of cold chain storage/transportation-cold chain design 18. Local production and consumption/ vertical farming, promoting local production 19. Accurately links demand and supply by building a partnership between suppliers and consumer using "big data"	24. Tax-free ports 25. Radical and disruptive interventions (*) **Social & Behavioural** 26. Change in Dietary/ Impact of food choice 27. Change in food shopping and consumption habits (**) 28. Shopping for more frozen food and less fresh food 29. Reduction in food waste- at the consumer end 30. Education children from young age about "farm to fork" 31. Knowledge exchange initiatives (e.g. “best before” versus “use by” date) 32. Social media campaigns and raising awareness - food choices and food storage habits 33. Shop and eat directly from local -From farmers to consumers 34. Improve skills and capacity for the efficient running of the food/cold chain operations/ development of new refrigeration cycles **Policy** 35. Food Safety policies (including temperature for the frozen food industry) 36. Food storage for resilience purposes
37. National Food Strategy to reduce waste 38. Fisheries Bill 39. Post Brexit Policies- decrease in workforce 40. Global Food Trade Policies- import duties ,WTO, EU Free Trade Agreement etc 41. UK climate and energy policies (***)	56. Transition to low GWP refrigerants in line with refrigerant policies 57. Increase the operating temperature of frozen food 58. Decarbonisation technologies (*****) 59. Decarbonisation of the national grid 60. Food Technology/ Novel sources of protein (******)

42. Regulation on re-manufacturing (circular economy)/ food packaging re-circulation/ food wate re-circulation 43. Different standards (integrated) for cold chains across food and pharmaceutical sector 44. Reform of red diesel and other rebated biofuels entitlement 45. Agricultural Policies-Policies for improvement in farming practices and production improvements 46. Regulation on food products and ingredients by FSA and EFSA 47. Right to Repair 48. Carbon tax on food **Technology and Infrastructure** 49. Modal Shifts 50. Improve the efficiency of cooling equipment (****) 51. Cooling demand aggregation 52. Digitalisation, smart data systems and control systems/ monitoring energy consumption at household, firm levels; Businesses adopting energy management softwares to reduce energy consumption; Warehouse 53. Block chain technology, internet of things etc in food supply chain at industrial, commercial level 54. Demand Side Management of heating and cooling loads 55. Transport infrastructure-Decentralised and distributed food supply systems	61. Novel food packaging and coating technology (*******) 62. Retail future technology (********)

7 APPENDIX 2: SUB-SUB-DRIVERS

Radical and disruptive interventions (*): 1. Eliminating of supermarkets 2. Decentralising manufacturing and retailers **Change in food shopping habits (**):** 3. On - line shopping (bulk) 4. On - line shopping (on - demand) (no storage)	20. Use of Heat pump cooling system 21. CO_2 based and heat recovery cooling systems 22. Alternative technologies to vapour compression refrigeration systems 23. Cryogenic refrigerates trucks 24. CO2 capture technology

5. On-demand delivery (ready to eat)
6. More home cooking
7. Meal kit compared with grocery meal

UK climate and energy policies (***):

8. Carbon tax on energy
9. Eco-design and labelling directive/ Energy standard for refrigeration
10. F-gas regulation

Reduce inefficiency of cooling equipment (****):

11. Optimized control system
12. Compressor efficiency improvement - Optimization of the compressor operating sequence
13. Optimization of the intermediate and low pressure set points
14. VSD of compressor, fan and pump
15. Use of electronic expansion valves
16. High efficiency microchannel heat exchangers, larger sized heat exchangers
17. Efficient Compressors: Two-stage rotary compressors, high efficiency scroll compressors with DC motors
18. Use thermal energy storage

Decarbonisation technologies (*****):

19. Cold storage, energy storage, low carbon transport vehicles e.g. using hydrogen, other renewables; design of energy efficient stores, warehouses

25. Emerge robotics in food industry/ restaurants
26. Harvesting of heat waste/ heat recovery

Food Technology/ Novel sources of protein (******):

27. Edible insects/ Edible algae
28. Lab - grown meet/ Synthetic food -meat

Novel food packaging and coating technology (*******):

29. Active packaging
30. Intelligent and smart packaging
31. Novel nanotechnology packaging film
32. Bio gradable and edible film

Retail technology (********):

33. Augmented reality
34. Just walk out shopping/ no lines, no checkout
35. Face – based buying
36. Product talking each other

8 APPENDIX 3: THE UK LIST OF WIN AND RISK SUB-DRIVERS

Sub-Drivers	Score	Sub-Drivers	Score
Risk Sub-drivers:		19. Decarbonisation of the national grid	-4.73
1. Temperature change	+7.23		
2. Population growth	+7.02	20. Increase the operating temperature of frozen food	-4.71
3. Extreme weather events (heat waves, flooding, flash flooding, drought, and storms)	+4.82		

4. Change in food shopping and consumption habits	+4.75		
5. Increase imported food	+3.83		
6. Increase humidity	+3.81		
7. Rainfall pattern	+3.08		
Win Sub-drivers:			
8. National Food Strategy to reduce waste	-5.22		
9. Reduction in food waste- at consumer end	-5.2		
10. Shopping for more frozen food and less fresh food	-5.03		
11. Improve skills and capacity for the efficient running of the food/cold chain operations/ development of new refrigeration cycles	-5.00 -4.93 -4.88		
12. Radical and disruptive interventions			
13. Change in Dietary/ Impact of food choice	-4.80		
14. Local production and consumption/ vertical farming, promoting local production	-4.78 -4.78		
15. Improve the efficiency of cooling equipment	-4.74		
16. Decarbonisation technologies	-4.74		
17. Increase in seasonal fruits and vegetables			
18. Transition to low GWP refrigerants in line with refrigerant policies			

Appendices: Top-Down Model

9 APPENDIX 4: DATA SOURCE FOR THE TOP- DOWN MODEL

	Sectors	Activity data	Food Share	Emissions factors
UK	Agriculture	Energy consumption in the UK 2020 -	Not Necessary	Greenhouse gas emission intensity of electricity

		GOV.UK (www.gov.uk) Final Energy Consumption Tables Table C4		generation — European Environment Agency (europa.eu)
	Manufacture	End Use Tables U4	Not Necessary	Same for all
	Cold storage	End Use Tables U6	Not Necessary	
	Transport	Intensity Tables I2	23% Road Freight	
	Retail	End Use Tables U6	Not Necessary	
	Food and beverage service	End Use Tables U6	Not Necessary	
	Waste	UK Greenhouse Gas Inventory 1990-2019: Annexes (defra.gov.uk)	complicated	
	Packaging	conversion-factors-2021-full-set-advanced-users.xlsm (live.com)	complicated	
Norway	Agriculture	SSB table 09288		
	Manufacture			
	Cold storage			
	Transport	SSB 11403, SSB 06988, SSB 07296, https://miljoloftet.no/globalassets/rvu/rvu-2020.pdf https://www.toi.no/getfile.php?mmfileid=39511 https://www.toi.no/getfile.php?mmfileid=46827 https://www.ssb.no/statbank/table/0974	Complicated	

		7/tableViewLayout1/		
	Retail	https://www.norgesgruppen.no/globalassets/ars--og-barekraftsrapport-2021.pdf https://coop.no/globalassets/om-coop/arsmeldinger/2021/coop-norge-sa-aarsrapport-2021-lr.pdf https://issuu.com/rematusen/docs/reme0388_ansvarsrapport_digital_h_y?fr=sYTIyOTQyMzg3ODA	Not necessary	
	Food and beverage service	SSB table 09288, SSB table 11558 https://data.brreg.no/enhetsregisteret/oppslag/enheter?naeringskode=56&sort=navn.norwegian,asc	Complicated	
	Waste			
France	Agriculture	ADEME, 2018[viii]	Not Necessary	RTE France[vii]
	Manufacture	Agreste, 2019 [ix]	Not Necessary	RTE France[vii]
	Cold storage	Bossard, 2016[x]	Not Necessary	RTE France[vii]
	Transport	-	-	-
	Retail	Barbier et al., 2019[XI]	Not Necessary	RTE France[vii]
	Food and beverage service	Barbier et al., 2019[XI]	Not Necessary	RTE France[vii]
	Waste	-	-	-

	Packaging	-	-	-
Italy	Agriculture	Istat PEFA Data[i]2019	Not Necessary	ISPRA Emission Factors[ii] GreenhouseGas Inventory (IT)[iii]
	Manufacture	*Same as Agriculture*	Not Necessary	*Same as Agriculture*
	Cold storage			
	Transport	*Same as Agriculture*	Istat Road Freight Tansport[iv] 2019 Food Share = 25%	*Same as Agriculture*
	Retail	*Same as Agriculture* GreenhouseGas Inventory (IT)[v] for fugitive emissions	RSE Report on Trade[vi] Food Share = 30%	*Same as Agriculture*
	Food and beverage service	*Same as Agriculture*	Not yet defined (food share to be identified on food + accommodation total)	*Same as Agriculture*
	Domestic	*Same as Retail for energy consumption and fugitive emissions*	Eurostat Household[vii] Cooking Share = 6.8%	*Same as Agriculture*
	Waste			
	Packaging			
Lithuania	Agriculture	Rodiklių duomenų bazė - Oficialiosios statistikos portalas	Lithuania's Greenhouse Gas Inventory Report 2022 https://am.lrv.lt/uploads/am/documents/files/Klimato_kaita/NIR_2022%2003%2015%20FINAL.pdf	**310** gCO_{2eq}/kWh. https://app.electricitymaps.com/
	Manufacture	https://osp.stat.gov.lt/lietuvos-aplinka-zemes-ukis-ir-energetika-2021/energetika/kuro-ir-energijos-suvartojimas	Lithuania's Greenhouse Gas Inventory Report 2022 https://am.lrv.lt/uploads/am/documents/files/Klimato_kaita/NIR_2022	*Same as Agriculture*

			%2003%2015%20 FINAL.pdf	
	Cold storage			
	Transport	12 % from all domestic transport	Lithuania's Greenhouse Gas Inventory Report 2022 https://am.lrv.lt/uploads/am/documents/files/Klimato_kaita/NIR_2022 %2003%2015%20 FINAL.pdf	
	Retail	Rodiklių duomenų bazė - Oficialiosios statistikos portalas	20 % from electricity for all services GHG (scope 1) same as from electricity	
	Food and beverage service	Rodiklių duomenų bazė - Oficialiosios statistikos portalas	8 % from electricity for all services	
	Domestic	Rodiklių duomenų bazė - Oficialiosios statistikos portalas	30,6 % from all domestic	*Same as Agriculture*
	Waste		Lithuania's Greenhouse Gas Inventory Report 2022 https://am.lrv.lt/uploads/am/documents/files/Klimato_kaita/NIR_2022 %2003%2015%20 FINAL.pdf	
	Packaging			
New partner included in the WP- research on national resources are ongoing				
Belgium	Agriculture			
	Manufacture			
	Cold storage			
	Transport			

	Retail			
	Food and beverage service			
	Waste			
	Packaging			
New partner included in the WP- research on national resources are ongoing				
Austria	Agriculture			
	Manufacture			
	Cold storage			
	Transport			
	Retail			
	Food and beverage service			
	Waste			
	Packaging			
Germany	Agriculture	2022_03_15_trendtabellen_thg_nach_sektoren_v1.0.xlsx (live.com)		CO_2-Emissionen pro Kilowattstunde Strom steigen 2021 wieder an | Umweltbundesamt
	Manufacture			
	Cold storage			
	Transport	Economic Sectors and Enterprises - Goods transport - German Federal Statistical Office (destatis.de)		
	Retail			
	Food and beverage service			
	Domestic	Energieverbrauch privater Haushalte | Umweltbundesamt		

	Waste			
	Packaging			
New partner included in the WP- research on national resources are ongoing				
Hungary	Agriculture			
	Manufacture			
	Cold storage			
	Transport			
	Retail			
	Food and beverage service			
	Domestic			
	Waste			
	Packaging			
New partner included in the WP- research on national resources are ongoing				
Poland	Agriculture			
	Manufacture			
	Cold storage			
	Transport			
	Retail			
	Food and beverage service			
	Domestic			
	Waste			
	Packaging			

Vii https://www.rte-france.com/eco2mix/les-emissions-de-co2-par-kwh-produit-en-france#

VIII ADEME, SOLAGRO, CTIFL, ASTREDHOR, ARVALIS, FNCUMA, . . . ITAVI. (2018). Agriculture et efficacité énergétique : propositions et recommandations pour améliorer l'efficacité énergétique de l'agriculture des exploitations agricoles en France.

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XI Barbier, C., Couturier, C., Pourouchottamin, P., Cayla, J.-M., Silvestre, M., & Pharabod, I. (2019). L'empreinte énergétique et carbone de l'alimentation en France. Club Ingénierie Prospective Energie et Environne

[1] ISTAT PEFA: Physical energy flow accounts (PEFA): Use by activity and energy flow. Reports the use of each source (fuel type or electrical energy) for different macro areas.
[1] ISPRA "Atmospheric emission factors of greenhouse gases from power sector in Italy and in the main European countries. Edition 2020" – Pag 54, table 4.1 Values for Natural Gas, Kerosene, Naphta, Gas Oil (burners), Residual Fuel Oil, Refinery gas, ethane and LPG, Other Petroleum Products.
[1] "Italian Greenhouse Gas Inventory 1990-2020. National Inventory Report 2022" – Pag 485, Table A6.2 "Petrol, experimental averages 2017-2020" and "Gas oil, engines, experimental averages 2017-2020".
[1] ISTAT, Road freight transport. Reports the ktonne-km for different type of goods. Share is computed as $\frac{Food\ products\ beverage\ and\ tobacco_{ktonne\ km}}{All\ Items_{ktonne\ km}}$ = 19%
[1] "Italian Greenhouse Gas Inventory 1990-2020. National Inventory Report 2022" – pag 185 - Table 2.F.1.a for fugitive gas emissions.

[1] RSE, "Metabolismo energetico degli utenti finali: modellazione analitica dei consumi". RSE is part of GSE, the company identified by Italy to pursue and achieve sustainability. The report contain the share of the Food market compared to the trade sector in terms of stores ($n_{food}, n_{fashion\ store}, n_{fuels}$). The energy demand for the "average" store is also reported ($e_{food}, e_{fashion\ store}, e_{fuels}$ ...) in kWh. Food store share has then be obtained as: $\frac{e_{food}\, n_{food}}{\sum e_{other} n_{other}}$ = 30%.

[1] EUROSTAT: Disaggregated final energy consumption in households – quantities. The "cooking" and the "total" household energy are reported. Food share is obtained using this ratio = 6.8%.

Appendices: Consumption Based Model

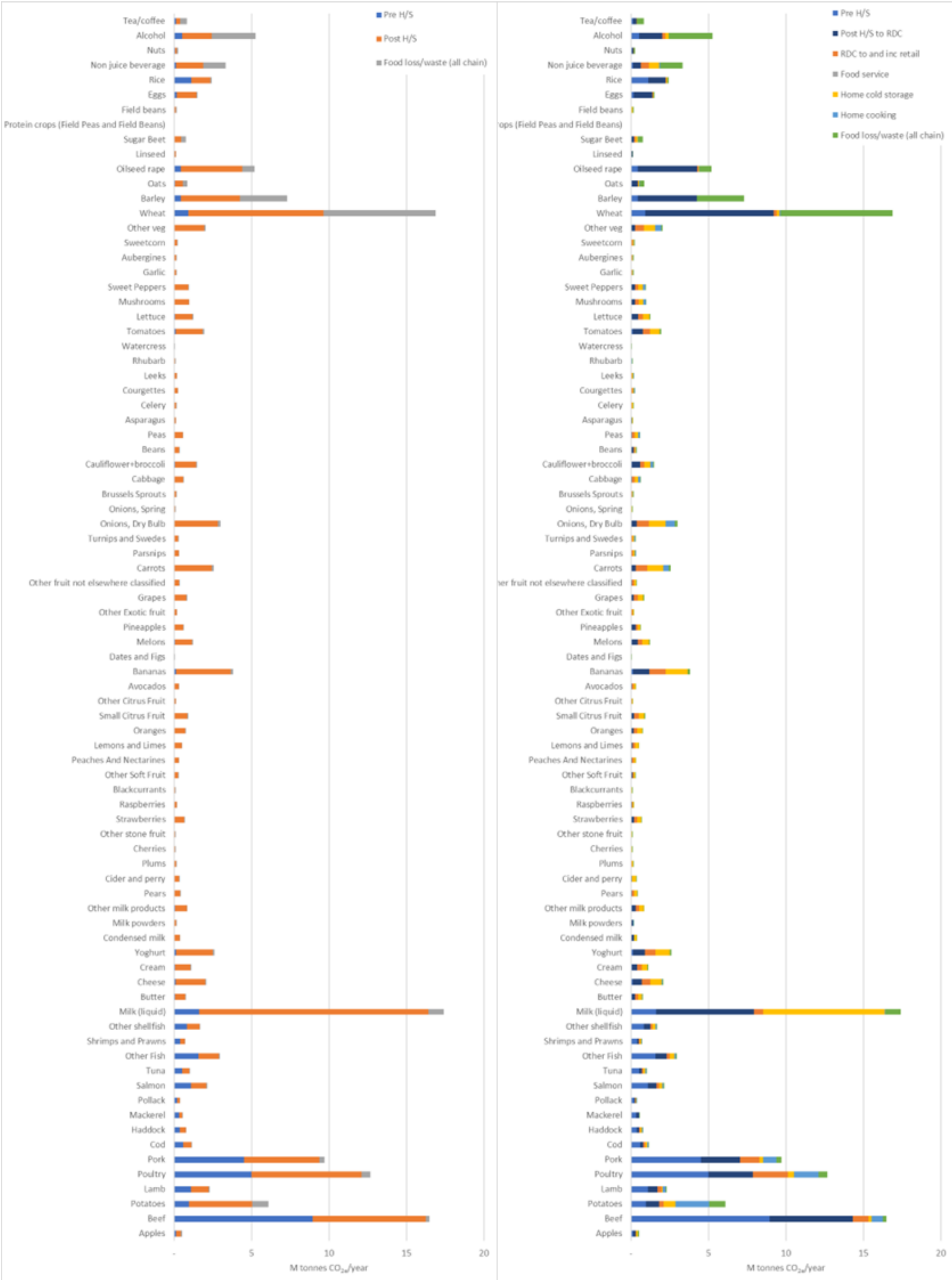
10 APPENDIX 5: FOOD TYPES INCLUDED IN THE MODEL

1. Alcohol 2. Apples	37. Milk (liquid) 38. Milk powders	72. Small citrus fruit 73. Strawberries

3. Asparagus 4. Aubergines 5. Avocados 6. Bananas 7. Barley 8. Beans 9. Beef 10. Blackcurrants 11. Brussels sprouts 12. Butter 13. Cabbage 14. Carrots 15. Cauliflower and broccoli 16. Celery 17. Cheese 18. Cherries 19. Cider and perry 20. Cod 21. Condensed milk 22. Courgettes 23. Cream 24. Dates and figs 25. Eggs 26. Field beans 27. Garlic 28. Grapes 29. Haddock 30. Lamb 31. Leeks 32. Lemons and limes 33. Lettuce 34. Linseed 35. Mackerel 36. Melons	39. Mushrooms 40. Non juice beverage 41. Nuts 42. Oats 43. Oilseed rape 44. Onions, dry bulb 45. Onions, spring 46. Oranges 47. Other citrus fruit 48. Other exotic fruit 49. Other fish 50. Other fruit not elsewhere classified 51. Other milk products 52. Other shellfish 53. Other Soft Fruit 54. Other stone fruit 55. Other veg 56. Parsnips 57. Peaches And Nectarines 58. Pears 59. Peas 60. Pineapples 61. Plums 62. Pollack 63. Pork 64. Potatoes 65. Poultry 66. Protein crops (field peas and field beans) 67. Raspberries 68. Rhubarb 69. Rice 70. Salmon 71. Shrimps and Prawns	74. Sugar beet and cane 75. Sweet peppers 76. Sweetcorn 77. Tea/coffee 78. Tomatoes 79. Tuna 80. Turnips and swedes 81. Watercress 82. Wheat 83. Yoghurt

11 APPENDIX 6 – EXAMPLE MODEL OUTPUTS (NOTE, NOT FINAL)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101036588


Pre H/S
Post H/S
Food loss/waste (all chain)
Tea/coffee
Alcohol
Nuts
Non juice beverage
Rice
Eggs
Field beans
Protein crops (Field Peas and Field Beans)
Sugar Beet
Linseed
Oilseed rape
Oats
Barley
Wheat
Other veg
Sweetcorn
Aubergines
Garlic
Sweet Peppers
Mushrooms
Lettuce
Tomatoes
Watercress
Rhubarb
Leeks
Courgettes
Celery
Asparagus
Peas
Beans
Cauliflower+broccoli
Cabbage
Brussels Sprouts
Onions, Spring
Onions, Dry Bulb
Turnips and Swedes
Parsnips
Carrots
Other fruit not elsewhere classified
Grapes
Other Exotic fruit
Pineapples
Melons
Dates and Figs
Bananas
Avocados
Other Citrus Fruit
Small Citrus Fruit
Oranges
Lemons and Limes
Peaches And Nectarines
Other Soft Fruit
Blackcurrants
Raspberries
Strawberries
Other stone fruit
Cherries
Plums
Cider and perry
Pears
Other milk products
Milk powders
Condensed milk
Yoghurt
Cream
Cheese
Butter
Milk (liquid)
Other shellfish
Shrimps and Prawns
Other Fish
Tuna
Salmon
Pollack
Mackerel
Haddock
Cod
Pork
Poultry
Lamb
Potatoes
Beef
Apples
-
5
10
15
20
M tonnes CO2e/year
Pre H/S
Post H/S to RDC
RDC to and inc retail
Food service
Home cold storage
Home cooking
Food loss/waste (all chain)
Tea/coffee
Alcohol
Nuts
Non juice beverage
Rice
Eggs
Field beans
ops (Field Peas and Field Beans)
Sugar Beet
Linseed
Oilseed rape
Oats
Barley
Wheat
Other veg
Sweetcorn
Aubergines
Garlic
Sweet Peppers
Mushrooms
Lettuce
Tomatoes
Watercress
Rhubarb
Leeks
Courgettes
Celery
Asparagus
Peas
Beans
Cauliflower+broccoli
Cabbage
Brussels Sprouts
Onions, Spring
Onions, Dry Bulb
Turnips and Swedes
Parsnips
Carrots
er fruit not elsewhere classified
Grapes
Other Exotic fruit
Pineapples
Melons
Dates and Figs
Bananas
Avocados
Other Citrus Fruit
Small Citrus Fruit
Oranges
Lemons and Limes
Peaches And Nectarines
Other Soft Fruit
Blackcurrants
Raspberries
Strawberries
Other stone fruit
Cherries
Plums
Cider and perry
Pears
Other milk products
Milk powders
Condensed milk
Yoghurt
Cream
Cheese
Butter
Milk (liquid)
Other shellfish
Shrimps and Prawns
Other Fish
Tuna
Salmon
Pollack
Mackerel
Haddock
Cod
Pork
Poultry
Lamb
Potatoes
Beef
Apples
-
5
10
15
20
M tonnes CO2e/year

enough-emissions.eu

Disclaimer: This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101036588.

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