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Abstract: This project discovers the sources of carbon emissions in the food production, the methods for measuring them and aggregating this data to determine the climate impact of a retail food item. Through the use of the EPCIS standard and a software architecture for collecting, cross-referencing and calculating the emission of discrete value chain stages, a calculation interface is designed and a prototype implemented.

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1. Introduction

Sustainable consumption has emerged as one of main concerns for goods producers and the wider population alike. One of the most often discussed areas of industry in terms of sustainability and carbon emission is food production and consumption. Goal Twelve of the United Nations Sustainable Development Goals (UN SDGs) focuses on how the natural environment is dependent on responsible consumption and production, while Goal Two specifically addresses sustainable agriculture as an instrument for food security and improved global nutrition[1][2]. The core sustainability issues are the impact of agricultural practices on the environment, the transportation of food from where it is grown to intermediate processing facilities, and ultimately to where people consume it.

GS1[3] is a standards organisation dedicated to digital transformation of supply chains globally, with the aim of improving product safety and consumer experiences. They have more than two million members and are partners of institutions such as the UN[4] and the International Standards Organisation[5]. While their GTIN[6] and EAN/UPC[7] standards are well known and used ubiquitously, they maintain a suite of other, compatible standards, including the Electronic Product Code Information Systems (EPCIS)[8].

EPCIS is a standard used to combine information from diverse sources across industries, for example, farms, warehouses and distribution facilities, to understand the journey an item or collection of products undertakes between production and delivery to the end customer. This information can then be used to analyse business processes within and between companies, and, perhaps more importantly, increase the transparency of production to inform business partners and consumers. While this standard is employed in other industries, for example pharmaceutical supply chains, it is not widely used as a part of the business data infrastructure of food production in Denmark.

A defining property of EPCIS is the possibility of extending it to include more custom attributes of objects or business processes, including data, collected and submitted by the actors within a supply chain, that can be used to infer the amount of emissions. During the course of this project, based upon an analysis of food product supply chains, an extension of EPCIS will be designed to carry carbon emissions data, and a prototype of a system for calculating the emissions impact of food items at the point of purchase will be implemented. The emissions data could then be used to inform the consumer about the emissions impact of the food product.

1.1. Motivation

The main reasons for choosing to conduct this project are the interest of companies and consumers to reduce their collective environmental impact. The specific topic was inspired by the GS1 Forum on the opportunities and challenges of climate labelling of food items[9]. On the day of the forum, GS1 members, including Coop[10], Salling Group[11] and Orkla[12], presented their vision on their role in the sustainability of the food industry and the particular challenge of meaningfully comparing the climate impact of substitutable goods.

The optimum strategy for the most sustainable food does not necessarily align with consumer habits, therefore, retail organisations have a responsibility to reduce the impact of the products moving through their supply chain, and inform the consumer of the most sustainable choice within a product category. A naive example of this is the difference between the emissions of purchasing a tomato grown in Spain and a tomato grown in Denmark. The Spanish tomato is grown outdoors while in season, but there is an environmental cost of transporting it to Denmark. A tomato grown locally has to travel less to reach the consumer, but the limitations of the climate and length of season mean that it is grown in an artificially climate controlled greenhouse. Systems that could display the resulting emissions of these differences could allow for more informed purchasing decisions throughout the year. This becomes even more important when processed food is considered, as the ingredients may be from disparate sources and change at different times of the year and there is an added emission cost in processing and packaging.

The industry appears to be open towards solutions that help to identify inefficiencies and signal their contribution to sustainability, as it has become an attractive marketing strategy, while questions about transparency and avoiding 'greenwashing' remain. 'Dansk Industri' are also promoting the allocation of government resources for developing a national database of food product climate footprint, available to companies, consumers and other interested parties[13], as well as a 'climate label', which would serve as an indicator of whether a company is more sustainable than the average enterprise[14].

Ultimately, a system that accounts for resource consumption, be it based on EPCIS or other standards, is a stepping stone towards a more granular and individual understanding of the impact of our own consumption habits on the environment. The key in this process is understanding which parts of the food processing supply chain, including growing, harvest, transportation, packaging and storage, are the primary contributors of carbon emissions.

The aim of the project is designing and implementing an application that calculates the aggregate carbon impact of food items from production to retail point-of-sale. The data required for this calculation is carried using an extension of EPCIS, a standard for information transfer and visibility in a supply chain. The principal components of the calculation are the energy consumed during the growing process, energy and materials used in processing and packaging and the emissions of vehicles used in transportation of raw and processed food products. Final calculated figures could then be used by companies along the value chain to identify possible avenues of emissions reduction or used to better inform the consumer about how the meals they consume affect the environment and show the relative impact of their choices in a meaningful way.

2. Problem formulation

On the basis of the introduction and motivation and the intended aim of the project, the problem formulation states:

How can the EPCIS standard be used to calculate the environmental impact of consumer products?

- What are the principal, measurable sources of carbon emissions in food production?
- How can EPCIS be used to capture and communicate food emission data?
- How to calculate the carbon impact of a unit of food?

2.1 Delimitations

During the project process it is necessary to define a scope for the exploration of the problem that is comprehensive and also achievable during the project period. While a general system for covering all and any retail products could be designed, for the purposes of this project and the necessity to create a prototype, only a narrow slice of the retail market will be considered - food products. The main focus is carbon emission sources, during growing, processing, transportation and storage of food products. This selection is based on the consideration in the methodologies of other life cycle analyses (LCAs) for food production. This is not the complete picture of all the emissions within a supply chain, only the parts that can reliably be measured and are resilient to variability, meaning the emissions calculation can only account for predictable steps in a product journey.

The emissions calculations in the design and implementation of the prototype will reflect these areas of interest. This approach matches existing literature in presuming the emissions contained within this system boundary account for the majority of the impact of the final product. The choice of focussing on solely carbon dioxide is based on its significance in the conversation about climate change and also its use as the benchmark for other greenhouse gases in the form of CO_2-equivalent, allowing a broader understanding of emissions in the relevant cases.

The focus on EPCIS is based upon its applicability to diverse product value chains for data transfer and visibility for both physical and digital products and its interoperability with widespread barcode standards. This standard itself has no native emissions, carbon accounting or other environmental monitoring system and the designed system will rely on some of EPCIS design principles. The underlying calculations, and the results thereof, are based on literature and design decisions, thus would be the same regardless of the usage of EPCIS or any other preexisting standard.

The project is an attempt to combine an analytical approach through understanding of how food production life cycles have been discussed in terms of greenhouse gas emissions, and a practical, engineering solution based approach to solve the problems discovered during the analytical phase. The factors that are ignored in the analysis and calculation are everything that is not possible to be directly controlled by the manufacturers or members of the value chain, for example, the wasted emissions of produce being discarded by retailers after the expiration of the best 'before date' or wasted by the consumer after purchase. Another ignored factor is the impact of packaging waste, whether it is recycled or not.

The prototype developed as the outcome of this project, uses simulated data due to the unavailability of real life data, as it is not currently collectd in the manner required for this emissions calculations interface to function. The locations and timing of processes are inferred from the information the manufacturers already provide on labelling. Data sources for calculations depend whether distinct data for the stages of a particular product are available or simulatable. Distance emissions for the sample products where the production locations are known can be inferred directly. Electricity consumption factors in farming, processing and storage are based on preexisting research and combined with publicly available data about the electricity grid. The masses of products and pieces and packaging have been found on the producers' websites or measured directly.

If additional or different factors would be considered in the emissions calculation, the figures would inevitably be different. A part of the challenge in communicating the importance of emissions impact is transparency on how a number was arrived at and show consumers and business partners what has and has not been considered.

3. Methodology

As the goal of this project is to develop a novel software solution based upon existing standards and literature, the process model reflects that. No system can be designed without understanding the surrounding environment and what is practically possible. The project process, while parts of it were conducted in parallel, can be separated into several distinct stages, shown in the diagram below. The process begins with a stage of learning, followed by evaluating the discoveries and creation of the system, while the process concludes with discussion of what has been achieved.

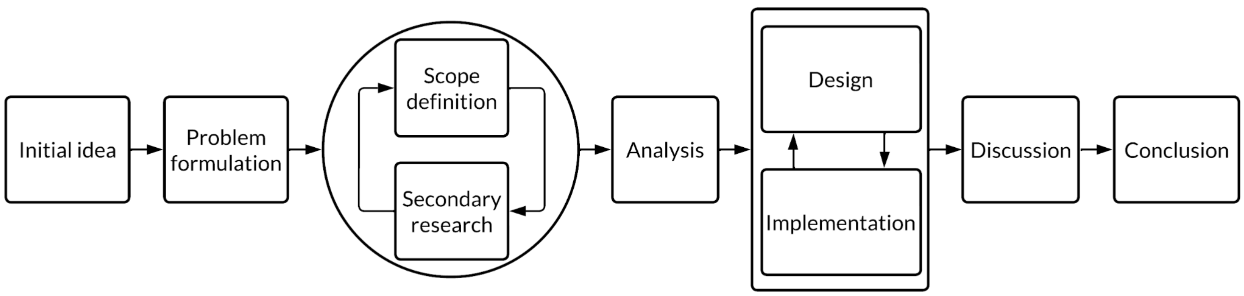

Figure 3.1 Process model diagram

The initial idea of aggregating emissions data along a value chain and combining it into a single figure was inspired by and brainstormed with GS1, as they are interested in promoting the use of their standards for sustainability in manufacturing and agriculture among other industries. The learning process here involved understanding the viewpoint and current efforts of retail chains, via their corporate social responsibility statements with focus on sustainability. This was done with the intent of finding out whether the claims they make can be connected to reality and whether the proposed solution might improve the current state of affairs. Another reason is that retail chains have an influence on the upstream members of their supply chains and thus might have an interest in more precise guidelines for their operations.

The problem is formulated based on the initial idea and the constraints of a master thesis project, thus it contains exploration of the core issue, methods of calculation and a proposal of a design for the corresponding system. The sub questions are intended to reflect knowledge discovery through the report, with each contributing to answering the primary question. The measurable emissions sources will be found in the Secondary Research section, the way EPCIS can aid in calculating emissions along a supply chain will be explored in the Secondary Research and Design sections, and the specific calculation formulas and methods will be discussed in the Design and Implementation sections. This corpus of knowledge and understanding will be the main source of responding to the main problem question.

The longest and, in a way, the most crucial stage, is iterative information collection from diverse sources with the combined goal of more finely defining the scope of the project and gathering the concrete information that will subsequently inform the rest of the project. Information collection entails a State of The Art section that contains a breakdown of the EPCIS standard, a review of life cycle analyses in agriculture and a subset of European Union rules on food labelling. These topic choices are based directly on the problem subquestions: the EPCIS standard serving as the medium for data aggregation and transfer needs to be understood to be implemented, past LCAs show what sources of carbon emission researchers have considered in the past, and food labelling has to be investigated to design an additional label for the emissions of a unit of food. Literature review was mostly informed by the ideas and constraints found within the State of the Art section, guiding towards exploring previous attempts of quantifying the emissions of retail products. Then a more precise look at how emission can be calculated in the major steps of food production - agriculture, transportation, packaging and storage. The section is rounded out by supporting information on how to present information regarding climate change in a meaningful manner.

Articles for the aforementioned two sections were found using a combination of the AAU Library search engine and Google Scholar. The kinds of search terms used were 'food emissions', 'agriculture life cycle', 'retail carbon emissions', 'food global warming potential', 'food labelling', 'emissions labelling', 'farming environmental impact', 'farming sustainability', 'climate change communication', 'fuel indirect emissions', 'packaging emissions'. 'refrigeration global warming potential', 'plastic manufacturing emissions', '' and many variations thereof. When an article references a previous analysis, it was often a good starting point in attempting to find previously calculated values, along with methodologies and search terms that can lead to other relevant search terms. In comparative studies, the researchers will often present reliable data sources of evaluating products and materials, and eventually their own contribution of usable figures.

Once a satisfactory diversity of data and information was gathered, the process of Analysis could begin. The section follows the rough structure of the Secondary Research section, and critiques the information with the goal of finding requirements for a software system. The usefulness and inspiration from EPCIS is used as the backbone for the software architecture, the broader learnings from LCA studies are used to formulate the approach with which the software will calculate the emissions of a single product. At this point, the labelling and nutritional aspect is summarised but does not contribute to the design of the proposed system in any way. The result of the analysis is a usage scenario from which the general requirements for the system, including what kinds of data needs to be gathered at each section of the value chain, what should be the factors and algorithms of calculation at each stage and how this information is then aggregated for the benefit of the consumer and, potentially, the producers, is drawn.

The Design section is designed to give a functional overview of the software components and their interactions. Requirements, use cases and data flows, generate an overall system architecture which serves as the guideline for initial Implementation. The system architecture is then separated into modules of common functionality and purpose and discussed in detail. The Implementation stage takes the design and creates a tangible software prototype of an emissions calculation interface using the EPCIS standard, data from preexisting LCA studies, along with other technologies determined to be fitting during the analysis and design stages. The design and implementation processes are intertwined and iterative in terms of that the initial implementation reveals limitations that require a significant adjustment of the design.

The Implementation section gives an even more detailed walkthrough of the flows of data in and out of the calculation interface, painting towards the unique considerations for each of the event scenarios. The formulas, based on previous design and discussion are included where relevant. It also contains the collected reference values for use in calculations and a discussion on implementation options and choices for the proof-of-concept system

The concluding sections are used to critique the validity of the methodological approach, the conclusions made and how the designed system could be improved or applied in different domains. The conclusion is used to answer the problem formulation and show opportunities for further research and development.

The entire project period is roughly eighteen weeks, and while most of the work was done concurrently, with related sections often being written at the same time, the time spent on the report can generally be divided into these overlapping stages - Idea and Problem formulation - two weeks, Secondary research twelve to ten, Analysis - ten to eight, Design - eight to six, Implementation - five, Discussion - eight to six and the Conclusion - around six weeks. This timeline is visualised in the figure below. This distribution of tasks reflects the nature of the problem formulation, as it requires an extended period of information gathering that then contributes to an intense design and generation process, eventually leading to a reflection upon the work done.

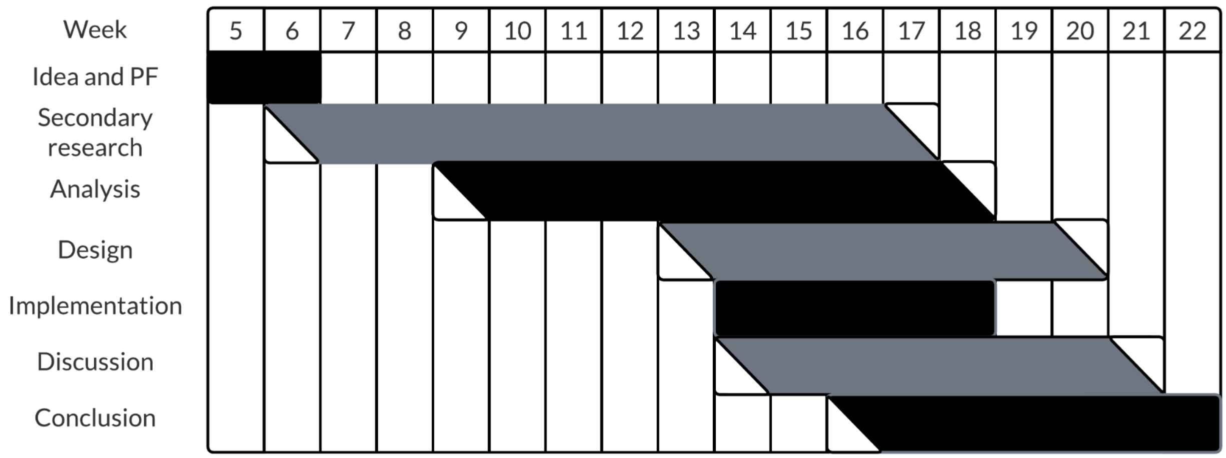

Figure 3.2 Timeline of major report sections

4. Secondary research

The secondary research section is divided into two subsections. The State of the Art deals with the known ideas from the Problem Formulation sub questions and lead to explore the standard that will be part of the consideration when designing the software prototype, an attempt to find useful avenues of interest in previous attempts to calculate the emissions burden of agriculture and the regulations and rules regarding food labelling. The information discovered then leads into a more specific Literature review. This review looks at specific attempts conceptually similar to the proposed system, how emissions may be calculated or estimated in specific parts of the value chain and how emissions data may be integrated within existing ideas of patterns of food labelling. The information discovered in this section is the major kernel for the subsequent Analysis section.

4.1 State of the Art

4.1.1 Electronic Product Code Information Services (EPCIS)

The purpose of the Electronic Product Code Information Services (EPCIS)[15] standard is to enable the creation and sharing of event data along a supply chain. Event data contains information about an object (or collection of objects), the nature of the action, for example, production or delivery, and by default includes the time and location of the event. Other, custom attributes of either the object or the event can be added by the organisations involved at their discretion. This data can then be used to examine the movement and status of objects, both physical and digital, in a business context. Usually this standard is used in situations where some physical object is handled, processed or transported within or between organisations. The benefit of EPCIS is its potential to be applied both within and between organisations, in cases when internal data management processes use a variety of incompatible applications and standards, and is independent of data carriers used in the supply chain. Objects can be trade items (products), pallets and containers, documents and other business assets. Digital media, such as music files and e-books can also be considered objects. Objects can be defined at either the class or instance level.

The standard's current version, EPCIS 1.2 has been in effect since September 2016. As of February 2022, the 2.0 release[16] has completed its public review and events phase, with no set deadline for its ratification. The main differences between the future and current standard are the addition of an additional 'How?' dimension, primarily for including sensor data, for example the temperature and humidity and object is being stored in and the move towards a REST design paradigm and JSON encoding, moving away from the current XML based implementation guidelines.

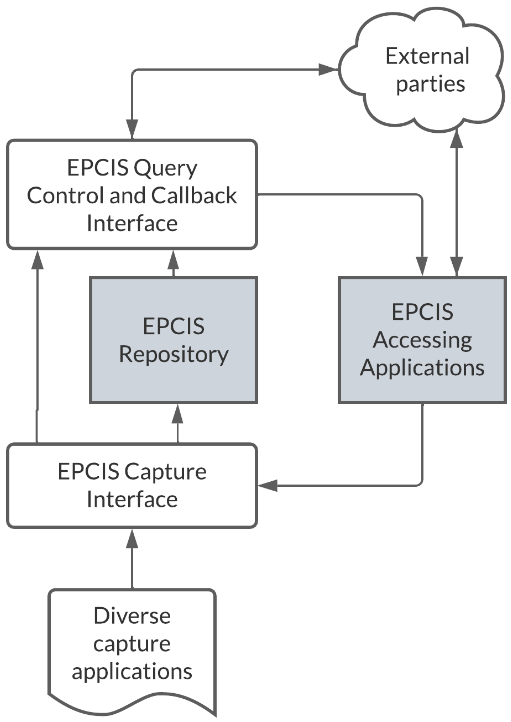

Figure 4.1.1.1 Simplified EPCIS system diagram. Adapted from[15, p.11]

EPCIS is expressed as a series of open and standardised interfaces for event data capture and querying, data standards and service operations for communicating with these interfaces, with these relationships shown in a simplified form in Figure 4.1.1.1 above. The interfaces are designed to connect capturing applications with visibility applications. The precise implementation of service operations and databases is up to the discretion of the developers.

Acquisition and computation of data is independent of the standard, requiring custom design data submission, collection and aggregation software when used in practice. EPCIS deals with a combination of historical and current data (Capture layer only deals with real-time data, meaning data committed to an EPCIS Repository must be synchronous in time with the physical action of the event). It can place data in a context beyond data carriers, relative to the physical world and business processes. It combines Identification data with an understanding of the business context in which this data was obtained. EPCIS events need not be linked to a data carrier observation, and can be generated by software independently.

It is designed to be used along with GS1 Core Business Vocabulary, which defines the data values used to populate EPCIS data structures, reducing the variation of how common business processes can be expressed. Persistent databases can be used but are not a requirement for direct communication between applications.

EPCIS fits within the information sharing standards of the GS1 system architecture, with the other main roles being identification of entities and capturing of data associated with them. The other standards in the Share layer are GDSN - master data of descriptive attributes of real world entities via GS1 identification keys, and GS1 XML EANCOM for transaction data, such as placing an order or delivery of a product. Master data for a given entity is mostly static, while transaction and visibility event data is continually created as more business is transacted in a supply chain.

The EPCIS Capture interface is used for delivery of EPCIS events from capturing applications to real time data consumers, including Repositories and Accessing Applications (AA). EPCIS Query Control Interface defines how AAs and trading partners can access EPCIS events after capture, usually through an interaction with an EPCIS repository. It operates in two modes: synchronous - response is delivered immediately after a client has sent a request; asynchronous - a client establishes a subscription to a periodic query. The asynchronous mode uses EPCIS Query Callback interface AAs are responsible for carrying out the business processes aided by EPC related data. The application being developed at the core of this project is an Accessing Application.

EPCIS specification principles are based upon a rich set of data types and access techniques, in contrast to the Capture layer. This also enables its extensibility to accommodate diverse business processes. The EPCIS framework is layered, with data structure and semantics separated from the details of data access services and binding to specific interfaces. This allows maintenance of a stable, common data meaning, even if details change across enterprises and time. The core set of data types and operations are modular and can be extended for specific industry or application purposes. Part of the system design of this project is an extension to the EPCIS specification.

The standard is created using a layered structure. Abstract Data Model Layer specifies the generic structure of EPCIS data, and general requirements for creating data definitions within the Data Definition Layer, and is not extensible. The Data Definition Layer specifies the abstract structure and semantics of the data exchanged using EPCIS. A Core Event Types Module is defined within the specification. The interfaces EPCIS clients use to interact are defined in the Service Layer. The aforementioned Capture and Query interfaces are defined in this layer. New data definitions can be created by subclassing the Core Event, implementing existing fields and adding fields required by a specific area of application, and used in contexts expecting an instance of the parent class.

In general, EPCIS is used to handle two kinds of data - event data and master data. Event data is created by business processes over time and gathered via the Capture

Interface. Master data provides the context to interpret associated event data. A system that extends and uses the Abstract Data Model must be able to produce and handle; Event Data - a set of related events, Events - data structures consisting of the Event Type, and one or more Event Fields, an Event Type - a namespace qualified name indicating which Event structure, defined in the Data Definition Layer, Event Fields - named fields within an event, Master data - Vocabularies with master data attributes associated with Vocabulary elements, Vocabularies - named sets of identifiers. The name of a Vocabulary can be used as a type name for an event field. Identifiers within a Vocabulary are Vocabulary Elements. It represents alternative values that can appear as values in specific Event Fields, Vocabulary Element - an identifier that names one of the alternatives specified in a Vocabulary. The value of an Event Field may be a Vocabulary Element . It is represented using a URI, and can have associated master data attributes, Master data attributes - a set of name-value pairs associated with a Vocabulary Element. Name must be a qualified name and the value can be of arbitrary type. A special attribute may be a list of children's vocabulary elements from the same vocabulary. EPCIS events can not be deleted or modified, but subsequent events may be used to change the effect of a previous event.

The EPCIS environment has a number of predefined and recommended constraints with the intention of creating a certain kind of customer lock in by creating dependencies by using the suite of GS1 standards. This approach has both benefits and drawbacks, with the main benefit being the cross-enterprise and cross-border interoperability with businesses that also share the GS1 infrastructure. Another benefit of EPCIS is that it is applicable to any industry that produces or handles physical or digital items. Effectively, EPCIS is a broad framework that allows for the creation of domain specific applications upon this base. A drawback may be the level of complexity for the initial implementation and the potential cost of implementation that may discourage smaller producers from taking advantage of such emissions accounting solutions, therefore an abstracted implementation with exposed simple interfaces, compatible with whatever software already in use, could reduce these costs and friction.

In a further section of the report, a system design that is capable of extending the Core Event Type and implementing an additional Vocabulary will be explored. The system will also use an implementation of Capture and Query Interfaces along with a repository as a part of the system context. The emissions calculation interface. Through the aforementioned capabilities, it becomes an Accessing Application that can create and submit new events to a Repository and give facilities access to existing relevant events via the Visibility interface, as a prerequisite of creating new events, among other actions that may be necessary at different stages of the supply chain.

4.1.2 Agricultural life cycle assessment studies

The agricultural life cycle is complex and varied depending on the particular products and location around the world, therefore the question of which sections of the value chain are the most emissive is a way to identify possible areas for improvement. The purpose of an life cycle assessment (LCA) is to understand the possible impacts of a product on the environment or "manufacturing products with the goal of protecting the environment, conserving resources, encouraging economic progress, keeping in mind social concerns, and the need for sustainability while optimising the product life cycle and minimising pollution and waste"[17]. Again, a life cycle consists of multiple stages that with the most comprehensive being cradle-to-grave, the process from raw material extraction to disposal. Several, more granular LCA boundaries exist, used for scoping a particular, more controllable part of the life cycle. A challenge for food products is that the manufacturers and distributors have limited control of how retail customers handle food products. There is no way of ensuring minimal waste, the purchased food may never be consumed and thrown out, thus the emissions that were created to produce an item having no utility whatsoever. Another contentious point is how food waste is recycled, if at all, in any particular region. Biological waste may end up being composted, burnt or left to decompose in a landfill with each of these methods having a different emissions impact. Therefore, food produce LCA investigations are mostly focused on cradle-to-gate parts of the life cycle - from raw materials extraction or production to the moment the products leave the hands of the distributors. Nevertheless, the first article discussed in this section deals with the emissions attributable to food loss along the entire chain, including at and after the point of consumption.

In the article 'What contributes more to life-cycle greenhouse gas emissions of farm produce: Production, transportation, packaging, or food loss?[18], the authors are motivated to investigate the emissions factors from the perspective of food loss along the value chain, reportedly 34% of food related GHG emissions in the US[19], while packaging is responsible for 20% of emissions for fruits and vegetables[20]. Their estimation model considers the aforementioned stages of the food production cycle - production, packaging, transport, storage and waste. Their criticism of previous LCA studies is that they often do not consider the role of food loss and packaging, or investigate insignificant regions or markets of production, thus their focus lies in products where the US is a major producer.

They performed case studies for three fresh products in particular - cherries, plums and onions. The formula used for calculating total emissions is the sum of cradle-to-grave emissions without food loss and the emissions caused by food loss, per unit of consumed food. The emissions without food loss are a sum of food production, food packaging, transportation, refrigeration in transit, retail and home and the emissions of packaging waste management.

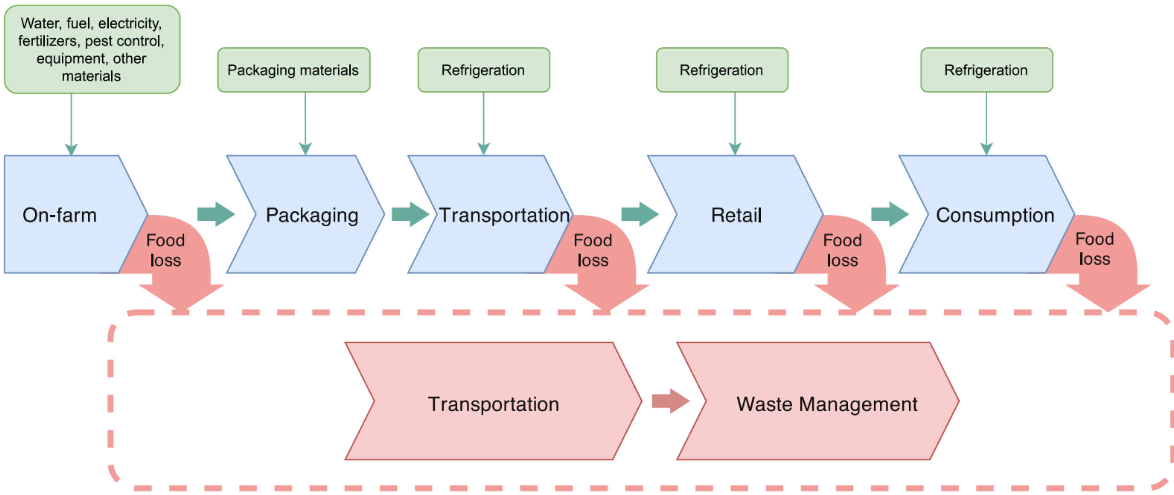

Fig. 1. Flow diagram of assessed food cycle and food loss stages and processes in the study.

Fig. 4.1.2.1 Sample flow diagram and measurements within a food production supply chain[18, p.3]

The conclusions of this paper are that food loss along the chain, especially at the consumer stage is a major GHG emission contributor. For the products in the study, the emission proportions attributable to food loss are between 19% and 61%, transportation 14-46%, packaging 11-31%, with production ranging between 7.7% and 30%. Food loss values are higher for fresh produce, as is expected. Packaging-wise, not choosing to use in-store packaging for onions and plums, can reduce GHG emissions by 10% and 4% respectively. They also recommend switching from polyethylene (PE) packaging to polylactic acid (PLA) materials for an added reduction.

In terms of the design of an emissions calculation interface, the findings in this paper can be used to allocate CO_2 emissions for products where there is incomplete knowledge of the chain. For example, only the mass of the product and the average Global Warming Potential (GWP) value for the kind of product are known, the emissions contribution of each stage can be estimated. Additionally, this article contains multiplication factors for road transportation, refrigeration and select types of packaging, all of them can be used in calculations where the timings of transport and refrigeration and the separate mass of packaging are known.

For any comprehensive greenhouse gas emission calculation measurements must be taken during the entire process. While it is possible to allocate electricity used in growing, or fuel used to transport certain crops from field to warehouse, the inherent emissions of growing the produce itself is a much more daunting task. In lieu of introducing measurement equipment or strict carbon accounting in each farm, maybe possible in highly industrial settings, existing literature must be used as reference in calculations instead.

‘Systematic review of greenhouse gas emissions for different fresh food categories’[21] is a literature review, combining data from diverse LCA studies, 369 studies published between 2000 and 2015, and is intended to be a reference for informing sustainable dietary choices, based on GWP - the potency of greenhouse gases in terms of its longevity in the atmosphere[22] and compared based on a reference unit of kilograms of CO_2 equivalent per kilogram of product (kg CO_2-eq/kg). The authors also present barriers to comparing food impacts, for example, variation in methodological choices, functional units and differences in time and region; no single review covers the entire range of foods available to consumers, narrowing data availability and quality, and lack of public domain databases accessible to consumers.

The factors shared among the explored studies include, analysis of input chemicals and fertilisers, fuel and energy for machinery and tending fields, processing, harvesting, along with transportation and refrigeration. Considered outputs were emissions from plants, animals and soil fertilisation. Plants grown in active greenhouses are considered separately, and for animals a kilogram of produce is a kilogram of bone free meat. Processes included in calculations for animal emissions include breeding, feed production, fertilisers, energy use for heating transport, processing and refrigeration. Wild fish emissions are mostly associated with fuel use and refrigeration. Importantly, calculations of the consumption stage, including travelling to retail locations, storage, cooking and food and packaging disposal are not included, nor are the resources for manufacturing associated infrastructure and equipment. 63% of the data was sourced from Europe, particularly the British Isles, Spain, France, Sweden and the Netherlands.

The collected results show a large disparity across food groups. When summarised, and sorted by median values, field grown vegetables (0.37 kg CO_2-eq/kg), field-grown fruit (0.42), cereals and pulses (not including rice) (0.50-0.51), tree nuts (1.20), fruit and vegetables grown in heated greenhouses (2.13), rice (2.55) with the highest value of any plant based crop. Products from non-ruminant livestock: eggs (3.46) fish (3.49), chicken (3.65), pork (5.77). Dairy products are also placed in this range. Ruminant livestock, lamb (25.58) and beef (26.61), are the largest emitters, due to their biology producing large amounts of methane, accounting for 55-92% of cattle greenhouse impact, but variability in impact depends on geographical location.

By the admission of the writers themselves, and the geographical location of studies the values are biassed towards agriculture in Europe thus application of these figures for production elsewhere in the world may not be accurate. Overall, the collected values are a rich resource for the emissions calculation interface. In a processed product the producer knows the masses of the constituent products, thus a combined GWP impact and the equivalent emissions can be calculated. This approach will be the most useful when the exact source or journey a product has taken is not known and estimations are necessary to fill in the gaps. The approach of using these collected values in the emissions calculation system will be discussed in the Analysis section.

4.1.3 European Union food labelling rules

The European Union maintains a variety of regulations and directives in regards to consumer protection and information, including the food production sector and the minimum requirements for food labelling. For a product to be eligible to be sold in the EU, producers are required to comply with rules on what information must be directly displayed on the label, for example, its name, ingredients and additives, allergen information, best before dates, quantity and with most relevance to this project, the nutrition declaration[23].

The emissions calculation interface will create an aggregate figure to give the consumer an idea of what is the environmental impact of their diet. The ability to display and contextualise this figure is a challenge in and of itself. The reason behind trying to understand the way nutrition is displayed on products ist that a way to approach the communication problem is to emulate the format in the context of emissions per weight of nutrient consumed. For example, the label should be able to show the difference of emissions between protein in beef and protein in beans. The purpose of nutrition declarations is that the consumer shall have a clear understanding of what is the value of the food they are eating, an idea that can be transferred to displaying the emissions of what people are consuming.

The current nutrition declaration rules[24] require a basic set of information - total energy value (in kilojoules and kilocalories), and the mass, in grams, of fat, sturates, carbohydrates, sugar, protein and salt. The formalised nutrition declaration can also include the amounts of mono-unsaturates, polyunsaturates, polyols, scratches, fibres and vitamins. It’s worth noting that there are products that don’t require specific nutrition declarations, including, but not limited to unprocessed and processed products consisting of a single ingredient, water, spices and food in packaging with its largest surface no larger than 25 cm^2. The possibility of using an adaptation of the format and rules of the nutrition declaration to display emissions data will be explored in an upcoming section of the report.

4. 2 Literature review

The following subsection summarises previous attempts at analysis, estimation and calculation of the carbon impact of food products, with the purpose of gathering information on how an algorithm for performing such a calculation should be designed. Additionally, methods for calculating the principal emission contributors in the food production supply chain are discovered, along with ideas of how to communicate emissions and their impact on climate.

4.2.1 Existing approaches

4.2.1.1 ISO Product carbon footprint standards

A set of ISO standards exists for measuring carbon footprint over the life of a product or service. This involves calculating emissions from the extraction of raw materials and manufacturing, through to emissions associated with the use and disposal of a particular product. The main standard is ISO 14067[25, p.53] - the standard to increase the transparency in reporting GHG emissions associated with the entire lifecycle of different products and services. ISO 14067 is aligned with previous ISO and exists to increase the comparability of product carbon footprints internationally. They include detailed guidance on requirements for public reporting and external communication, as well as additional guidance on verification and assurance of product carbon footprints. This standard is created with the intention of mitigating the negative effects of GHG emissions through the development of procedures for measuring, reporting and validating emissions for the promotion of sustainability across industries. The methods and approach described in this document is fitting for the use within organisations or parts of supply chains for GHG accounting - accurate tracking of the emitted and saved gases in a particular industrial process. For this project the most relevant sections on Life cycle inventory analysis that discuss the data collection, validation, creation of the system boundary and allocation of the GHG emissions[26, p.19].

GHG Protocol Product Lifecycle Accounting and reporting standard was launched in October 2011 after a three year development process. This standard builds upon existing ISO environmental guidance and aims to provide a general framework for accounting and reporting product lifecycle GHG emissions. Public reporting is required to claim conformance to the standard.

PAS 2050: PAS 2050 was developed by the British Standards Institute in response to a desire for a consistent method for assessing the life cycle GHG emissions associated with products or services. The standard is widely recognized, internationally applied and provides a consistent method for assessing product life cycle GHG emissions. The standard can be used on a wide range of product and service types including, goods and services, business-to-consumer, manufacturers, retailers and traders. PAS 2050 does not set requirements for product carbon footprint external communication. These standards give a set of guidelines on what is expected in an LCA system boundary and what the recommended practices are to ensure consistency over time and region and an attempt to unify methods of GHG reporting.

4.2.1.2 The Casino Carbon Index

The Casino Group[27] is a mass market retail organisation based in France that in 2008 designed and implemented the Casino Carbon Index (CCI) for their food production value chain. The CCI[28] takes into account the greenhouse gases emitted at five major stages: agricultural production, food processing, transportation from fields to warehouses, packaging (from extraction to recycling) and distribution from the warehouse to the consumer.

The baseline for the production calculation is based on existing Life Cycle Analysis (LCA) literature for growing, rearing and extraction of the raw products and then proportionally distributed upon each ingredient of the final product. It does not explicitly include the energy costs used in the growing process. The production process contribution is the greenhouse gases emitted by the energy consumption of the production plants manufacturing Casino products and LCA data from Bio Intelligence Service[29]. The transportation footprint between the field and processing facilities is the average distance travelled by all of the mass of a product's components, including raw ingredients, partially processed products and packaging. The emissions from the processing facility to Casino warehouses is calculated separately, using the average distance the finished product, including packaging, travels to the warehouse proportional to the delivered volume. The emission factors used in the calculation are data from the Bilan Carbone method[30]. Packaging emissions are a combination of the material extraction process, production and end-of-life processing. All levels of packaging - primary, multipack and palletising - are considered. Yet again, Bilan Carbone data is used proportional to the weight of each material used in the packaging. The final step is distribution emissions generated by the warehouses, transport between warehouses and retail stores, store operations and the transport between stores and customers. As the conditions and requirements for different food categories may differ, there are variations in how emissions in this step are allocated, for example, electricity use for refrigeration is assigned to fresh and frozen produce, not items stored at room temperature.

Figure. 4.2.1.2.1 CCI emissions figure for 100g of the product displayed on the front of the packaging (top), complete CCI information on the back of the product.

The emissions figure is then aggregated and displayed to the end consumer in a similar fashion to nutritional information - CO_2 emitted per 100g of the product. On the other side of the product packaging a more detailed label is displayed. It includes the Casino mission and commitment statement, a concise definition of how the CCI is calculated, a relative impact scale and an indicator of recyclability of the packaging. The impact scale is based on data from ADEME[31] the French Environment and Energy Management Agency.

CCI was rolled out for a selection of Casino brand products in 2008, with the rest of its product range included in the following year. Along with the labelling system, an informational website was created, for displaying additional information, details of the calculation, other ecological advice and links to Casino partners. The labels even included a barcode that could be scanned with a mobile phone camera.

The label serves a branding purpose as a visibility marker for Casino products and as a part of an awareness building message. The calculation also revealed the differences in packaging and produce suppliers, allowing to optimise emissions from the viewpoint of the business. Overall, this label is a comprehensive solution for estimating the emissions impact of a food product. The level of transparency and partnerships and endorsements from government and activist organisations gives a level of legitimacy to the provided information. Possibly, the most impressive aspect of this system is that it attempts to take into account all aspects of the product journey.

4.2.2 Agriculture

There are six recognised stages of an agricultural lifecycle: production and transportation of inputs; cultivation; processing; distribution; consumption and waste management[32]. Most interest lies in the first two stages - production and cultivation - as that is where the majority of environmental impact occurs via growing animals, manure management, fertiliser use and energy for farm equipment.

Processing consumes energy when converting or combining raw products into food items. The distribution stage expends energy mostly in transporting and storing the processed goods before they are purchased by consumers. Consumption emissions originate from storage and preparation, eventually leading to waste, which can be handled via conventional landfilling or incineration, in addition to, composting and digestion. The latter two stages are ignored in this project due to their variability, as the producers only have direct control of the composition of products, enabling or limiting their reusability and compostability, with the rest of the chain handled by municipal or national waste handling schemes.

Energy use in agriculture stems from industrialisation and advancements in technology, such as motorised equipment, synthetic fertilisation and pest control, and the public requirement for year long supply of diverse foods, requiring either shipping from other regions or using artificially climate controlled facilities to grow exotic products more locally. A United Nations Food and Agricultural Organisation estimate attributes 18% of global GHG emissions (and 50% of methane) directly to livestock and crop production[33]. Other factors include effects on the nitrogen cycle, water use repurposing of forests into arable land.

From an LCA perspective, a functional unit must be chosen, for example, 1 ton of produce or 1 hectare of land. The practical values in the production of inputs stage, the figures that need to be taken into account are: the energy used to manufacture agrichemicals (fertilisers and pesticides), animal feed and energy used to transport production inputs. The figures that are more difficult to allocate are the energy and production costs (and disposal) of equipment and buildings which must be spread across the entire operation over a longer period of time. The raw agricultural inputs usually consist of seeds, agrochemicals, water and energy for crops and breeding of animals for dairy and meat production.

4.2.3 Transportation

The transportation component is arguably the simplest to calculate using data that is carried with EPCIS. If the starting and finishing points for a journey are known, as well as the type of vehicle used, the emissions of this journey can be approximated. The total emissions can then be allocated to the total mass of the relevant goods being carried.

For fossil fueled road vehicles, a ‘Well-to-wheel’ approach can be used - combining the direct emissions from the vehicle for the duration of the trip with the indirect emissions it took to produce the fuel itself[34]. This paper presents a direct way of calculating a more objective, empirically based, emissions figure than the advertised figure from the automobile manufacturers.

The calculation for direct emissions is based on vehicle mass, engine capacity and declared fuel consumption and whether diesel or gasoline is used. The indirect fuel emissions are based on the properties of the fuel - fuel density, energy content, its CO_2 emission factor and the previously calculated adjusted fuel consumption.

$FC_{InUse,G}$ = 1.15 + 0.000392 · cc + 0.00119· m_{ICEV} + 0.643 · FC_{TA}	Fuel consumption in use, gasoline, litres/100km Engine capacity in cm3 Vehicle mass in kg Type approval fuel consumption in litres/100km
$FC_{InUse,D}$ = 0.133 + 0.000253 · cc + 0.00145 · m_{ICEV} + 0.654 · FC_{TA}	Fuel consumption in use, diesel, litres/100km Engine capacity in cm3 Vehicle mass in kg Type approval fuel consumption in litres/100km
ICEV_Em_{WtC}= $(1/3.6\times10^{11})$ · F · ρ · EC · FC_{InUse}	Indirect CO_2 emissions of ICEVs in gCO_2/km Indirect CO_2 emission factor for pollutant in mg/kWh Fuel density in g/L Energy content of the fuel in kJ/kg Fuel consumption in use, litres/100km

Table 4.2.3.1 Adjusted fuel consumption formulas for internal combustion and battery electric vehicles[34, p.27]

$ICEV\_Em_{WtC}$= $(1/3.6\times10^{11})\cdot$	Indirect CO_2 emissions of ICEVs in gCO_2/km
$F\cdot$	Indirect CO_2 emission factor for pollutant in mg/kWh
$\rho\cdot$	Fuel density in g/L
$EC\cdot$	Energy content of the fuel in kJ/kg
FC_{InUse}	Fuel consumption in use, litres/100km

Table 4.2.3.2 Indirect carbon dioxide emissions for internal combustion vehicles[34, p.28]

The data required for road transport emissions calculation would be distance driven (inferable from waypoints), the model of vehicle and the fuel used. When looking into the emission for transportation there is choice in how much to consider in the well-to-wheel or only direct emissions. Direct emissions are more measurable during the actual process, with the calculation involving the distance travelled and the declared emissions factor from the manufacturer. These factors are published to comply with regulations but may not reflect the reality, as the emissions are also affected by outside factors, such as weather, driving style traffic, age of vehicle among other reasons. The inclusion of well-to-wheel emissions will greatly increase the emission per kilometre, it can be an attempt to show a more 'real' impact, and, when seen as a proportion of the total impact of a particular product, may encourage the manufacturers and distributors to look into the efficiency of their transportation solutions and consider alternative fuels or electric vehicles where possible.

Long distance travel over sea or air might be more difficult to allocate, and could only be reliable if measured directly. For example each journey produces a certain amount of emissions, which can be attributed to the entire mass of the craft. If the masses of the craft and the relevant shipment are known, the emissions can be allocated proportionally. Fortunately, some estimations in this area already exist, specifically, oceanic shipping emissions considered roughly 0.05 kg of CO_2 equivalent per ton of produce[35]. For aircraft travel, the considerations are similar to road vehicles, as the emissions depend on the type of aircraft. The variance in values is caused by distance travelled, type and age of aircraft, flight path, weather among others. The values appear to be in the range of 1.23 g to 5.37 g of CO_2 per kilogram of cargo per kilometre[36]. These and other values are used as a part of the transportation emissions algorithm created in the Implementation section.

4.2.4 Packaging and storage

In order to transport raw produce from the field to other parts of the value chain, they need to be stored in a vessel for the duration. Produce is often transported in bulk, so containers and large reusable boxes are used initially. As the products near the consumer, smaller and more convenient packaging is required. Most supermarkets will stock unprocessed produce in both loose and prepackaged formats, with almost all processed products placed in some kind of packaging. The reason for packaging is not just convenience, it preserves food products and creates confidence in the consumer in regards to product quality and safety, and can be used to communicate information about the food item[37].

Production of reliable and safe packaging is essential to food provision and nutrition, but comes with its own emissions cost. It is up to the manufacturers to decide how their products are packaged - what are the materials used and how can it be handled at and after disposal is not always as important as food preservation, low cost, durability and efficiency during production[37]. Another complicating factor is that often an item of packaging is made from several components, each made of separate material. For example, a can is primarily made from some metal, like aluminium or tin, has a plastic lining to protect the contents and a cardboard label. A regular plastic water bottle is made from three components - bottle itself, the cap assembly and the label - all made from a slightly different type of plastic with favourable properties for the task at hand[37]. To determine an accurate figure to reflect the emissions of this packaging, a calculation algorithm must be created.

Storage can appear to be more abstract, as some food items, for example, honey or canned foods don't require special storage conditions and can last several years without spoiling. That is in stark difference to products that require cooling, like dairy and meat, and frozen foods, requiring a deep freeze. It has to be said that the shelf stability of most foods can be extended by freezing them, but products and their quality after this process is inconsistent. In order to simplify the calculation of storage emissions and simultaneously capture collateral emissions of the storage facilities, the aspect of storage that can be easily tracked is the time period it spends in a facility. Once the time period is known, the amount of electricity consumed at the facility can be allocated to products. As the physical location of the facility is also known, its electricity consumption can be cross referenced to the emissions burden of the electrical grid. An electricity grid may be dynamic in the makeup of the exact energy sources at any given time, meaning that the emissions impact may change at differing times of network demand and may change throughout the year. Generally, the emissions caused by electricity generation depend on where in the world a facility is situated, along with the adjacent networks where electricity may be exported to and imported from.

To deal with all of these variables, a system would have to directly measure time and electricity consumption along with the attributes of the electrical grid at any one time. This may be impractical and prohibitively expensive, therefore reference figures must be used. electricityMap[38] is a company creating services and applications that monitor and analyse electrical grids in terms of their impact on the environment.

With most relevance to this project, they have created an Application Programming Interface (API), that allows access to their real-time and historical data, as well as forecasts of usage. The main attributes accessible through this API are the sources of electricity, meaning whether energy in a particular area was produced from windmills, coal, nuclear or other power stations, and the amount of carbon that was emitted in the production of this electricity, output as CO_2 equivalent. The Emissions Calculation Interface could use the historical data of the time span between the physical items arriving and leaving a facility as the start point for allocating storage emissions. This same electricity usage approach can be applied to the processing stage of the food value chain, as it can combine the diverse nature of processing done across product groups, only somewhat reducing the fidelity of the exact source of emissions, while still gathering a measurable and reliable figure.

4.2.5 Communicating climate change

Agriculture produces significant volumes of greenhouse gas emissions, with figures varying from 26%[39] or between 21% and 37%[40] of global greenhouse gases, while at the same time being greatly affected by climate change. Climate instability reduces farming productivity, more variability in production levels, and can increase food safety related risks, especially affecting smaller and subsistence farmers. This is a motivator for agriculture to adapt and change to more sustainable practices [25, p.31 - 35]. Exposing the reality of climate impact to consumers who are unaware of the issues could also happen through labelling and simplified access to information. Communicating this importance of limiting climate change from the viewpoint of food production is a challenge on top of calculating the figures themselves. Consumers have differing attitudes and carbon literacy[41] so choices in how the market is targeted are important.

Climate change could be perceived by consumers as an issue distant from everyday problems, with their lives having no measurable connection to this problem. There may be feelings of emotional distance as if climate change does not affect them but future generations or people not within their concern. Due to these possible roadblocks, companies should take care when designing green marketing and communication strategies. The personal relevance of people’s lives in the context of climate change should be highlighted. Attempts to guilt or frighten your customer base may not be the best approach, as it may alienate or discourage from taking actions. Advertising can be used to associate emissions reduction with self-improvement or other positive self-image angle instead of a sacrifice or quality of life reduction. Climate issues may also be presented as a common societal enemy, requiring a concerted effort to fight it, as a way to inspire current,simple and focused actions with beneficial outcomes in the future. Using the surrounding community may also be an approach, appealing to peoples' attachment to their identities and places of living, showing emissions conscious behaviour as a way to foster a sense of solidarity. Some level of entertainment or interaction, beyond just laying out information in a passive manner can also improve engagement.

The output of an emissions calculation is a number, expressed in mass of gases for the item a person may be holding in their hand, and the information could be interpreted in a number of ways. To err on the side of caution, no quality should be applied to the figure, allowing consumers to compare with other products and judge for themselves whether the emissions should affect their purchasing habits. At the same time, if a person's attention has been caught, they should have the opportunity to find out more about the issue in general or just some way to contextualise the numbers within their life experience, be it housing energy costs or kilometres travelled in their car. This encourages supplementing the single emissions figure with a barcode or web address that can lead to further resources on understanding both their personal emissions and the impact of food choices in general.

5. Analysis

This section is designated for summarising and critiquing the information gathered in the Secondary Research section in the context of the system proposed in this report, from now on referred to as the Emissions Calculation Interface (ECI).

In general, this section should be able to answer several crucial questions that will inform the Design of ECI. There are effectively two processes that need to be designed within this project - a flow of data collection and aggregation and a calculation algorithm that, using the collected data, outputs an emissions figure. This then begs the question - How should data be gathered, what can be inferred from this data and how to deal with both automation and manual input. The next major question is what should be the components and factors considered in an emissions calculation and how total emissions of a product journey should be distributed to individual products and nutrients. To answer that, the sources and proportions of emissions in any given product must be found. Finally, once a figure is found, how should it be shown on the product itself, what is the information available on the label and how should consumers access additional information.

5.1 Use and purpose of EPCIS

The standard itself, in its base form, has nothing to do with emissions tracking or calculation. Fortunately, its extensible nature can be taken advantage of to achieve the goal of ECI - gathering data along a supply chain. EPCIS is not a requirement to create a supply chain emissions tracking system, but it serves as a kind of constraint and architectural guide - the system being designed must be able to communicate with established infrastructure and follow, at least, the basic design paradigms. It also provides a framework for data handling, thus formalising and codifying what data is necessary while at what precision and frequency it shall be collected is a separate design decision. The only true requirements this constraint generates is the need to implement two interfaces - Capture and Visibility, ability to generate the XML files for each event in compliance with EPCIS, and vocabularies for interpreting the new types of data should be created.

In general, EPCIS is used to handle two kinds of data - event data and master data. Event data is created by business processes over time and gathered via the Capture Interface. Master data provides the context to interpret associated event data. A system that extends and uses the Abstract Data Model must be able to produce and handle; Event Data - a set of related events, Events - data structures consisting of the Event Type, and one or more Event Fields, an Event Type - a namespace qualified name indicating which

Event structure, defined in the Data Definition Layer, Event Fields - named fields within an event, Master data - Vocabularies with master data attributes associated with Vocabulary elements, Vocabularies - named sets of identifiers. Master data for a given entity is mostly static, while transaction and visibility event data is continually created as more business is transacted in a supply chain.

Within the Emissions Calculation Interface, master data would be all types of categorical entities, variables that are unique items within a set, for example facilities, types of product, types of vehicle and store locations. Event data primarily would be the information that is necessary to infer emissions, such as timing information, masses of products, electricity used and distances travelled. The event data should be fairly fluid, requiring only a basic set of information, with the option for facilities to add more detailed information, for example, their emissions calculations or data from LCAs of their own processes. Otherwise, the algorithm has to deal with situations of missing or incomplete data and fallback to average or previously used values.

5.2 Emissions sources

The emissions directly attributable to agricultural processes are difficult to unify, as the exact sources are diverse - greenhouses, equipment, buildings and others. Some farms may keep track of these specifics, so could be used in ECI. For others, LCA of specific products must be relied upon. The property of raw products that has to be kept track of is its mass and type. The main resource in the implementation of the system will be the aggregated table of Global Warming Potential values for food products[21]. The issue with relying on this reference is that it may not accurately reflect a 'green' or a particularly emissive farm. As the value is a compound figure of the life cycle from the far to the customer, in practice a proportion will be used for this stage, and additional emissions will be added in a more precise manner. The reported share of production emissions lies between 7.7% and 30% Benefits of using measurements from this and similar tables will also be useful in cases where the emissions impact a food product or particular ingredient is difficult to measure, either because it is in small quantities or already a processed food product. The expansion and use of GWP instead of purely CO_2 is motivated by the fact that often the main GHG of a particular process is not carbon dioxide, but the normalised GWP can instead give a more complete understanding of the climate impact of an agricultural or industrial process. The main measurement that has to be kept along the entire digital and physical chain is the mass of the product, aggregated initially and itemised the closer it gets to the consumer. The Casino Carbon Index methodology of allocating the emissions proportionally according to previously measured expectation of which parts of the lifecycle emit the most is a major inspiration to the algorithm within

ECI. Electricity use during growing is not the only source of emissions for producing plants or livestock - water use and agricultural chemicals for pest control and fertilisers also produce emissions in use and production. This is excluded from the calculation for individual products, as it is impractical to measure and allocate this precisely. An option that would allow including this in the calculation is if the total amount of water and chemicals could be accounted for across all of the production over a period of time, for example a year. Then a proportion of this figure could be assigned to a particular harvest, in terms of an average of the yearly yield.

Similarly to farming or animal rearing, processing can be a variety of activities at different levels of energy use and emissions creation. The one aspect that does seem to be shared is some sort of mechanical processing or heat treatment using machinery that consumes electricity. Yet again, if a processing facility has its own power generation or is aware of the emissions of the electricity they use, this information can be collected. A more likely and readily available measurement is the electricity used, either by the specific machine or a combination of many. The carbon intensity of the electricity grid in a particular location can be inferred, if it is known what fuels are used on the network. The carbon intensity or even the generation make up is not static, as it adapts to varying demand in different seasons and times of day. Therefore, instead of requiring facilities to calculate the attributes of the grid, an Electricity Emissions API[38] is used instead. The only data that is required are the kilowatt hours used, the timespan of processing and the geographical location of the machinery. Storage emissions of goods along the chain can also be attributed using the energy spent by the warehouse for the time being a set of items reside there, with additional multiplication factors if there is time spent in refrigeration or freezers.

An approach to estimating the emissions impact of packaging would be to figure out the materials, and their proportion, of a piece of packaging and find what are the emissions of producing a unit of mass of each material and then generating a value that represents the complete packaging. The manufacturer must input the known materials and their proportions into the event data submitted to the Emissions Calculation Interface, where it will be cross referenced with Global Warming Potential (GWP) values for the specific materials. From then on, this value will follow the product until the end of the value chain. The GWP reference table for materials is built up from values discovered during a literature search for previously calculated emissions benchmarks. The moment where retail packaging is added to the product is the last step where the information contained in the unique identification number can be modified, unless an additional event is generated when the item passes through the cash register, meaning that the value would be different if the QR code is scanned before or after purchase. If no detailed information about packaging is available, an emissions percentage of 11 to 31% can be used. Food that is not in individual pieces of packaging at the retail stores can be attributed a reduction of 4-10% of greenhouse gas emissions at the packaging stage.

As the produce is moved to more distant facilities, transportation becomes an emissions contributor. The measurements needed for transportation depend on the mode. For road transport the necessary information is the distance driven (can be inferred from the production location, intermediate warehouses and retail stores), the type of fuel used, total mass of the vehicle and the volume of the engine, all of which would have to be manually input at each facility. Where no direct measurements of transportation are available, a Mapping API can be used to determine routes based on the start and end points of a shipment. For more complex transportation systems for example ocean shipping or air transport values from previously published studies must be used, unless precise real-life figures are available. If no direct measurements of transportation are available, the proportion of CO_2 generation attributed to transportation can be anywhere between 14-46%.

To summarise, most of the emissions attribution depends on a handful of direct measurements, primarily mass of the items that actions are taken upon, more specific measurements, such as electricity used or distances travelled, and a reliance on previous research for multiplication factors and third party APIs for simplifying the calculation process and reducing the amount of direct measurements at the edges of the system. Due to the system boundary, no aspect of the product can be accounted for beyond the point of purchase, which excludes the carbon emissions contribution of food loss.

5.3 Emissions labelling and communication

As discussed in previous subsections, this system should be able to provide information to both retail customers and the companies involved. For the commercial side, a focused analytics suite could be employed that includes emissions data to find possible parts of the physical business where emissions could be reduced.

Taking the example from how the Casino chain of retail stores designed their climate labelling, a small summary is available on the packaging itself, with more detailed information available on a website once a QR code is scanned. The basic information ought to be branding of the label, the emissions figure up to the point of packaging and the custom, scannable code. An important design decision is how to contextualise the figure, as a single number might not be meaningful for some consumers. An option would be comparing the figure with everyday activities, such as driving a car or taking the bus or an hour of activity on a smartphone. Another possibility to compare is choosing a set of common and popular products as a baseline for comparison. An advance mode could be choosing a set of products similar or related to the purchased product, for example cartons of milk from a variety of producers and countries of origin when scanning an Arla product, to see which option is the least emissive overall. The purpose of the expanded description is to inform the consumers of how the figures were estimated and to see the timeline and locations where the food they are holding in their hands has travelled through.

An important aspect of this exercise is the allocation of emissions per macronutrient. On European food labelling the nutrient amounts are expressed in grams per 100 grams, thus, to create an allusion, the emissions could be shown as grams of CO_2 equivalent per 100 grams of nutrient. Similarly to the nutrition label, the numbers are absolute not relative and do not indicate whether the product in question is better or worse than any comparable product, leaving the choice up to the consumer. A sample of how an amended nutrition and emissions table may look is presented in the figure below.

As the focus of the ECI is in data gathering and management, the precise way of designing and displaying the nutrition and emissions relationship is not going to be a part of the system directly, but possible applications and alternatives will be discussed at the conclusion of the report.

Næringsindhold	Pr. 100g	CO_2-eq / pr. 100g
Energi, (kJ, kcal)	1890/452	Total 112 g
Fedt, heraf mættede fedtsyrer	20 g 5.1 g	17.9 g 4.6 g
Kulhydrat, Heraf sukkerarter	44 g 9.3 g	29.3 g 8.3 g
Kostfibre	21 g	18.8 g
Protein	14 g	12.5 g
Salt	0.17 g	0.15 g

Figure 5.3.1 Sample modified standard nutrition declaration with the third column showing the carbon dioxide equivalent per nutrient.

5.4 Supply chain data gathering

To make this system operational, the participating companies must have the infrastructure to gather and input the diverse data points throughout their operations. This might be a significant roadblock in the deployment of an emissions tracking system. From a business perspective, two possible solutions to this are possible, either bundling emissions tracking with a general supply chain analysis system or tracking becoming a requirement of certification for sustainable businesses. The bundling option could be an incentive for companies to evaluate the true sustainability of their supply chains, while at the same time improving their knowledge of their overall business processes. Certification plays a role in manufacturers' ability to claim their products fulfil certain requirements and is a key tool in marketing to customers. A requirement for a certificate such as Svanemærket[42] could include a requirement for fine grained carbon accounting for businesses nationally and this system could be used as one of the options for the technical implementation to fulfil this requirement. For products where the supply chain is not interested in doing elementary product tracking, the system will have to rely on existing data for determining the emissions of certain products or parts of the value chain.

While most food products will pass through a similar, and often even shared, value chains, they are not always exactly the same. The system must allow for cases where, for example, production, processing and packaging happens at the same location, or instances where a product is not processed but is packaged for retail. These circumstances mean that each input and aggregation must be its own, self-contained module, that is compatible with the rest of the system in an agnostic manner. This modularity also means that calculations don't have to be performed in real time, with only directly measurable information being collected.

Another purpose of using EPCIS in this system is that it is compatible with other standards, including GTIN[6] and could enable communication between businesses and across borders. The emissions data that would be carried in an event requires a vocabulary that identifies the type of event, the kinds of product and packaging, and the businesses and locations a product might travel through. Each company would have access to the data to enable creation of EPCIS events that are relevant to them - information about the type of items they produce, their assigned vocabulary values and information about their partners. There should be a possibility for automation of some of this process for larger facilities that already use computer infrastructure for tracking or measurement, to reduce the additional load on human operators. . For manual human input a user interface that converts form inputs into EPCIS event compatible data, while the automated system must provide a generic interface for other systems that can interpret received data. The specific properties or attributes being collected as a part of the event will be specified in the requirements definition.

From the EPCIS viewpoint, the generated events must be collected in a database which must have interfaces that allow posting and retrieving to it. Collection is straightforward and one-directional, a generated event cannot be modified once placed in the repository, with any advances or modifications possible only with additional events with a reference to a past event. Retrieval must allow for two kinds of interaction: one for calculation purposes, the other for displaying data to an interested party. The Visibility interface for calculation takes the info stored in an event and generates its own Emission

Event, that contains a reference to the EPCIS event and is stored in its own repository. The events are the product of the core algorithms for each event type. Visibility for interested parties refers to the ability to track products by the producers or other members of the value chain and, eventually for displaying the product and emission information to the consumer.

When packaging is involved, similarly to the food products, their emissions impact is dependent on the material and mass used for a unit of packaging. The multiplication factors are available from manufacturers and existing LCA analyses. Packaging must also be separated between bulk packaging for transport and the retail packaging that is handled by the end customer. Individual packaging is often made from several components so the mass proportion of each material has to be measured. This is also the point in the chain where each item will be assigned a unique ID, so it could be printed on the labelling for later identification and creation of the information page, accessible through a 2D barcode.

As the products get closer to the consumer, they pass through a storage and distribution network as groups of individual items. Each transportation, storage and retail event affects the items of a group equally. This part of the chain should be the most straightforward to automate, as the values can be inferred from transit distance and time spent in storage. The accuracy of this stage is dependent on how precise the product information is, for example, expiration dates and whether it has to be refrigerated. The products from the same group might end up with slightly different values, depending on how far or long they travel from final processing until the retail location. The granular information is updated and assigned to the unique identification numbers.

5.5 Usage scenario

In order to define user requirements for this proposed system and show a sample of how information would be gathered along the supply chain, a scenario is presented.

For a food product, the supply chain begins with the raw products at the field. In this example the final retail product is 'Hanegal Kærlighed og Kartoffelmos'[43] - a prepackaged meal with onions and potato as two of the primary ingredients. The farm in this scenario produces both and has a certain mass of each raw product earmarked for the processing facility. On this day, 600 kg of onion and 1000 kg of potato have been harvested. An employee on the farm inputs this information into a system that is used for the farm's internal management and yield measurement but also generates the first, two separate for each product, EPCIS events, indicating the time, place, type of product and mass harvested. This information can be used to infer how much CO_2 was emitted during the growing process. As this varies depending on the product and facility, in the ideal case, the electricity used for equipment and the emissions of various chemical processes involved in growing is included in the event, otherwise falling back upon baseline figures for the specific product. The production emissions figure is appended to the event and stored in an EPCIS repository, with an identification number that can be accessed during later stages.

The next stage begins when the raw produce moves to another facility, which can be straight to packaging, or in this case, an intermediate processing facility where the raw products will be transformed, combined and then packaged before they're ready for retail. If it is assumed that the processing facility is not placed at the farm, raw produce must be transported there. The action of placing the harvested produce (of certain mass) in a vehicle would also require an employee to enter a Transportation Event linked to the previous harvest event, with the additional information of the destination and vehicle properties. This data then is used to append the initial product event with the expected CO_2 emissions from the trip, for a total preprocessing emissions tally.

A particular event within EPCIS occurs when a large item needs to be separated into smaller, related items - a disaggregation. This is what would happen as a part of the processing - a large shipment of raw products being eventually split into smaller portions as a part of the final product. This is arguably the most complicated part as at this point the item IDs that will be used to generate the QR codes on the labels are created. In this example, each item will contain 104 grams of potato and 96 grams of onion, among the remainder of the ingredients, along with their respective emissions allocation. From an EPCIS viewpoint each small item must be able to be traced to the initial harvest. The ID generation happens here as it must be printed on the packaging at the next stage. The ID is also a requirement for being able to add more information at further steps of the chain. The data required at the processing stage is the electricity use per item, multiplied by the carbon emissions burden of the electricity grid at the location of the processing plant.

Processing is often accompanied by packaging and the factors that must be considered here are the electricity used and the mass of the packaging (and individual part of the packaging, if made of multiple materials) and the attributable emissions from its production. This figure is then added to the individual small item emissions of the processed product.

These finished items are now entering a distribution phase which will involve one or more Transportation or Storage events. The previously discussed transportation actions apply with the addition of an aggregation events from a large number of small items into a larger shipment, with a known mass, to a warehouse or retail location. Storage data necessary is its location and the electricity attributable to the storage of the item or set of items. This may be difficult to measure, as warehousing is rarely static, so an average of electricity consumed per unit of mass over a month (or other period of time) should be used.

The system ought to be flexible enough to allow for both manual and automatic input of these events, depending on the sophistication of equipment and level of automation at each of the facilities involved. The outlined approach would also mean that even if two items are created at the same facility, but they are sold in two distant stores, their emissions figures will differ as they are assigned to the unique identification number.

6. Design

This section is dedicated to using the sum of information from the State of the Art and Analysis sections to create a set of use cases and a roadmap of system requirements that will subsequently form the system architecture of the emissions calculation interface.

This section begins with a system context diagram followed by an ECI component diagram and domain specific lists of the general requirements and use case diagrams that contextualise the requirements for the use as an implementation guideline. This is a selection of the requirements deemed to have 'MUST' status, as they constitute the bare minimum of functionality to deliver the promised outcome - the Minimum Viable Product (MVP).

6.1 System context

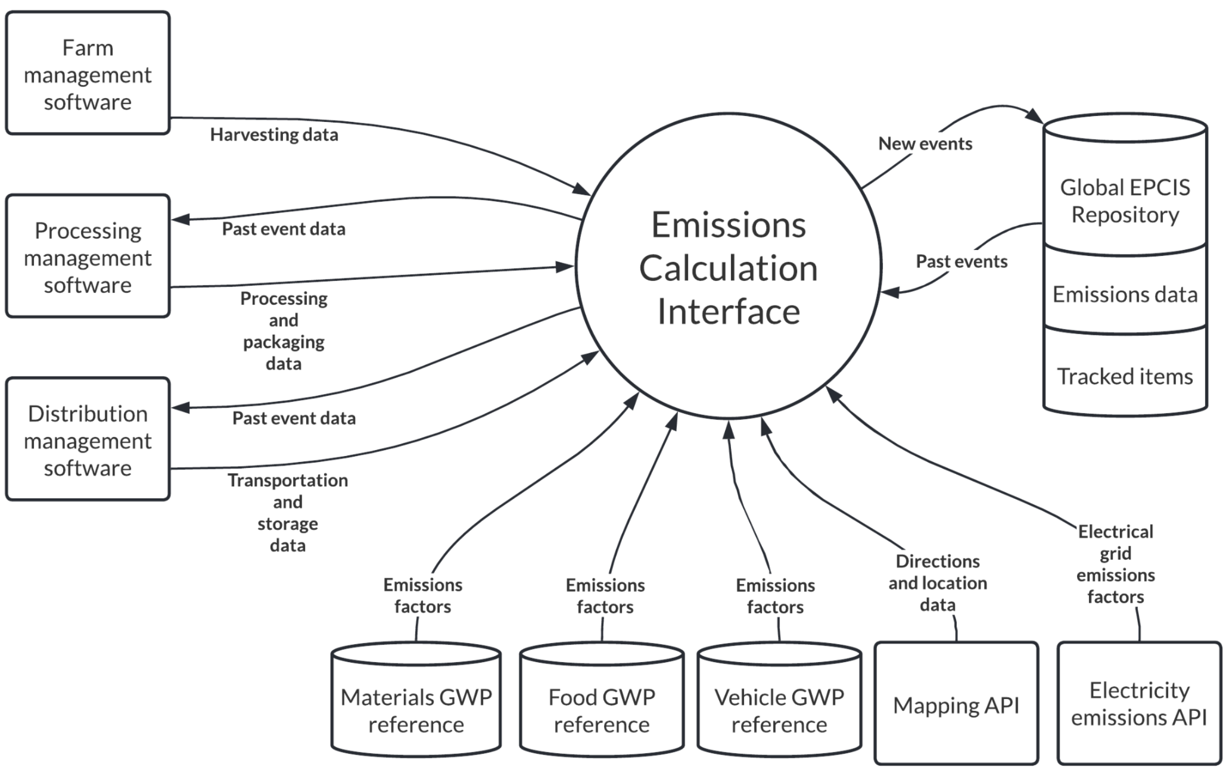

Figure 6.1.1 System context diagram

The diagram above shows the ECI in the context of the environment of external systems it requires to operate. The systems positioned on the left side are software that already exists or must be implemented at the relevant facilities. Facility management software may be capable of a multitude of operations and measurement, only some of it is relevant to the calculation of emissions. For these systems to interface with the Emissions Calculation Interface they must have the ability of external communications using a protocol, based upon EPCIS, or a simplified protocol that provides the basic, attributable values for products and identifiable items, that are later used to construct EPCIS events by the core interface itself. The exact attributes and their presentation are discussed later in the design section.

Third party reference services, shown underneath the ECI in the diagram, are static and dynamic tools that are queried for data necessary to create the emissions figures, mostly emissions multiplication factors. For materials and food the values are based upon previous research into the Global Warming Potential and emissions, codified into a per mass unit factor, allowing the interface to generate an estimated emissions figure. The fuel consumption figures for vehicles are a combination of the data input by the manufacturers and distributors and previous research of determining the emissions of various transport modes. The mapping API is used to calculate travel times and distances, which are then multiplied by factors gathered from the Vehicle GWP reference. The use of a mapping API may be replaced or supplanted by directly measuring the distance travelled by vehicles, though this would require additional software and, possibly, hardware to be installed. The electricity emissions API is used for calculating the emissions of processing, storage and electric vehicles. The use and reliance on APIs is intended to reduce the complexity of the core system, simplifying implementation. This also allows for flexibility in choosing the data source over time, in cases of service outage, lack of data richness and other reasons. Another enabler of flexibility is the use of basic protocols and interfaces, because the exact nature of how any particular farm collects data or what system they use is not known ahead of time. This data agnostic approach also allows for an easier integration of any additional facilities that may choose to use this system over time. As the ECI receives diverse data, its main task is to combine the data from supply chain and the reference data to generate an emissions figure. This figure is then appended to an EPCIS event and submitted to the Repository. The ECI is also responsible for allowing access to relevant past events, for example, a shipment arrives at a distribution centre and in order to register that it has arrived in and Arrival event, the system at the facility must find the appropriate Departure event to register that the journey has been completed so other actions may be taken upon these items.

The purpose of analysing the environment surrounding the Emissions Calculation Interface (ECI) was to understand the possible data inflows and outflows for it to perform its proposed function. In combination with understanding of how emissions can be calculated using data from diverse sources the core functionality of the ECI can be defined.

All of Secondary Research, the Analysis of it and knowledge of distributed information systems serve as the starting point for eliciting requirements - discovery.

These can be considered user requirements that describe the general capabilities of the system[44, p.83-84]. This is motivated by the fact that during an iterative development process, more specific system requirements[44, p.83-84] reveal themselves, in turn allowing for a more precise description of how the ECI shall operate. The outlined requirements are entirely functional requirements, mostly actions triggered by some user or actor interaction with the system, with some requirements in each subset dedicated to the domain requirements[44, p.86] that allow the ECI to comply with the data format of the EPCIS standard.

6.2 System architecture

The ECI can be described on two levels - the core, at which the calculation and output generation happens and the periphery where the required information is collected, sorted and transformed. This separation is created to reduce the need to implement workflows that have duplicate functionality - the core handles common operations while the elements within the periphery are more task specific. This two tier setup also allows for a modular system - each of the functional blocks is independent of each other, allowing facilities to only use the parts of the system that are necessary for their operations. The core components are shown in the diagram below.

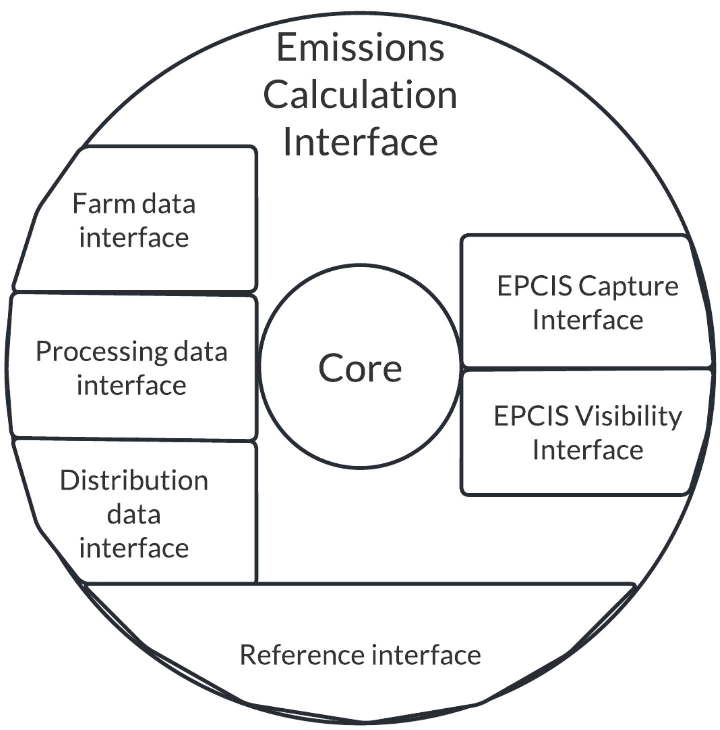

Figure 6.2.1 ECI Core structure and components

Functional Requirement #1 creates the ability to add agnostic interfaces to collect diverse data for emissions calculation. This is a crucial requirement for possible future expansion of the types of data being collected. FR #2 replicates the same requirement but in the access to reference value space, it must be possible to add more data sources in the future. FR #3 is the main function of the core - combine collected and reference data to generate emissions figures. FRs #4 and #5 are what make this system compliant with the EPCIS standard and its Repository feature - the data store for events and associated data. FRs #6 and 7# use the aforementioned interfaces to communicate new events and include past events to build event trees. An important property of the core is that it only directly interacts with the associated interfaces, never a user or external system. This ensures the data integrity and format conformance before any calculations are applied.

FR #1:	Core system must expose data collection interfaces
FR #2:	Core system must have access to Reference interfaces
FR #3:	Core system must generate an emissions value based on input data
FR #4:	Core system must implement an EPCIS Capture Interface
FR #5:	Core system must implement an EPCIS Visibility Interface
FR #6:	Core system must generate events
FR #7:	Core system must be able to reference past events

Table 6.2.2 Functional requirements for the ECI core

The function of the reference interface is straightforward - allowing the core system access data that allow calculation of an emission figure. Some values, for example the emissions of an electrical grid change over time and differ from place to place, so must be queries frequently or in real time (FRs #8 and #10), while the attributes of vehicles are less changeable over time so can be stored in a static table and updated on a per need basis (FRs #9 and #11).

FR #8:	Reference interface must be able to query values from third-party service
FR #9:	Reference interface must be able to query values from stored values
FR #10:	Reference interface must gather most recent data
FR #11:	Reference interface must be updatable

Table 6.2.3 Functional requirements for the ECI Reference interface

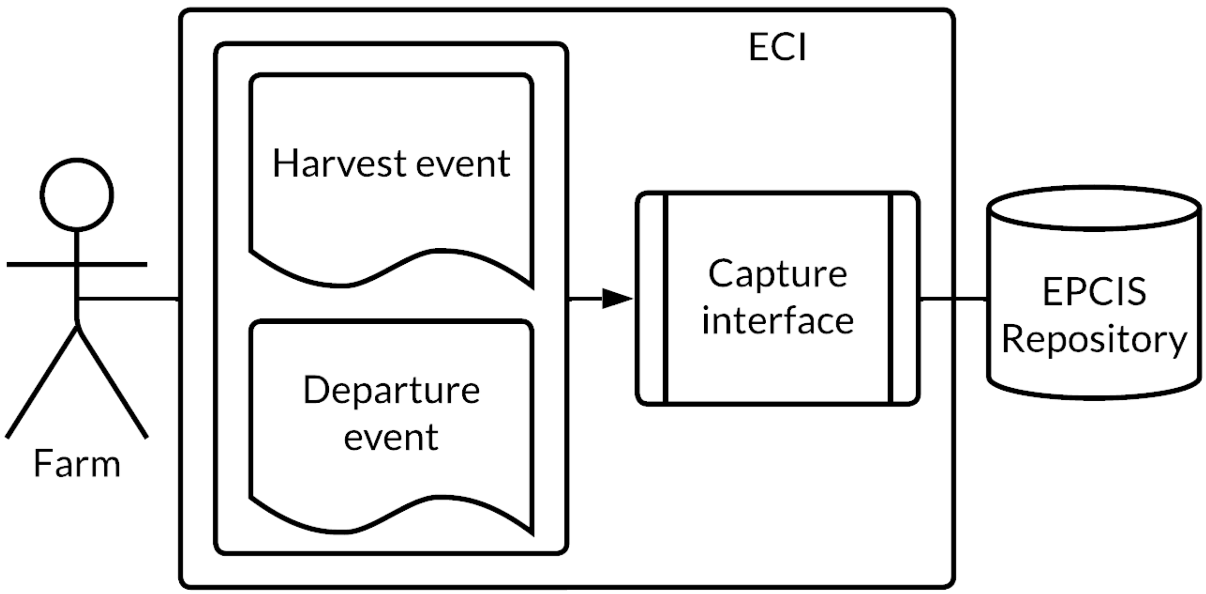

Figure 6.2.4 Use case diagram for interacting with the farm data interface

The digital analog of the physical products begins at the moment when farm management software is used to register a harvest. This includes the most basic information - the mass and type of product harvested (FRs #12 and #13). Alongside this info the farm management software must identify its location, preferably using a standardised identifier or an address that can be interpreted by the farm data interface. This data is later used by the ECI core to generate a Harvest event (see figure above) that contains the time, location, amount and type of product. Some farms may process or package products on the farm but for the cases where the raw produce leaves in bulk, the interface must handle information about a shipment leaving the facility via a Departure event, containing the time of departure and a reference to a past Harvest event.

FR #12	Farm data interface must be able to record harvest mass
FR #13	Farm data interface must be able to record harvest type
FR #14	Farm data interface must be able to identify the location of the harvest
FR #15	Farm data interface must be able to register the departure of a harvest

Table 6.2.5 Functional requirements for the Farm data interface

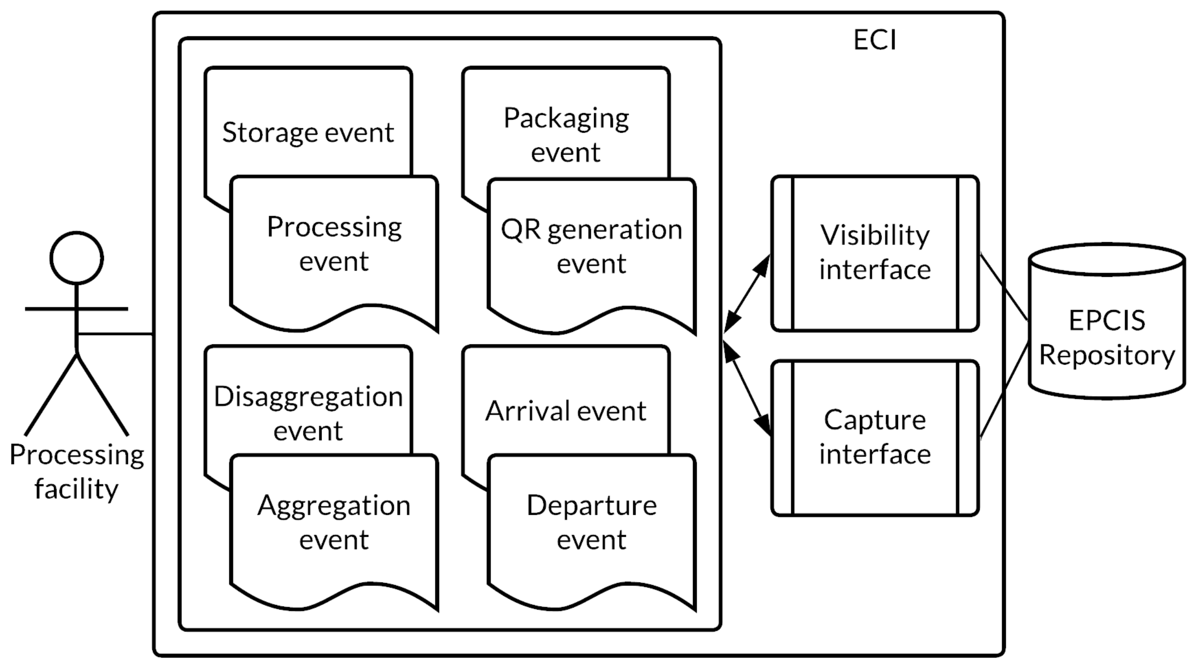

Figure 6.2.6 Use case diagram for interacting with the processing data interface

The processing data interface is the richest and most capable of the interfaces currently part of ECI. It reuses the Departure Event shared by the Farm data interface but includes a handful more (figure above). The information needed to create an Arrival event is a reference to a past Departure event and the time and location of a shipment arriving. Another pair of reciprocal events are Disaggregation and Aggregation. A large shipment may be separated into smaller units by disaggregating it before processing and a collection of smaller items may be aggregated before future shipments. Both these events require a reference to a past event and the number of items a single item is being split into or reference to multiple item events that are combined into a single item. An item may also be subject to a Storage event which marks the starting point of long term or special storage conditions, for example cooling or freezing, that carry some direct energy use. The most important event type in this suite is a Processing event, that contains information of electricity used to process an item. This, if necessary can be followed by Packaging events where the attributes are the electricity used, the mass and material of the packaging. An event simultaneous with Packaging is the QR generation event used for identifying individual items outside the EPCIS ecosystem, intended for use by the end consumer. Once a QR generation event has happened the associated item can no longer be disaggregated, only aggregated into larger distribution shipments.

FR #16	Processing data interface must be able to register the arrival of a shipment
FR #17	Processing data interface must be able to register the departure of a shipment
FR #18	Processing data interface must be able to disaggregate an item
FR #19	Processing data interface must be able to aggregate items
FR #20	Processing data interface must be able to register a period of storage
FR #21	Processing data interface must be able to register processing of products
FR #22	Processing data interface must be able to register packaging of products
FR #23	Processing data interface must be able to associate a distinct item with a QR code

Table 6.2.7 Functional requirements for the Processing data interface

The intended use of the distribution data interface is for handling either the intermediate or the final products in facilities that do not involve processing. The events generated are effectively a subset of the ones available within the processing data interface. It can handle items arriving and departing, splitting or creating collections and storage.

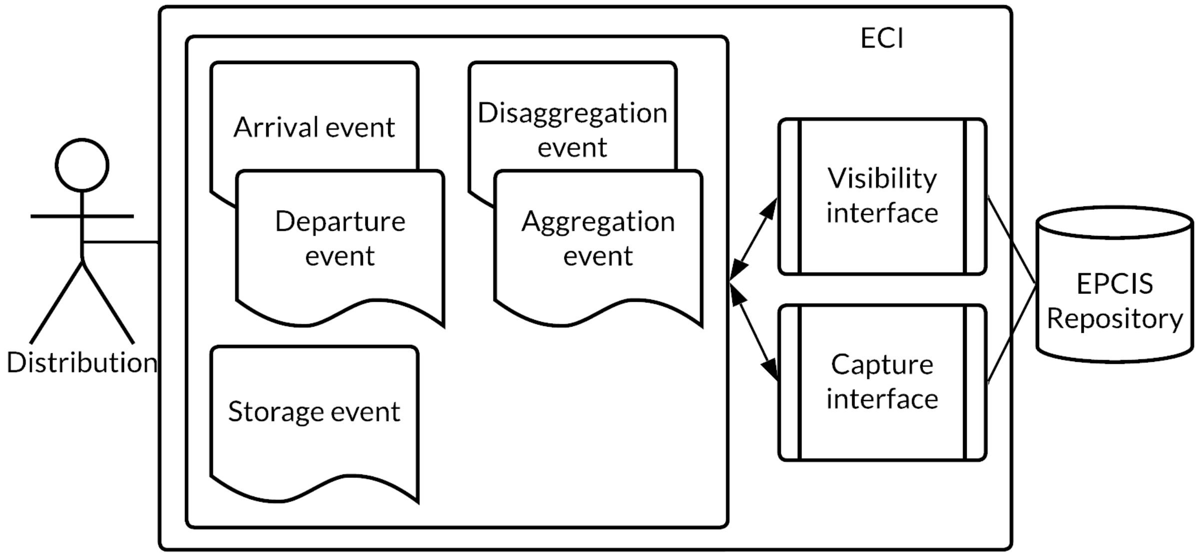

Figure 6.2.8 Use case diagram for interacting with the Distribution data interface

FR #24	Distribution data interface must be able to register the arrival of a shipment
FR #25	Distribution data interface must be able to register the departure of a shipment
FR #26	Distribution data interface must be able to register the departure of a shipment
FR #27	Distribution data interface must be able to disaggregate an item
FR #28	Distribution data interface must be able to aggregate items

Table 6.2.9 Functional requirements for the Distribution data interface

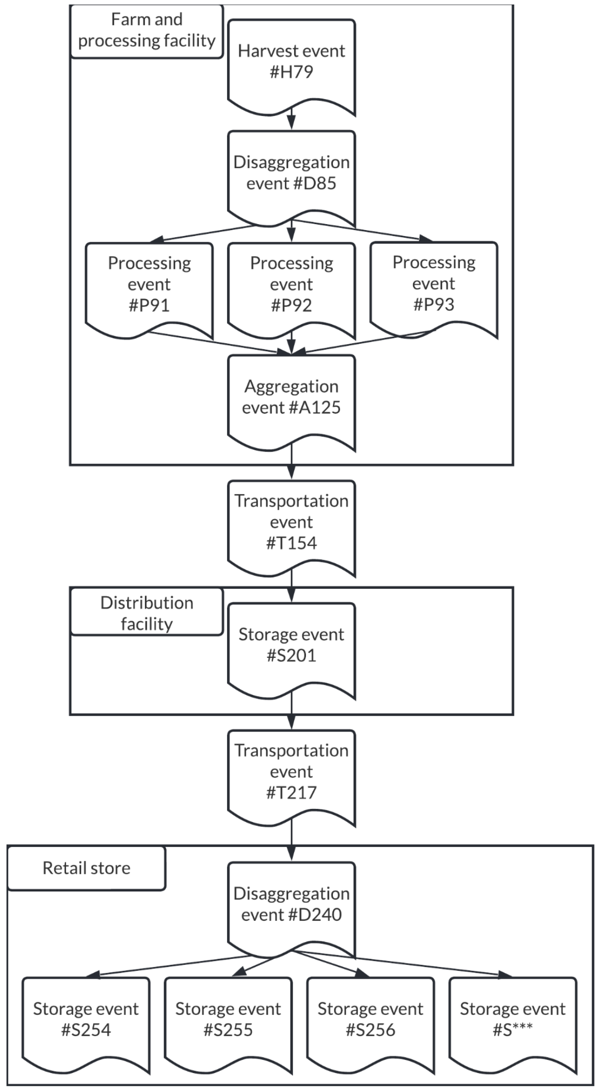

Figure 6.1.10 Sample event flow diagram

The presented components, the requirements and associated use cases show the structural setup of the system in order to produce a chain of events. The preceding flow diagram shows a tree of related events on how they would be perceived from the viewpoint of the entire value chain once an item has reached a customer facing store.

The separate sample input entities - farm, processing and distribution software - have a one-to-one relationship with the Emissions Calculation Interface but from the viewpoint of the final, identifiable product it has gone through a linear, linked process. When using an event approach, each event is separate but can have a relationship to a past event. The way ECI is intended to be used, a harvest event serves as a root of a tree - events performed upon the items associated with the harvest event, must branch off at least one initial event. If an event concerns an action that has taken place in the past, it must contain a reference to that event or events, for example, a transportation event (either arrival or departure) will refer to all the most recent harvest or processing events concerning the physical items being transported. In the illustration above, a sample event tree is shown, with the purpose of showing the kinds of events that may be generated in the diverse facilities along the supply chain. The event identification numbers are for illustrative purposes only and not in sequence to show separation in time and the potential for other, unrelated events having taken place in the meantime. This diagram shows the distinct, formatted events submitted into the EPCIS repository, with their tree structure only revealed by direct internal references. The need to link to past events is motivated by the need to allocate the emissions along a tree branch to a single, final, identifiable item. The emissions of a single harvest event may be distributed to hundreds of items by the time a product reaches the shelves. An event must also contain access information to limit access only to the intended facilities and activity information on whether the physical items may be acted upon. Each bounded rectangle represents a single physical location where any amount or manner of events may take place.

6.3 Testing

Creation of requirements and associated system design necessitates some manner of validation. Other aspects of understanding whether a system like this can be created and used in real world scenarios are discussed in the following Implementation and Discussion sections.

The previously listed requirements are what can be considered the building blocks of a proof of concept or Minimum Viable Product. In a real-life environment, this system would have to be put into practice for any reasonable test of usefulness and quality. Usefulness not only in the sense of allowing to find valuable information but also the ways the input mechanisms for this system would fit into existing workflows. Through this process it is inevitable that additional requirements would be found for a more comprehensive, secure and resilient version of this system would be discovered. It has to be said that this is likely to only concern how data is input or modified before calculation of emissions figures. Adjustments of the core calculation formulas themselves would have to be modified either in the case of a reconsidered system boundary or research that would require change of multiplication factors or other GWP reference values.

The implementation of a prototype is a type of validation to establish whether the data flow is possible at all, at a small and naive scale. As the requirements are known, test cases for these requirements can be constructed. The ability to construct testable cases indicates that requirements are at least logically implementable[44, p.111]. In an application at a production stage, beyond the core functionality, the architecture must be aligned with non-functional requirements[44, p.152]. In terms of performance, the core calculations would be the most active part of the system and is the most crucial functionality, therefore should be localised within a small set of components, with the least amount of practical distribution. For cases when security is a concern, some type of tiered architecture with different access levels should be used. This idea applies to the currently exposed APIs, with permission to only use the relevant functions and no way of accessing the core calculation directly. Also, more practical protection of the calculation from the parties involved, possibly increasing trust in the security of the application. Related to security is also an access management layer - allowing access to relevant and sensitive data only to the parties involved. This is only slightly simplified by the need to be in physical possession of the items, or at least their identifiers, in the form of barcodes, NFC tags or other methods of labelling. Nevertheless, a facility identifier carried within events would be necessary to control the parties delegated to interact with the items and events. This aspect has been ignored as it is a problem in and of itself, independent of supply chain tracking or emissions calculation For the sake of continued modularisation, these auxiliary systems shall be outside the EPCIS environment.

Along with security and access management layers, special care must be dedicated to developing an error handling layer for the application to deal with both predictable and unpredictable errors. Predictable errors include incorrect input or loss of communication between some of the system modules. These errors can be handled in two ways, either notifying the user that an error has occurred and they have to attempt their action again, or an automated system that will repeat the desired user action, once it is possible, in the background.

Small scale testing is necessary to show if there are any glaring errors or omissions in the base system. With additional knowledge and feasible fixes complete, a larger scale prototype can be built, with the purpose of testing more users and an increased amount of data. At this stage integration problems between the modules will have to be resolved and made as generic as possible to ensure compatibility with possible future expansion.

Once the amount of frequent users grows, availability of service may be of concern. The exposed APIs should have more than one instance to handle large amounts of traffic. The calculations can be performed by objects generated from the class for each time an event needs to be generated. The number of separate and distinct components allows for maintainability on a function scale without affecting the rest of the interface or the core system. Data production is separated from the consumption of data and data structures are isolated to create a ‘single source of truth’.

7. Implementation

This section will be used to present the values intended to be used in an implementation of the ECI, the decision flows for each of the event types and snippets and discussion on how an implementation may take place.

7.1 Input and output flows

Based on the system architecture, the most important parts of the ECI are the date collections interfaces and the formulas to calculate the emissions. Once this core activity is taken care of, the EPCIS aspect of the system takes over. Over time, the system must be able to identify related paste events and, ultimately produce a single figure for presentation to the consumer. This whole idea is apparent when any of the defined physical events takes place - the date flows from the raw information input, via an interface, through a core in which it is decided how to deal with the raw data, an emissions figure is produced and appended to a new EPCIS compatible document.

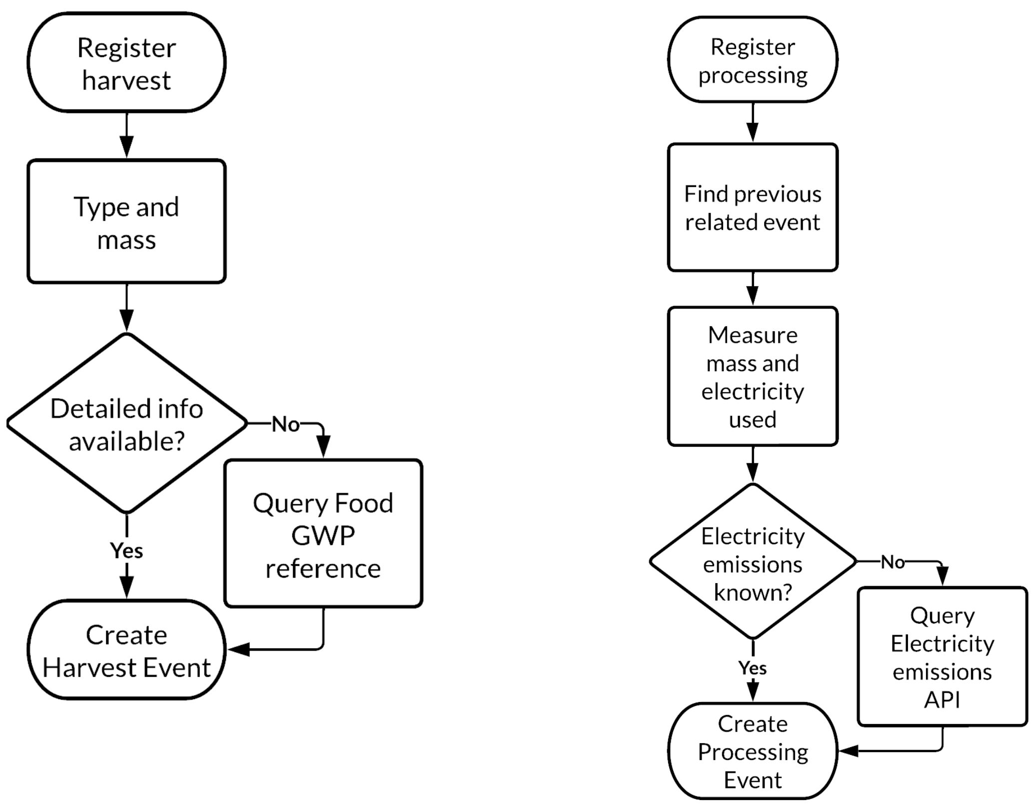

Figure 7.1.1 Flowcharts for Harvest (left) and Processing (right) Event generation

This is an optimistic version of the software that allows for the possibility of fine grained data at the facilities, meaning it doesn't have to depend on third party APIs or reference tables. Nevertheless, the possibility to infer emission only from knowing the type of product and its mass remains. The Harvest Event is the only in the ECI Event subset that doesn't require a reference to at least one past event. The formula used in this case (without detailed data is):

$m_p \times production_{\%} \times GWP_p$,where m_p - mass of product in kilograms, $production_{\%}$ - proportion of lifecycle allocated to production, GWP_p - product GWP value.

When an item is processed it already exists in the EPCIS Repository, so it has to be found by reference as it already has some emissions attributed to it. The electricity spent is multiplied by the carbon intensity of the network and then added to the previous emissions: $m_{CO2\text{-}eq}$ + (carbon intensity × kWh), where $m_{CO2\text{-}eq}$ - the existing emission and kWh - electricity used in processing.

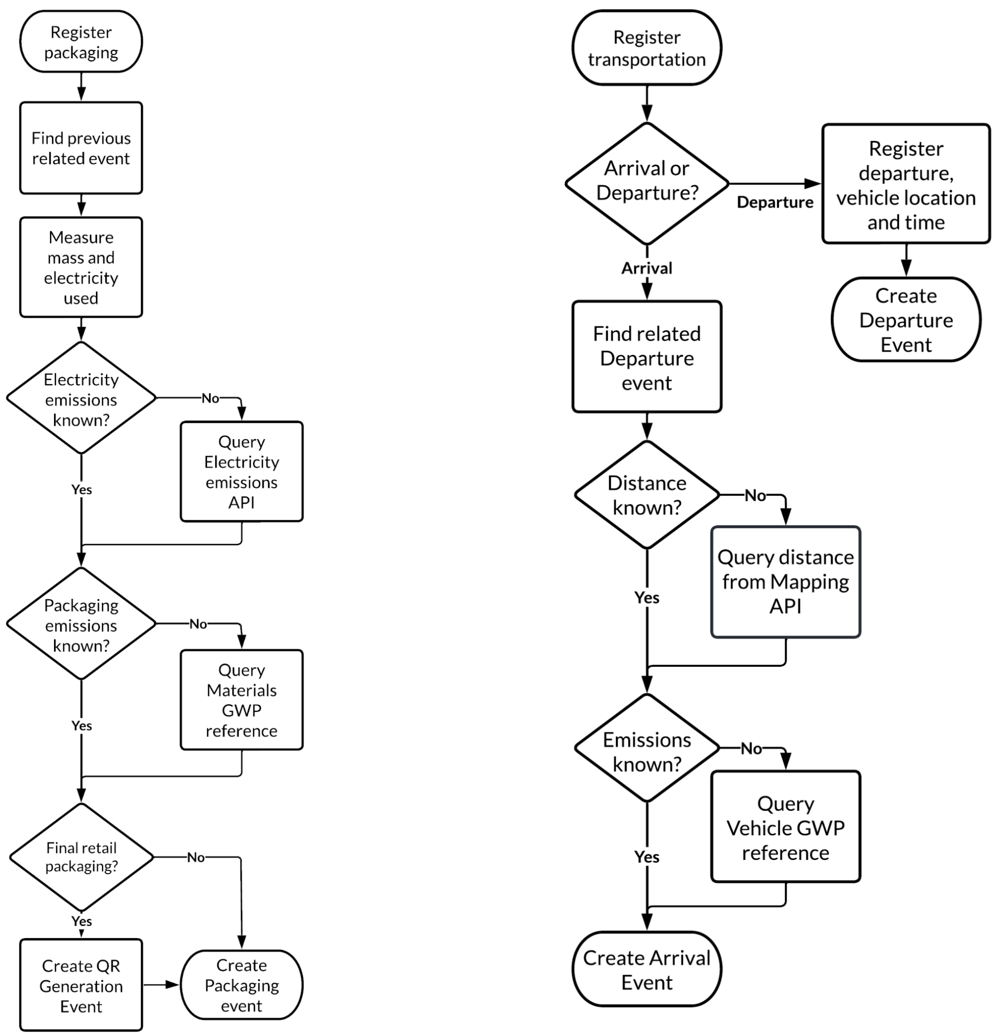

Figure 7.1.2 Flowcharts for Packaging, QR Generation (left), Departure and Arrival (right) Event generation

The pattern repeats for packaging, where the additional emissions come from electricity usage and the GHG burden of the packaging, or in cases of laminates, each material separately: $m_{CO2\text{-}eq}$ + (carbon intensity × kWh) + ($m_{packaging}$ × $GWP_{packaging}$) ,
where $m_{packaging}$ - mass of packaging and $GWP_{packaging}$ - the emissions factor for packaging material(s).

Transportation depends on knowledge of the vehicle and the distance travelled. No single formula can be presented here as it is different for each mode, but it takes into account the type of fuel and its emission factors, the mass of the vehicle and the proportion of the shipment of the total mass. The vehicle reference is based on either data from previous studies or manufacturer data sheets. The Mapping API used for the prototype is the server-side Google Maps Directions API[45].

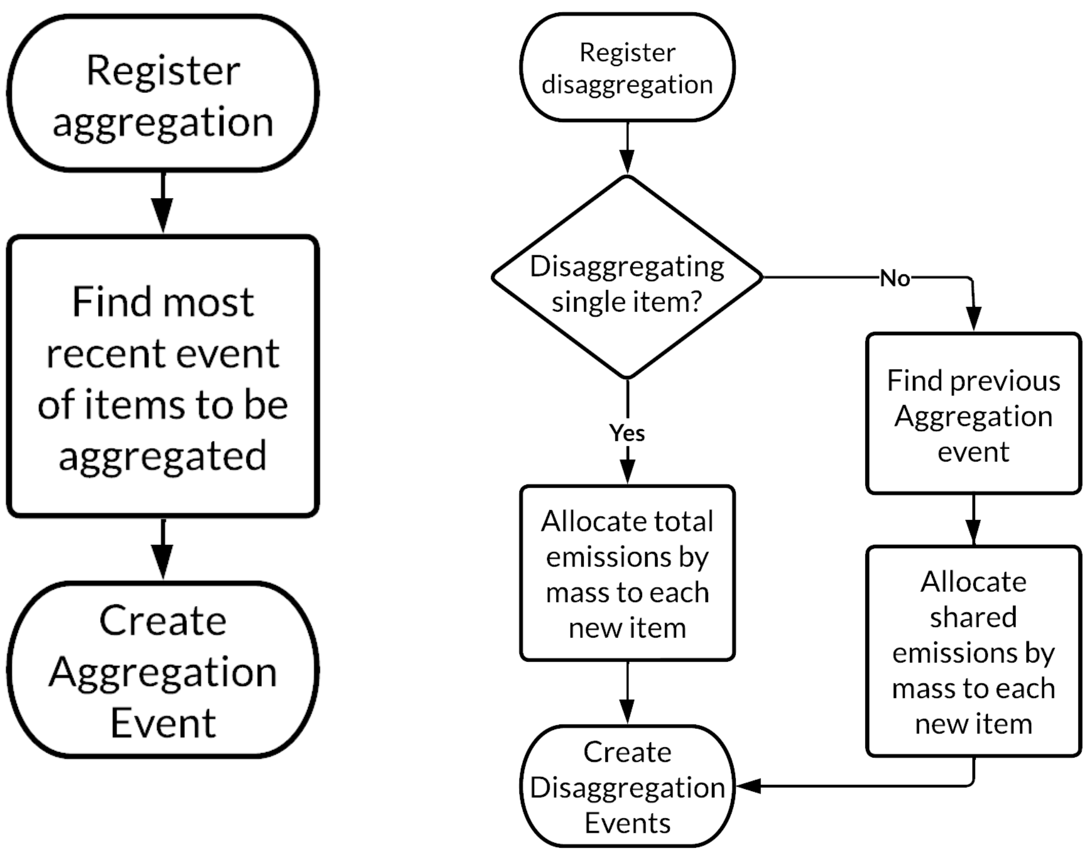

Figure 7.1.3. Flowcharts for Aggregation (left) and Disaggregation (right) Event generation

Aggregation and Disaggregation Events do not create emissions from the viewpoint of ECI, just redistribute the collected carbon by the mass proportions of the items either being split or joined. Aggregation is useful in cases of transportation, where each item will eventually be disaggregated and a small proportion of the transport emissions will have been added to it.

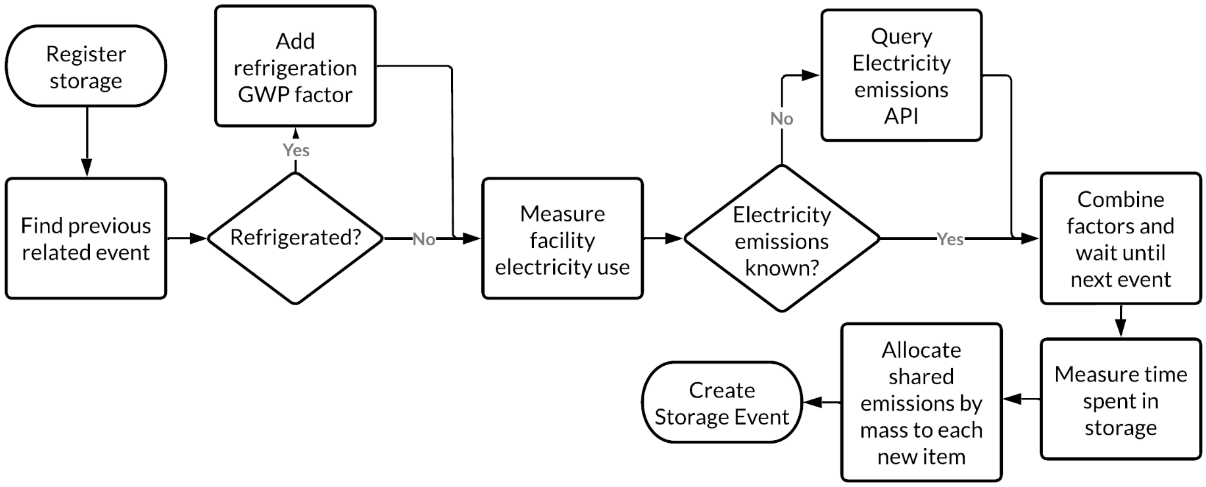

Figure 7.1.4 Flowchart for Storage Event generation

The flow for measuring storage emissions may appear to be complex, but in reality it is straightforward. Similar to Transportation Events regarding distance, Storage Events depend on two points in time, the start and end of storage. The total time spent is allocated electricity use and multiplied by the carbon intensity of the network. An additional factor is added for cases of refrigerated or frozen foods.

7.2 Reference values

This section contains tables of the reference values and emissions factors used when precise information is not available.

Product or product group	Median GWP, kg CO_2-eq/kg
Potatoes	0.18
Sugar beet	0.24
Vegetables (all field grown vegetables)	0.37
Fruit (all field grown fruit)	0.42
Barley	0.43
Cereals	0.50
Wheat	0.52

Passive greenhouse fruit and vegetables	1.10
Milk, world average	1.29
Rice	2.55
Pork, world average	5.77
Cheese	8.55
Butter	9.25
Beef, world average	26.61

Table 7.2.1 A subset of Global Warming Potential Values for common food categories and products[21].

The table above is a small slice of the GWP values that are used in the system, with some products even having geographical location specific values. This table is dynamic in the long term, as either new products are added or old values are reconsidered in light of new research and measurement.

Emission factor	Value
Refrigeration during transport	0.0025 kg CO_2-eq / (m^3 * km)
Refrigeration during retail	2 kg CO_2-eq / (m^3 * 24h)

Table 7.2.2 Emissions factors for storage scenarios involving refrigeration. Adapted from [18].

A unique aspect of refrigeration calculations is that it uses the volume of the product instead of just the mass. Ideally, the facility provides this information about the items or shipment, otherwise the volume must be inferred from the known mass and a density value for a material or product.

Material	Value, kg CO_2-eq / kg
Cardboard packaging[18]	1.1
Polyethylene Terephthalate packaging[18]	2.7
Polyethylene packaging[18]	1.9
Polylactic acid packaging[18]	0.62
Single layer corrugated cardboard[49]	0.353
Double layer corrugated cardboard[49]	0.574
Plastic bag[49]	0.046
Kraft brown paper[50]	0.13
Low-density polyethylene (LDPE)[50]	0.02
Polypropylene[51]	1.63
Aluminium[52]	105.328

Table 7.2.3. Emissions factors for common packaging materials

Using the materials' factors is straightforward - multiplying the known mass of packaging with a previously calculated ratio value. It has to be said, that similarly to food product GWP, there appears to be a high variance in the published factors, usually due to either different system boundaries or manufacturing processes.

Fuel	Fuel density, g/L[46]	Indirect emission factor, mg_{CO2}/kWh[47]	Fuel energy content, kJ/kg[46]
Gasoline	737	239890.71	46400
Diesel	846	278961.75	45600

Table 7.2.4. Density, emission factor and energy content of common fuels

The table above is used when dealing with internal combustion engined vehicles with known consumption rates and engine volumes.

Flight distance, km	Carbon dioxide emissions, g/pkm	Carbon dioxide emissions, g/(km * kg)
< 500	206	2.458
500 - 1000	154	1.838
< 1000	450	5.370
1000 - 1500	130	1.551
1500 - 2000	121	1.444
< 2000	140	1.671
> 2000	111	1.325
1000 - 5000	300	3.580
> 5000	320	3.819

Table 7.2.5. Carbon emissions dependent on flight distance in passenger kilometres and kilograms per kilometre. Adapted from [36]

The data is based on passenger transport, which may contain mixed cargo on board. In an effort to generalise the formula, each passenger and their luggage can be considered as cargo of some mass. For approximating the emissions load per kilometre each passenger is assumed to be 83.8 kg on average, according to estimations from[48, p.68] for the average adult.

7.3 Prototype implementation considerations

EPCIS is designed to be compatible with any programming language or framework, with the only constraint being that communication between EPCIS endpoints uses XML. The entire back end of the prototype system is written in PHP, a common web technology supported by most servers and with plentiful documentation of itself and the third-party services used in this project. It is implemented in a modular fashion, reflecting the requirements outlined in the design. A general data input interface can be used at each stage where either a human or another system adds data to the flow. It defines the possible event types: harvest event, transit event, processing event, packaging event and storage event. Currently, only manual input is possible.

Initially, the prototype is developed in a naive manner, without the use of EPCIS. This is the first part of an iterative process, before committing to a vocabulary and data flow that is compliant with EPCIS. It is done in order to discover possible choke points or redundancies before a more complete system is implemented.

The module of the system that will generate events most often is the transportation aspect, happening between the other links of the value chain. This calculation requires a basic set of information - the distance moved and the type of vehicle and the useful mass, meaning the product or constituent parts. The type of vehicle is necessary to determine the emissions per kilometre of transport. For road vehicles this has to include the mass without a load, to know how much of the emissions can be attributed to the produce carried, the size of the engine, the type of fuel used and the manufacturers declared fuel consumption for any particular vehicle. This calculation (SOTA section X. Vehicle emissions) along with tailpipe emission, includes the indirect emissions of the fuel production, also known as ‘well-to-wheel’. The output of this calculation favours either low volume engine vehicles, high mass vehicles and electric vehicles. For other modes, for example aeroplanes, trains and ships, the calculation is much more ambiguous and therefore uses multiplication factors from existing research.

```php
function getPerKilometerEmissions($vehicle_info, $transit_mass, $fuels) {

    function icev($vehicle_info, $transit_mass, $fuels){
        $consumption = null;
        if ($vehicle_info[0] == 'diesel') {
            $consumption =
                (0.133 + (0.000253 * $vehicle_info[1] ) + //engine volume
                (0.00145 * ($vehicle_info[2] + $transit_mass)) + //getting the per kilometer emissions value based on
                (0.654 * $vehicle_info[3])); //declared consumption
        } else {
            $consumption =
                (1.15 + (0.000392 * $vehicle_info[1])) +
                (0.00119 * ($vehicle_info[2] + $transit_mass)) +
                (0.643 * $vehicle_info[3]);
        }
        $emissions = ((1/3600000000000) *
        $fuels[$vehicle_info[0]][1] *
        $fuels[$vehicle_info[0]][2] *
        $fuels[$vehicle_info[0]][3] *
        $consumption);

        return $emissions;
    }

    $per_km_emissions = null;


    //calculation differs dependent on fuel type
    if ($vehicle_info[0] == 'gasoline' || $vehicle_info[0] == 'diesel') {
        $per_km_emissions = icev($vehicle_info, $transit_mass, $fuels);
    } elseif ($vehicle_info[0] == 'electric') {
        $per_km_emissions = bev($vehicle_info, $transit_mass, $fuels);
    }

    if ($per_km_emissions != null) {
        return $per_km_emissions;
    } else {
        die('calculateTransitEmissions(): null output');
    }
}
```

Figure 7.3.1 Sample code snippet implementing the flow of calculating the per kilometre emissions for road vehicles

8. Discussion

The main aspect that is lacking in this project is the direct input of a company or organisation working in the food production industry. There is no reason to believe that the information found in the explored academic sources is not accurate, but in situations when a piece of software that may be interacted with in unpredictable ways is designed without the input of the people supposed to use it, it runs the risk of being based on best intentions, not reality. In a continuation of the ideas explored in this project, either in an academic or enterprise context, a thorough process must be undertaken to validate the assumptions laid out in this report. The key in creating a real Emissions Calculation Interface would be willing partners with a stake in using the finished product for actual operations not just as a marketing ploy, but to capture the long term competitive advantage of sustainability.

Another aspect that should be improved is the complexity of implementation of a system like this. It may have been an overstatement to attempt to create a full scale example of an EPCIS integration, rather than just a proof of concept it turned into. An actual product would require the resources of an entire IT department.

The discovered data can always be questioned as the diversity, quality, location and separation in time is variable. This creates an average image of reality that has never been true, thus a real system would require the most recent and, if possible, data and analysis of the business taking part in this system.

Climate change focused information may also vary in relevance to consumers and may be more of interest to companies themselves. A complete system could take advantage of collection of data over time, either to analyse or check the claims companies make about their own sustainability. Some consumers might not find the emissions total a meaningful metric in their purchasing choices, as it may be outweighed by other considerations, for example, price or brand loyalty. The separation of emissions per nutrient may not be an appropriate use of the principle, and should not be discussed without a deeper understanding of nutrition, not just the raw values in a product. Emissions data could be useful for supplements that can be created from either animal or plant sources, where a comparison of emission might be more fair.

From a software design perspective, the interfaces of ECI could have been designed in an alternative manner. Focusing instead on exposing the functions rather than facility focused packages. This would become a necessity, if additional types of facility could be connected to the core system and would allow for combining custom, modular interfaces. Currently, each of the outward facing data collection interfaces may contain duplicate functions. Even if in the backend it is a single, shared implementation, there is no logical reason why the interfaces shall be constrained in this way. For example, in a case where a processing facility may only need to generate QR barcodes, why should their software be modified to comply with the rest of the functions of the Processing data interface? Implementation would be more straightforward and less expensive if each of the functions could be used as a simple service and combined as necessary. This can be considered as an architectural requirement if developed for use as a real product.

There is a possibility that the specific output values for products would differ in systems with similar purposes. Variability is introduced the moment a system boundary is drawn. In the case of this project, a significant inclusion is the indirect 'well-to-wheel' emissions of transportation, increasing the transport emissions contribution by an order of magnitude. An important omission is the emissions after the product has reached the consumer's hands. The role of waste, composting and recycling of packaging can not be understated. Reasons to include or exclude certain parameters may be motivated by practical reasons such as access to data or, more cynically, the outcome or learnings intended to be presented by the use of such a system. A food producer may want to present themselves as 'green' thus highlighting the aspects of their business that are sustainability focused and downplay the attributes that are in conflict with this idea. Even though the inspiration for this project came from the interests of the wider retail industry - improved sustainability and positioning these companies as sustainable - the aim was to find an objective way of calculating emissions. The final design produces a figure but does not qualify it in relation to other food products. This judgement free approach is supposed to be much more about informing the consumer rather than activism. The informative aspect is also why it was attractive to form the ideas in the context of a data sharing solution, as a way of improving the richness of data in food retail, but possibly, across industries that produce physical goods for the mass market. The richer the information companies have about themselves, the more legitimacy they have over the claims they make. Transparency and accountability are at the core of creating trust between producers and the consumer market therefore the choice of participating in a shared emissions accounting scheme, regardless of whether it is based upon EPCIS or other standards, would be a significant step forward in creating awareness and the need for responsibility along the entire value chain, regardless of activism or marketing goals.

Sustainability, in general, sometimes appears to be an abstract concept, without clarity what are the actions that can be made to make oneself more sustainable. A business has a choice of how to influence their environmental, social and economic impact.

9. Conclusion

This report commenced with the problem formulation and it’s subquestions:

How can the EPCIS standard be used to calculate the environmental impact of consumer products?

- What are the principal, measurable sources of carbon emissions in food production?
- How can EPCIS be used to capture and communicate food emission data?
- How to calculate the carbon impact of a unit of food?

According to the collected data and methodologies of life cycle analyses and other investigations of the greenhouse gas emissions related to agriculture and food production the principal sources of carbon emissions are the growing process, including such aspects as fertilisation and use of heavy machinery, the energy use of processing, storage and packaging food products, transportation of raw and processed products to the consumer and waste through food loss along the value chain.

This information, in combination with EPCIS design principles, fed into the design of an Emissions Calculation Interface, that collects physical product attributes, for example mass, location, energy used, over a product journey and formalises this data into an event based system. This food emission data can then be aggregated and analysed to inform and increase transparency with the end consumer and business partners along the supply chain.

The chosen method for calculating the emissions of a single food product is allocation of carbon dioxide equivalent to a unit of food, proportional to the masses of all its constituent components, be it raw and processed food or packaging, as the components move, are split and aggregated into the final product over time and space.

The EPCIS standard, while not designed with sustainability within itself, can be a useful tool when combined with custom software architectures can improve the knowledge of producers and manufacturers in food and other industries, allowing them to identify inefficiencies that, if addressed, can have a positive climate and sustainability impact. A fully fledged EPCIS based system must be developed and trialled to determine whether it gives an analytical advantage alongside existing LCA methodologies and certifications.

10. Future perspectives

Carbon and other greenhouse gas accounting need not be limited to the food industry. There are no production and manufacturing processes that don't emit GHGs in some manner. LCA findings are designed for well defined, predictable processes, but they may be aided by more dynamic, real-time and data driven analysis tools. In business environments with tight margins and constant attempts to find competitive advantage, the necessity to understand your own processes is greater than ever.

Certification for labelling or membership in climate initiatives usually depend on fulfilling and maintaining some set of requirements. Organisations that maintain these certificates may be interested in understanding the processes of their members, both to ensure compliance and to identify areas for future improvement.

Large production corporations may produce thousands of products at hundreds of facilities, often sharing infrastructure with other businesses. A company may choose their contractors on the basis of their sustainability, or request they become part of the digital value chain along with the physical one.

Even though the calculation interface is intended to be objective or neutral, valid questions regarding trust in this system remain. A level of automation can mitigate attempts to circumvent measurement or input of false figures and an integration with some blockchain technology could be an option to improve this situation. In the specific case, EPCIS events already resemble submissions to a blockchain through their immutability. If the purpose of emissions accounting is creating or restoring trust, taking advantage of available technology is fast becoming a selling point for pioneering consumers.

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