Carbon Calculations over the Life Cycle of Industrial Activities

A "Carbon Vision Project Industry" funded by the Carbon Trust, EPSRC and NERC

POSITION PAPER

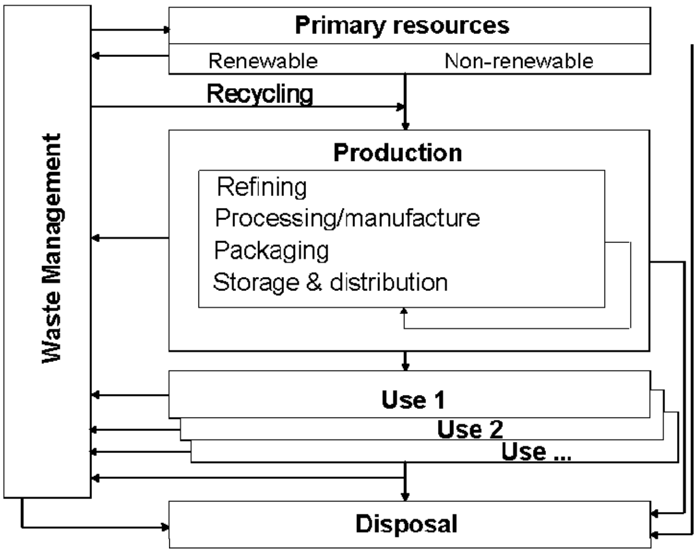
This paper outlines the main aim and the scope of the CCaLC project as well as the overall methodological approach. This is followed by a description of the four case studies that will be considered within the project and the scope they will cover. The aim of the paper is to help end-users and other stakeholders understand better what they could expect from this project and how they might be able to benefit from its outputs.

Project aim

The main aim of this project is to develop a life cycle methodology and decision-support tools for estimating the inventories of carbon-equivalent (i.e. greenhouse gases) in different industrial sectors along complete supply chains.

Project scope

Wherever possible and meaningful, the scope of the project will be from 'cradle to grave', encompassing the whole life cycle of the activity under study. Where appropriate, recycling and 'cascaded' use of products and materials will also be considered. This is illustrated in the figure.



However, the scope of individual case studies to be developed within the project may not always be from 'cradle to grave' but from 'cradle to gate' or from 'gate to cradle'. This is explained in more detail further below in the section on *Case studies*.

Project outputs

The following are the four main outputs from the CCaLC project:

1. **A general life cycle methodology and decision-support tools** for:
   - calculating environmental and economic impacts of life-cycle carbon inventories, including "carbon added" and "value added" along the whole supply chains, and
   - optimising on environmental and economic objectives to identify a range of optimum low-carbon options;
2. **A standard data acquisition methodology and databases** for use in carbon inventory calculations;
3. **A general modelling framework and a software package** for calculating carbon inventories, with a suite of tools designed for specific sectors; and

4. **Case studies of different industrial sectors** to examine different business, political and economic scenarios for carbon management and reduction, and estimate the environmental and economic implications of low-carbon materials, products, processes and services.

1. Methodology

The project will use a whole systems approach to develop a life cycle methodology for an integrated environmental and economic analysis of carbon intensity of different industrial systems. This will involve both environmental and economic aspects of the emissions of carbon equivalent, enabling estimation of "carbon added" and "valued added" at each stage of the supply chain.

A general Life Cycle Assessment (LCA) database and modelling framework will be developed that could be used by any industrial sector as well as by policy makers. Although the emphasis of the project is on carbon-equivalent estimations, the methodological developments will not be limited to carbon alone but will also enable estimations of other environmental impacts. This is particularly important when assessing different options to ensure that carbon inventory is not reduced at the expense of other environmental impacts.

The methodology for estimating the economic impacts will entail assigning values to the flows of materials and energy along the supply chain, both as a result of investment and operating costs. This will enable the identification of low and high value-adding activities and processes and their relation to environmental impacts. In addition, the project will investigate the options for, and the associated costs of, carbon mitigation measures. Such an insight would be particularly useful to those companies becoming involved in emissions trading.

The methodology will also incorporate suitable optimisation techniques to enable identification of optimum material, product and technological options that would lead to a low-carbon economy. Multi-criteria decision analysis (MCDA) will be used to help manage and trade-off different environmental and economic criteria.

Some of the methodological issues that will be addressed within the project include:

- Basis and time scales for analysis;
- System boundaries;
- Recycling and 'cascading';
- Allocation;
- Carbon sources and sinks;
- Integration of environmental and economic data; and
- Data availability, transparency and uncertainty.

2. Databases

A standard data acquisition methodology and databases will be developed for estimations of carbon inventory as well as other environmental burdens impacts. The databases will include life-cycle material and energy flows associated with various supply chains as well as the value added along the supply chain. A distinction will be made between the foreground and background data, with the former describing activities or operations which are the focus for study and the latter relating to the economic context in which the foreground activities are embedded. The foreground data will be collected from the industrial partners on the project while the background data will be sourced from various LCA databases.

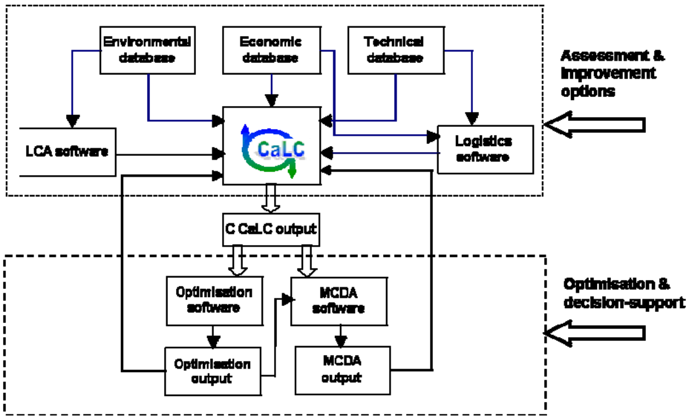
3. Software platform

A flexible software platform will be developed to reflect the needs of end users, enabling them to ask a range of different question, including:

- What is the carbon intensity of this supply chain? And of my process/product?
- Where are the 'hot spots'?
- Where is the value added?
- How does value added relate to "carbon added"?
- What are the low-carbon options for reducing the carbon intensity?
- What would be the cost? And value added?

- What are the trade-offs between environmental benefits and economic costs?
- What policy measures are needed for reducing carbon emissions?

As shown in the figure, the CCaLC software tool will have two main parts, with the first enabling LCA/valued added analysis and identification of options for improvements and the second providing systems optimisation and multi-criteria decision support.



Depending on the needs of the end user, the CCaLC software will be developed at three levels with basic, intermediate and/or advanced capabilities, as follows:

Level 1
At this level, CCaLC will support simple/screening LCA and value added studies and will have the following basic capabilities:
- Simple, spreadsheet-based, models
- Built-in databases, examples, case studies and scenarios; and
- Simple multi-criteria decision analysis to support decision making.

Level 2
This intermediate level will support full LCA and value added studies and will enable the end-user to:
- Pose specific questions beyond the built-in case studies and scenarios; and
- Manipulate existing as well as define own systems, scenarios and data.

Level 3
The Level 3-user will be able to carry out detailed LCA and value added studies and will have access to advanced capabilities of the CCaLC software, including:
- Creation of own LCA/value added models and input of own data;
- Process and logistics optimisation with access to the appropriate commercial software packages; and
- Full multi-criteria decision analysis (MCDA) with access to a commercial software package.

4. Case studies
To support the development of the methodology and software platform, four sectors and related supply chains have been chosen as “test beds”: Chemicals and related products; Food & Drink; Bio-feedstocks and Biofuels.

Chemicals and related products
This case study will focus on the carbon footprints of various chemicals and related products. The work will also include calculation of value added along the supply chain and comparisons with carbon added. The main emphasis will be on identifying low-carbon options that could be implemented in this supply chain. The products to be studied include basic chemicals, polymers and packaging. The role in reducing carbon intensity of process optimisation and intensification as well as improved product formulation through novel chemistry will also be examined.

Food and drink
For this case study, a macro-scale analysis of food and drink systems in the UK will be undertaken to identify the carbon ‘hot spots’. Subsequently, both “marginal” and “disruptive” options that could be introduced to reduce the carbon footprints in this supply chain will be identified and investigated in more detail. The supply chain will include agricultural activities, raw material processing, food and drink manufacture, packaging, storage (refrigeration) and waste management.

For this case study, a macro-scale analysis of the food & drink systems in the UK will be undertaken. It will take national food & drink consumption, production, imports and export statistics as a starting point. Subsequently, specific "disruptive", step changes in technologies that could be introduced to reduce the carbon intensity of food & drink production will be identified and investigated in more detail, informed by the whole system modelling approach developed for the macro-scale analysis.

Bio-feedstocks

This case study will investigate the use of various bio-feedstocks (e.g. cereals, sugar, woody crops, waste) to produce chemicals. One of the questions that will be addressed from the carbon footprint and value added points of view is whether biorefineries should be geared toward producing platform chemicals that are precursors to high value added chemicals, or to producing raw materials that could be a starting feedstock for existing refineries or chemical plants. The case study will cover the whole supply chains as far as possible, from growing or obtaining the biomass through its processing to producing chemicals.

Biofuels

This case study will investigate the supply chains associated with both bio-diesel and bio-ethanol, including different feedstocks and production routes. The case study will also include consideration of advanced biofuels, such as bio-butanol, which has several processing and handling advantages over ethanol and which is expected to come to the market in the near future as a gasoline bio-component. The use of biofuels in the other three supply chains addressed here will also be investigated

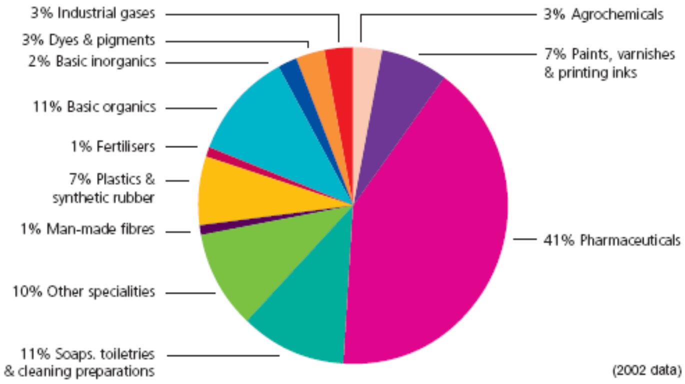
Further detail on the case studies is provided below.

Case study: Chemicals and Related Products

Background

The UK chemical industry manufactures nearly 50,000 of different products on about 4,000 sites across the country (Action Energy, 2005). It is the UK's top manufacturing export earner, with an annual trade surplus of nearly £5 billion on sales of £33 billion, of which £29 billion was accounted for by exports in 2002 (CIA, 2003). Value added in the chemical industry by sub-sector is shown in Figure 1. In 2003, total emissions of CO_2 eq. were 4.96 M tonnes (DEFRA, 2007), the majority of which came from CO_2 from energy use with the rest contributed by the emissions of N_2O and CH_4 in various manufacturing processes.

Figure 1: Value added by sub-sector



Aim of the case study

The main aim of this case study is to develop a life cycle methodology and a decision-support tool to enable robust estimations of carbon inventories along the complete supply chain and identification of low-carbon options for the sector.

Specific objectives and outputs from the case study

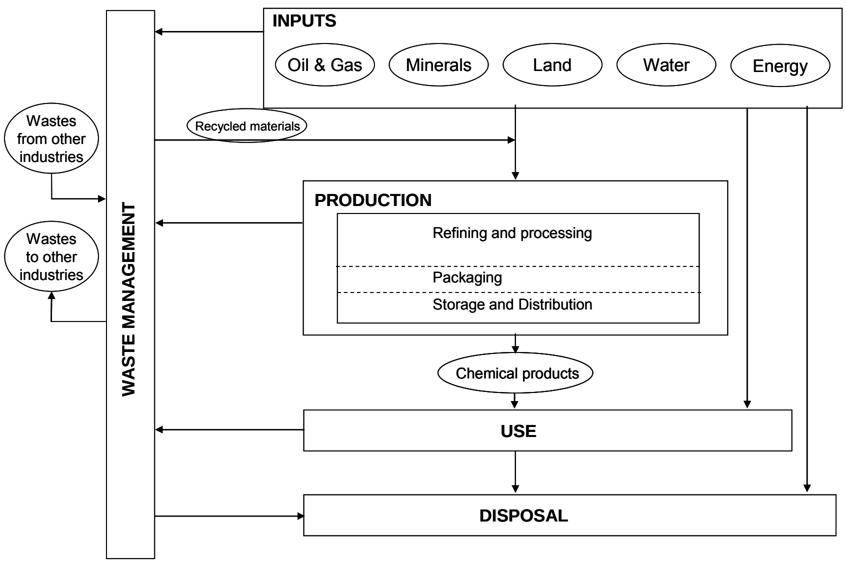
The following specific objectives and outputs from the case study have been identified in collaboration with the industry partners:

- estimation of carbon inventories along the complete supply chain;
- identification of ‘hot spots’ in the supply chain;
- systems optimisation and identification of most efficient ways for reducing carbon intensity, including marginal and discrete changes;
- development of strategic and practical tools that business and policy makers can use for strategic positioning and to bring about significant changes; and
- identification of best ways to disseminate the outputs of the case study for different types of audience (industry, policy makers, suppliers, consumers).

Case study scope

Wherever possible and meaningful, the scope will be from ‘cradle to grave’, encompassing the whole life cycle, from the extraction of raw materials through production of chemicals, their transport and use to waste management (see Figure 2).

Figure 2 Chemicals supply chain



Methodology

Chemical products can be classified in a number of ways but for the purposes of this work, the classification used by the UK National Statistics Office for bulk chemicals will be used, i.e.: basic organic; basic inorganic; fertilisers and nitrogen compounds; industrial gasses, plastics; and synthetic rubbers. A whole systems approach will be used to develop a life cycle methodology for estimation of carbon inventories of the industry as a whole as well as of individual chemicals and related products. The preliminary results for the life cycle emission of carbon equivalent for some chemicals are shown in Figure 3. The work will also include calculation of value added along the supply chain and comparisons with carbon added. Figure 4 shows some preliminary results of that work.

Figure 3 Carbon footprint of some chemicals

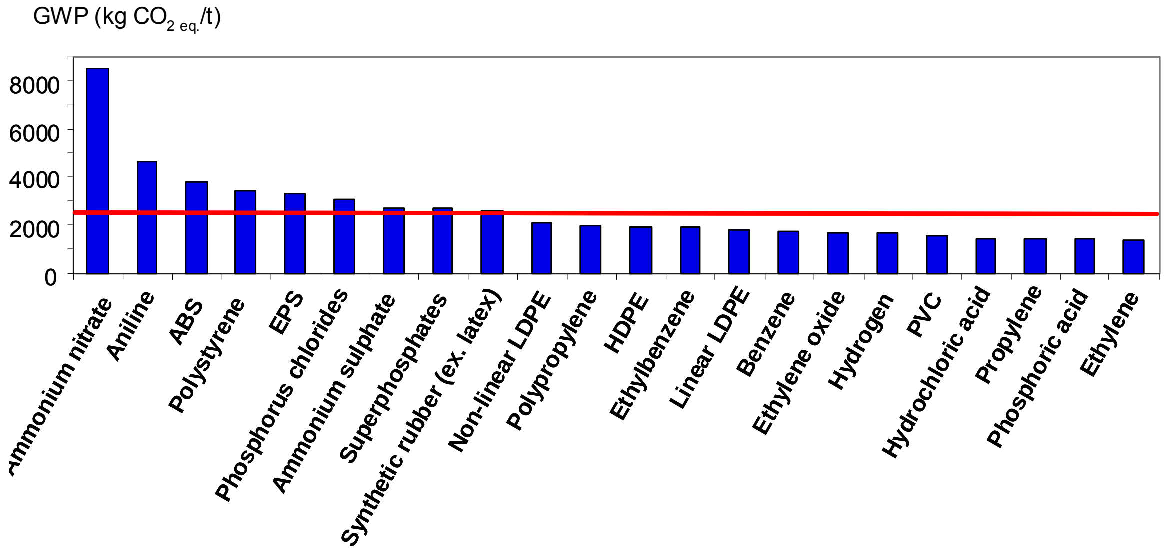
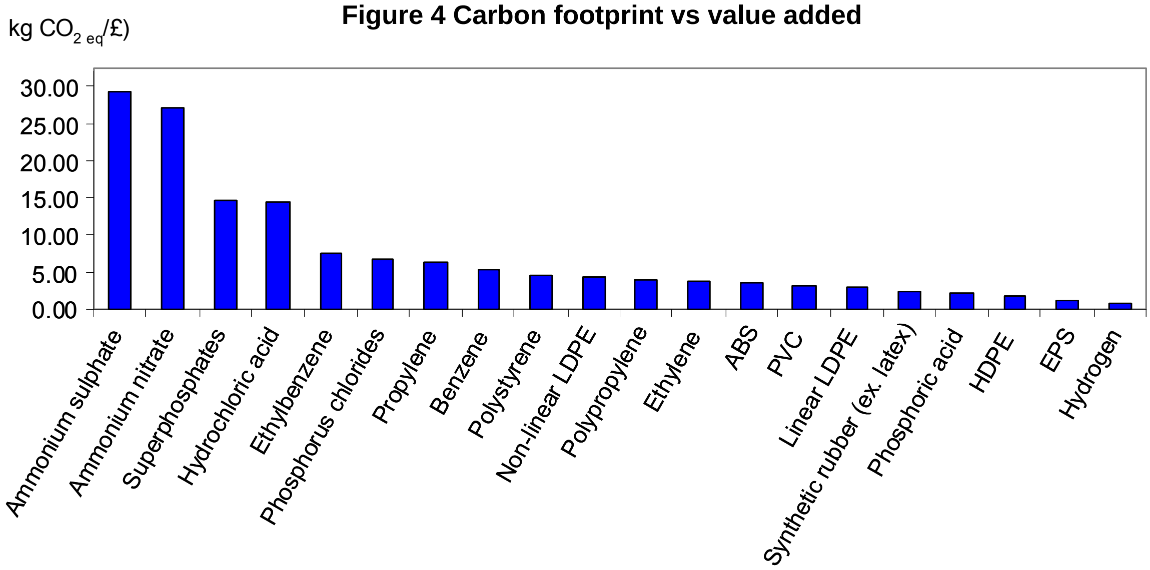


Figure 4 Carbon footprint vs value added



Taking into account the preliminary estimates of carbon equivalent emissions, production volumes and value added, possible chemicals to be studied in more detail include:

- ethylene and derivates (largest total carbon equivalent emissions);
- benzene and derivates, including synthetic rubbers (relatively large per-tonne carbon equivalent emissions and relatively high production volume;
- polyvinyl chloride (largest-volume plastic in the UK); and
- steel products (interesting methodological issues, e.g. recycling and allocation).

References

Action Energy (2005). Introduction to the Chemicals Industry. *Action Energy (Carbon Trust).* *http://www.actionenergy.org.uk/energywizard/sector_information.asp*

CIA (2003). Industry Facts. *www.cia.org.uk/newsite/industry_glance/facts.htm*

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Case study: Food and Drink

Background

The food and drink industry is an important sector for the UK economy, providing employment for 455,000 people (1.7% of total employment) in nearly 8,000 businesses. As shown in Figure 5, the food and drink supply chain consists of:

- agricultural activities;
- food and drink production;
- food and drink use; and
- waste management.

With the annual emissions of 45.8 Mt CO_2 eq., agriculture contributes approximately 7% of the UK's GHG emissions (DEFRA, 2005). The main sources of $CO_{2\ eq.}$ are enteric fermentation (CH_4), manure management (N_2O) and agricultural soils (N_2O). Production of food and drink is the third largest industrial user of energy (FDA, 2002), with the main sources of CO_2 being processing, refrigeration and transport.

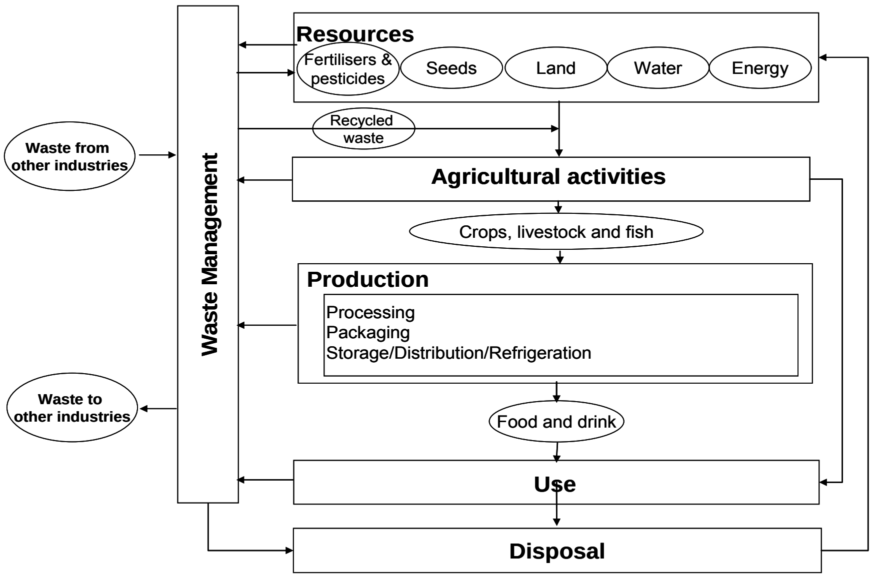

Figure 5 Food and drinks supply chain

For example, refrigeration in supermarkets contributes around 5% of the UK's energy consumption (Safeway, 2004) and the UK food transport accounts for 3.5% of UK total CO_2 emissions (Garnett, 2003). Other sources of CO_2 eq. from this part of the supply chain, notably non-methane VOCs, are whisky maturation, bread making, food heating and processing of oils and fats; refrigeration is also a major source of CFCs (DEFRA, 2005). Consumption of food and drink is also responsible for significant use of energy and the related emissions of CO_2 from food cooking, heating and refrigeration. Finally, all parts of the supply chain generate other emissions to air and water as well as solid waste. The latter includes in particular organic residues and packaging waste (generating approximately 10% of the country's industrial and commercial waste).

Aim of the case study

The main aim of this case study is to develop a life cycle methodology and a decision-support tool to enable robust estimations of carbon equivalent emissions along the complete supply chain and identification of low-carbon options for the sector.

Specific objectives and outputs from the case study

The following specific objectives and outputs from the case study have been identified in collaboration with the industry partners:

- estimation of carbon equivalent emissions along the complete supply chain;
- identification of 'hot spots' in the supply chain;
- systems optimisation and identification of most efficient ways for reduction of carbon equivalent emissions, including marginal and discrete changes;
- development of strategic and practical tools that business and policy makers can use for strategic positioning and to bring about significant changes; and
- identification of best ways to disseminate the outputs of the case study for different types of audience (industry, policy makers, suppliers, consumers).

Case study scope
Wherever possible and meaningful, the scope will be from 'cradle to grave', encompassing the whole life cycle, from the extraction of raw materials through agricultural activities, production, use, transport and waste management (see Figure 5).

Methodology
Realisation of a low carbon economy in this sector is highly dependent upon competing priorities – such as economies of scale between globalised and localised delivery systems, consumer preferences for foodstuffs, and alternative policies regarding land use. Food and drink systems present a number of challenges for measuring carbon inventories due to the interconnected nature of these systems – leading to the methodological issues concerning system boundary definitions and allocation between co-products. For example, many agricultural systems produce co-products (e.g. oil and meal from rapeseed; milk and meat from cows) as do many food and drink processing activities (e.g. white flour and bran from wheat grain; curds and whey from milk; CO_2 and cattle feed from alcoholic spirits production). Therefore the results of carbon "footprinting" for such systems can depend critically on methodology, and it is particularly relevant to use a whole system modelling approach.

For this case study, a macro-scale analysis of the food and drink sector in the UK will be undertaken. It will take national food and drink consumption, production, imports and export statistics as a starting point. Data will be collated on national use of agricultural inputs such as pesticides and fertilisers, and cross-referenced with published recommendations for different crop types. This information will be augmented by standard LCA data on production and use of fertilisers, pesticides, agricultural machinery and energy requirements for processing foodstuffs and transportation; carbon storage in organic matter will also be included in the analysis. This will facilitate carbon modelling of the whole life cycle of different categories of food and drink products, revealing hot spots at the national scale. Subsequently, specific "disruptive", step changes in technologies that could be introduced to reduce carbon intensity of food and drink supply chain will be identified and investigated in more detail, informed by the whole system modelling approach developed for the macro-scale analysis.

With the specific reference to the food systems, the study will focus on full meals rather than on single food items. In order to address the general trend towards an increased consumption of ready-made-meals, a comparison between meals made from fresh produce and ready-made meals will be conducted. For these purposes, the following types of meals with respect to the ingredients will be considered: classical, organic, local, imported and vegetarian. Several typical meals will be chosen for study, including typical breakfast, lunch and dinner, as well as seasonal meals such as Christmas lunch. The case study will consider various food manufacturing options, different cooking methods, transportation and packaging.

References
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