

**AUTO-ID LABS**

# The Potential of the EPC Network to Monitor and Manage the Carbon Footprint of Products

## ***Part 2: Dynamic Carbon Footprint Demonstrators***

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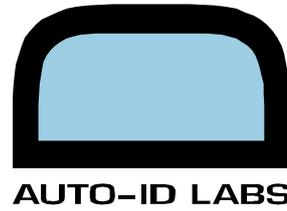
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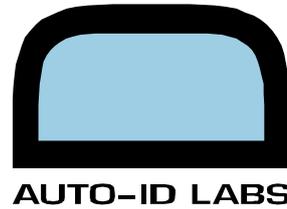


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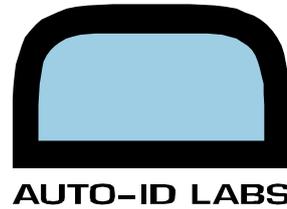
## Abstract

The carbon footprint of products is emerging as an important indicator for the economic and environmental sustainability of supply chains. Companies are increasingly using this measure to learn where in the value chain they can most easily and cost-efficiently reduce their greenhouse gas emissions. Pressure from major consumer segments and upcoming governmental legislation are adding to the internal pressure to account for product-level environmental impact. Companies have an opportunity to leverage supply chain tracking technologies to simplify the currently costly and time-intensive carbon accounting process. Once the product environmental impact “from cradle to grave” is automatically monitored, significant optimization opportunities become transparent for companies to implement them. Additionally, retailers can use the emission and energy-related data to offer environmentally-aware consumers value-adding services that directly address their information needs, at the retailer premises or at home.

This paper is the second whitepaper on “the potential of the EPC Network to monitor and manage the carbon footprint of products”. The first report provided a review of carbon accounting practices on the enterprise and product levels, outlining use cases where the EPC Network can be leveraged. The paper at hand presents a prototypical implementation of an integrated supply chain scenario where stakeholders benefit from automated environmental impact assessment and communication. In one part we focus on carbon footprint calculation and particularly on the usage of EPC event data to deduce emission-relevant parameters that are currently manually collected. In another part of the scenario we exemplify a mobile-based service that a retailer can offer to consumers who want to access carbon footprint information. The paper presents the underlying concepts and a prototypical implementation that showcases the value for companies. This lies in reduced time and money to conduct impact assessment studies, discovery of new optimization opportunities, and responding to consumer-demand for value-adding services. Early technology adopters will try to seize these opportunities, thereby acting as a market leader in their respective industries.

## 1 Introduction

Companies aim to increase their supply chain efficiency and reduce energy and waste costs by assessing the life cycle environmental impacts of their products and services [4]. They are also faced by increasing government pressure, e.g. recent legislation proposed by the French government requires that all products sold to consumers in France must have a carbon footprint label by January 2011 [10]. Also, several studies indicate that consumers want to know the carbon footprints of the products they buy, and some are willing to pay a price premium for eco-friendly products [20, 1]. These drivers are leading to several pilot



projects, notably in the consumer goods industry, that focus on the product carbon footprint as a prominent indicator related to greenhouse gas emissions and energy usage [5, 7, 19, 12, 21]. The goal of these pilots is two-fold: to find optimization opportunities across the supply chain and to communicate these efforts to the consumer via a carbon label.

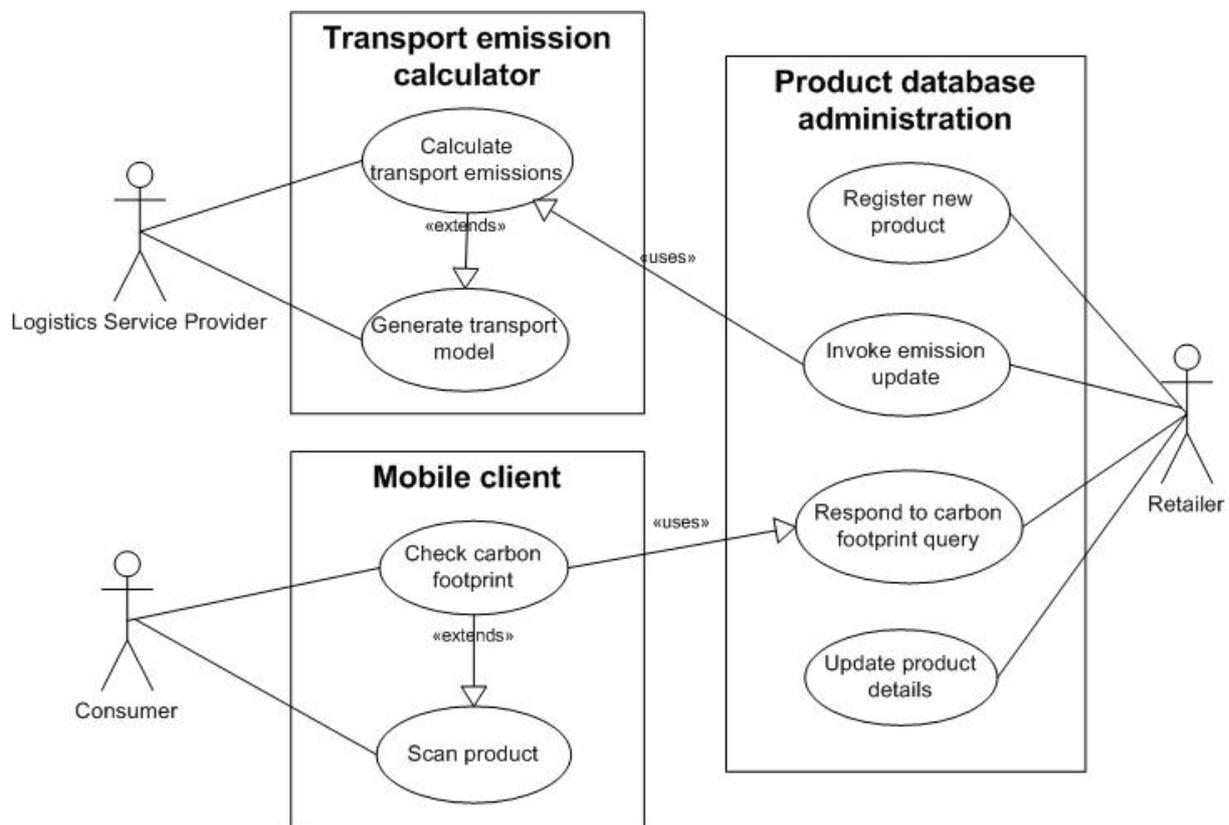
Several challenges still exist, both regarding emission data collection and communication to the consumer. First, the process of calculating an environmental indicator of one product is a time-intensive and costly process, especially because of data provisioning and model building. This makes it prohibitive for companies to calculate impact indicators for thousands of products in their portfolio. Also, emission-relevant data is dynamic in the sense that it changes often in time and among different instances of the same product [14]. These frequent variations have implications both on calculating the product carbon footprint values and communicating them to the consumer. Namely, an accurate, timely view of the emissions requires provisioning real supply chain data for calculating the impact indicators. This is still not the case in current carbon footprint pilots. On the communication side, consumers must be able to base their buying decisions on the updated values of the environmental indicators, thus rewarding or punishing the company's environmental efforts [2]. This is not possible with the current labelling pilots that rely exclusively on physical labels that cannot easily reflect the frequent supply chain changes.

In order to address the above shortcomings, this paper proposes the dynamic calculation of carbon footprints by leveraging track and trace data and communicating the results to consumers via mobile phones. We take the EPC Network as a prominent tracking infrastructure and deduce from it the required emission-relevant data. Since some of these attributes, e.g. the vehicle type, are currently not tracked in such infrastructures, this paper shows we extend the EPC network's capability to deduce the required data. We also demonstrate how the calculated emission values are dynamically made available for consumers on their mobile phones, thus bridging the current gap between back-end calculation and shop-floor consumer communication.

The approach presented in this paper provides several advantages. First, it extends the tracking capabilities of an existing infrastructure to cover data needed in the environmental impact assessment domain. It leverages these data to automate the time-intensive life cycle assessment (LCA) process, even providing more accurate results due to using real-world data. Finally, we provide consumers timely access to the updated results as soon as they become available, thereby empowering the end-users in their purchasing decisions.

Section 2 provides an overview of the integrated scenario that shows the roles and actions of the different actors. After the overview, we go in the details of the two major parts: section 3 explains the supply chain tracking and emission calculation focusing on the transport stages and section 4 outlines the presentation of information on the consumer's mobile phone. In each of these sections we (1) review the state of the art approaches pinpointing their shortcomings, (2) outline the proposed solution, and (3) describe our corresponding implementation. We conclude in section 5.

## 2 Scenario Overview



*Figure 1. Use case diagram of the overall scenario*

Fig. 1 provides an overview of the emission calculation and communication scenario. We focus on transport emissions as an example life cycle stage for the former but include all other aspects for the latter. The actors and their main actions are explained in the following.

**Logistics Service Provider (LSP):** The first actor is the one who manages and reports on the transport emissions of products. We assume this is done by a dedicated logistics service provider, but, depending on the supply chain set-up and data access rights, this can be carried out by other partners. The major use cases of the LSP are:

- **Generate transport model:** The LSP automatically generates, from EPC event data, a model that describes the transport processes of the product following a life cycle assessment (LCA) approach. This model can also be visualized in a graphical interface.
- **Calculate transport emissions:** After generating the transport model, the LSP can calculate the carbon footprint due to the cumulative product distribution activities or the average per unit product. This functionality is also made available via a web service that can be externally called.



**Retailer:** The second actor is the retailer whose main use cases focus on managing its product database. The retailer interfaces with the LSP whenever it needs to update the products' transport emission data and with the consumer whenever he/she queries for carbon footprint information. With this mode of interaction, the retailer and consumer don't have access to the EPC data; instead they would only see the resulting emission values. The retailer use cases are:

- **Register new product:** The retailer adds a product to its database, specifying basic product information in addition to estimates of the different life cycle emissions. Some of these won't change often, e.g. raw materials and production, but some are more dynamic and would be later updated.
- **Invoke emission update:** The retailer can call the web service provided by the LSP to update the transport emissions of any of the products it sells.
- **Respond to carbon footprint query:** Whenever a consumer queries for carbon footprint information, the response (data and user interface) is generated on the retailer's server and sent to the user's mobile phone where it is displayed.
- **Update product details:** Changes to "static" product information can directly be performed from the retailer's "admin" view.

**Consumer:** The last actor is any end customer equipped with a mobile phone that is capable of scanning barcodes.

- **Scan product:** The consumer scans the barcode of a product with his/her mobile phone. First feedback is shown already on the scan screen in the form of a scale from red to green, along with a mark that shows how the product at hand compares with the rest of the category. This provides a first visual feedback to the consumer.
- **Check carbon footprint:** Detailed environmental impact information, including the footprint breakdown and consumption tips to minimize the emissions can be displayed on the mobile phone.

This section gave an overview of the whole integrated scenario. The paper will focus on the innovative aspects of the scenario, namely leveraging the EPC network for transport emission calculation (section 3) and communicating the results to the consumer (section 4).

### 3 Determining Transport Emissions

This section explains how event data from the EPC network is leveraged to automatically calculate product transport emissions. We start with an overview of current state of the art tools pointing out their main shortcomings, and then we detail out the developed concept and its respective design.

## 3.1 State of the Art Environmental Accounting Software

There are mainly two kinds of environmental accounting software. The first focuses on setting up and managing emission accounts of enterprise activities, e.g. for reporting and optimization purposes. The second takes a product-view and its goal is to assess the cumulative impact of all the activities across the product's life cycle.

Example state of the art solutions from the first category are CarbonView from Supply Chain Consulting [18] and SAP Carbon Impact, formerly known as Clear Standards before being acquired by SAP [17]. These solutions allow companies to build inventories of greenhouse gas emissions or similar environmental indicators at different levels (e.g. plant, enterprise, supply chain). Enterprise carbon accounting software have many helpful features, such as capabilities to model actual business scenarios e.g. transportation routes, and they even allow suppliers to directly contribute data for supply-chain-wide emission calculations. Relevant data from enterprise management systems can be imported into the emission accounting models to save the effort of entering them manually. Comparison between different scenarios is possible, along with visualizing the results in dashboards.

The second category of environmental accounting software is known as life cycle assessment (LCA) software, according to the methodology they are based on. LCA is an internationally standardised methodology (ISO 14040 series) that quantifies resource consumption and potential environmental impacts of products. Usually, the entire product lifecycle is taken into account, from resource extraction over production and use until end-of-life. In an LCA, an inventory of energy and material flows related to the analysed product is built, usually neglecting the time when an input or an output takes place. In a next step, resources and emissions are related to impacts such as climate change, land use, or resource depletion, and are typically expressed in the form of indicators, e.g. CO<sub>2</sub>-equivalents for climate change. This step is called the life cycle impact assessment. Two of the most widely used LCA software tools are GaBi from PE International [15] and SimaPro from PRé Consultants [16]. The object of study of an LCA project usually involves numerous processes across its lifecycle, typically spanning many partners "from cradle to grave". LCA tools enable users to assess the environmental impact of products and services by putting an environmental cost of each process involved in the product's lifecycle. The state-of-the-art software assist users in many important aspects of their work, including scope specification, product lifecycle model building, process tree visualization, data provisioning, providing impact assessment methods, and finally calculating the life cycle inventory and performing the impact assessment.

Despite the advanced capabilities that environmental accounting tools offer, they still have some shortcomings that prohibit impact calculation in an automated, accurate manner. Taking product transport emissions as an example impact category of a highly dynamic nature, the presented software does not rely on real world tracking data but rather on aggregated process information, e.g. total amount of product transported in a certain period, an estimated percentage share of the used modes of transport, etc. This reduces the accuracy of the outcome and the confidence in the results. Also, LCA software still requires

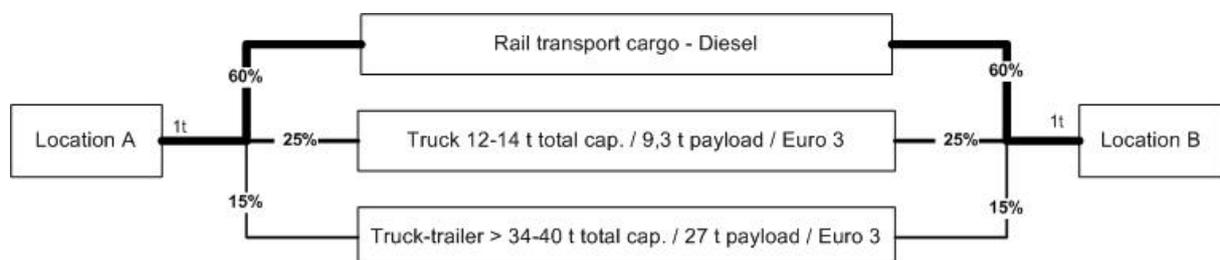
the users to “manually” build the product model by mapping out each life cycle process and collect its respective data. This is a costly and time-intensive effort that would prohibit companies from performing these studies on thousands of products in their portfolios. The next subsection presents a concept where track and trace data is used to automatically generate and visualize the transport part of an LCA model, in addition to calculating the resulting environmental indicator values.

## 3.2 Extending the EPC Network Tracking Capabilities to Determine Transport Emissions

This subsection explains how we extend the tracking capabilities of the EPC Network to deduce supply chain parameters crucial for environmental indicators and then use this information to generate the life cycle models and calculate the respective transport emissions. We specify the required data capture setup, then outline how the data is collected and finally used in the model building and emission calculation.

### 3.2.1 Data Capture

The EPC Network is suitable to track data sources needed in LCA studies because these require product trace information e.g. where the product and its components have traveled. However, additional data sources are important for environmental impact, e.g. vehicle type, and are not found in EPC events. This paragraph outlines how real-world data is captured to enable the tracking of the required parameters.



*Figure 2. Modelled transport processes*

Each transport segment that a product covers across the supply chain, identified by two end locations and a vehicle type, should be included in the LCA model. For example, transports between locations A and B carried out using different vehicle types are considered as different transport segments and are modelled as such (c.f. Fig. 2). The different vehicle types result in different environmental impacts, thus the need to differentiate them for proper assessment. Since this information isn’t normally captured in EPC events, we have to provide a reader-infrastructure set-up to deduce the vehicle type without imposing any

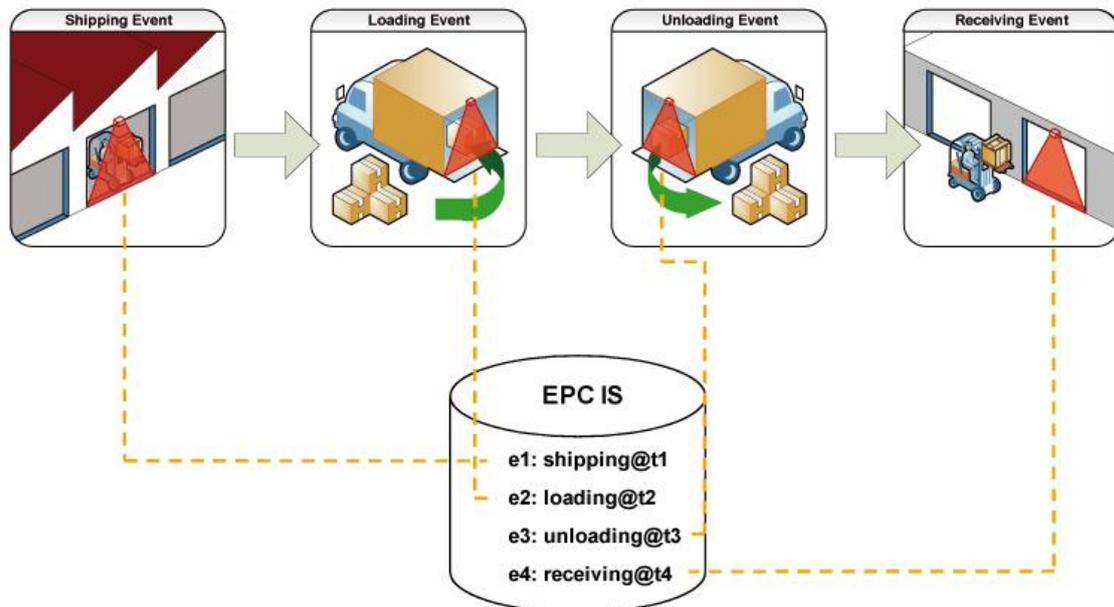
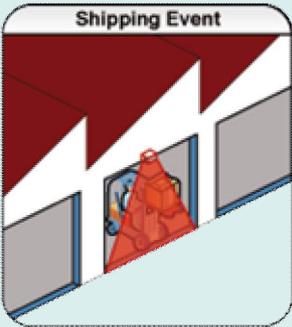


Figure 3. Events comprising a transport process

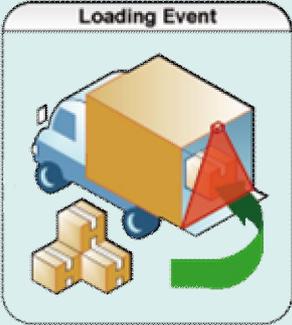
change to standard EPC events. Additional data is necessary to build the life cycle transport model, including start and end locations, the distance between them, and the mass of the transported product along each segment. In the following we present the data capture steps for one example transport segment that allow us later on to collect all this necessary information.

Four EPC events pertaining to the one object (e.g. item or aggregation of items) are needed to capture emission-relevant data for one transport segment. These events – shown in Fig. 3 – are shipping event (captures the start location), loading & unloading events (capture the vehicle type), and receiving event (captures the end location).

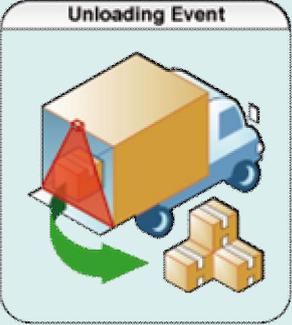
**Shipping event:** The object is scanned by a reader located at the shipping dock of a fixed geographical location, e.g. a manufacturing plant or train station. The resulting event is stored in an EPC IS repository with the attributes shown below.

	epc	unique object ID
	bizStep	shipping
	readPoint	Stationary reader identifier SR1
	bizLocation	location of the shipping entity
	eventTime	shipping time t1

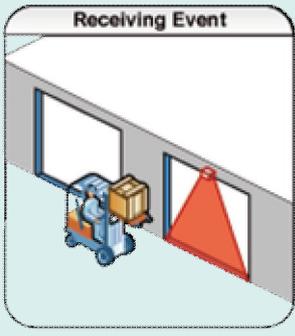
**Loading event:** To automatically deduce the transport process when calculating the emissions (c.f. Fig. 2), an identifier that points to the vehicle type is needed already at data capture. This can be achieved by having a mobile reader that is onboard the vehicle. Once the tagged object is loaded, the RFID reader generates an event with the attributes shown below. The transport process can later be deduced by knowing which reader was used from the readPoint attribute.

	epc	unique object ID
	bizStep	loading
	readPoint	Mobile reader identifier MR
	bizLocation	null
	eventTime	loading time t2

**Unloading event:** The unloading event is the inverse of its loading counterpart. The same mobile reader scans the object when the transport is concluded and an event is stored in the EPC IS repository. The attributes are shown below.

	epc	unique object ID
	bizStep	unloading
	readPoint	Mobile reader identifier MR
	bizLocation	null
	eventTime	unloading time t3

**Receiving event:** The last of four events is generated when the object is received at the intended location. There it is scanned by a second stationary reader and the attributes of the stored event are as follows.

	epc	unique object ID
	bizStep	receiving
	readPoint	Stationary reader identifier SR2
	bizLocation	location of the receiving entity
	eventTime	receiving time t4

This paragraph illustrated the required infrastructure setup to capture the needed data for one transport on a sample segment. Assuming other transport events are captured in a similar way, the next paragraph describes how the emission-relevant data are deduced.

### 3.2.2 Data Collection

The data needed to derive transport models are deduced from the EPC events stored in EPC IS repositories. An EPC Discovery Service can be used to collect the events from different repositories, but for our purposes we can assume that this step is already done. All the raw data required to model a single transport operation is expressed in a quadruplet of events as shown in Fig. 4.



Figure 4. Example of a quadruplet

The transport process information is collected as follows:

- **Start location:** The starting location is derived from the bizLocation of the shipping event.
- **End location:** The end location is derived from the bizLocation of the receiving event.
- **Type of transport:** The loading and unloading events include the same readPoint, namely the mobile reader identifier MR. The exact vehicle type can be determined through a mapping of mobile readers to specific transport processes.
- **Distance travelled:** The start and end locations include geographical location data. We identify the covered distance by means of an external distance calculator service that takes the locations as input.



- **Transported items:** The number of transported items (in case of aggregations) and their product class is already available in the EPC events.
- **Transported mass:** In addition to the number of transported units, the mass per unit is needed to calculate the total mass per transport. This is retrieved via an interface to an enterprise system that provides product master data.

### 3.2.3 Model Visualization and Emissions Calculation

Emissions pertaining to each transport segment are calculated using the formula:

$$\text{emissions} = \text{emission factor} \times \text{total mass} \times \text{distance}$$

The mass and distance are collected as explained above and the emission factors are retrieved from LCA databases. To find the total environmental impact (of transporting all the instances of the product), we sum up the emissions for each transport segment. Users can also query the impact of a specific (normalized) mass of the product, e.g. the footprint due to one unit. This requires a dedicated mass balancing step in the LCA model. The model can be visualized similar to what is offered by state of the art LCA software.

## 3.3 System Design and Implementation

This subsection provides an overview and screenshots of our developed prototype. The system is completely implemented in JAVA and uses the Fosstrak [9] implementation of EPC IS. The emission factors of the transport types are based on the GEMIS [13] LCA database.

In addition to the main functionalities explained above, we also implemented an event simulator through which transport events (quadruplets) can be easily generated and stored in an EPC IS repository. This is used for demo purposes and also allows companies to test and compare supply chain scenarios. The user specifies the transported product class, the start and end locations, the LCA transport process, and the quantity of items involved. The application then simulates the events with the chosen attributes and sends them to the EPCIS repository through the EPCIS capture interface. As the simulator is not the novel component of our system, we will not go into more details about its design and implementation.

### 3.3.1 Transport Footprint Creator

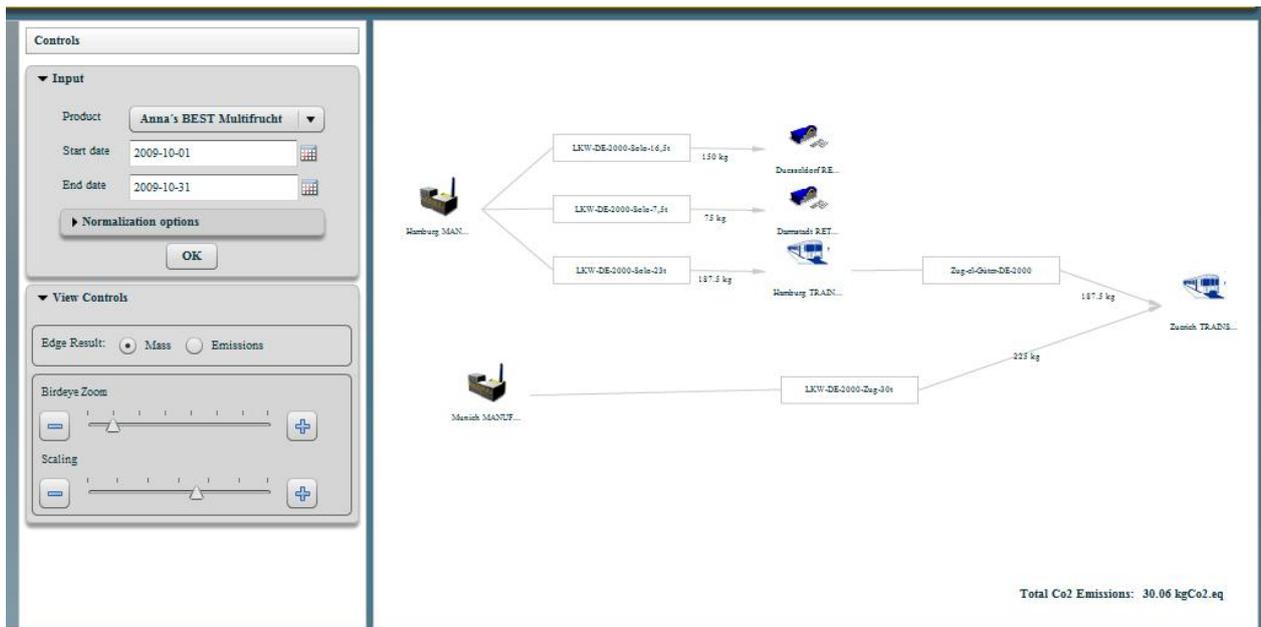
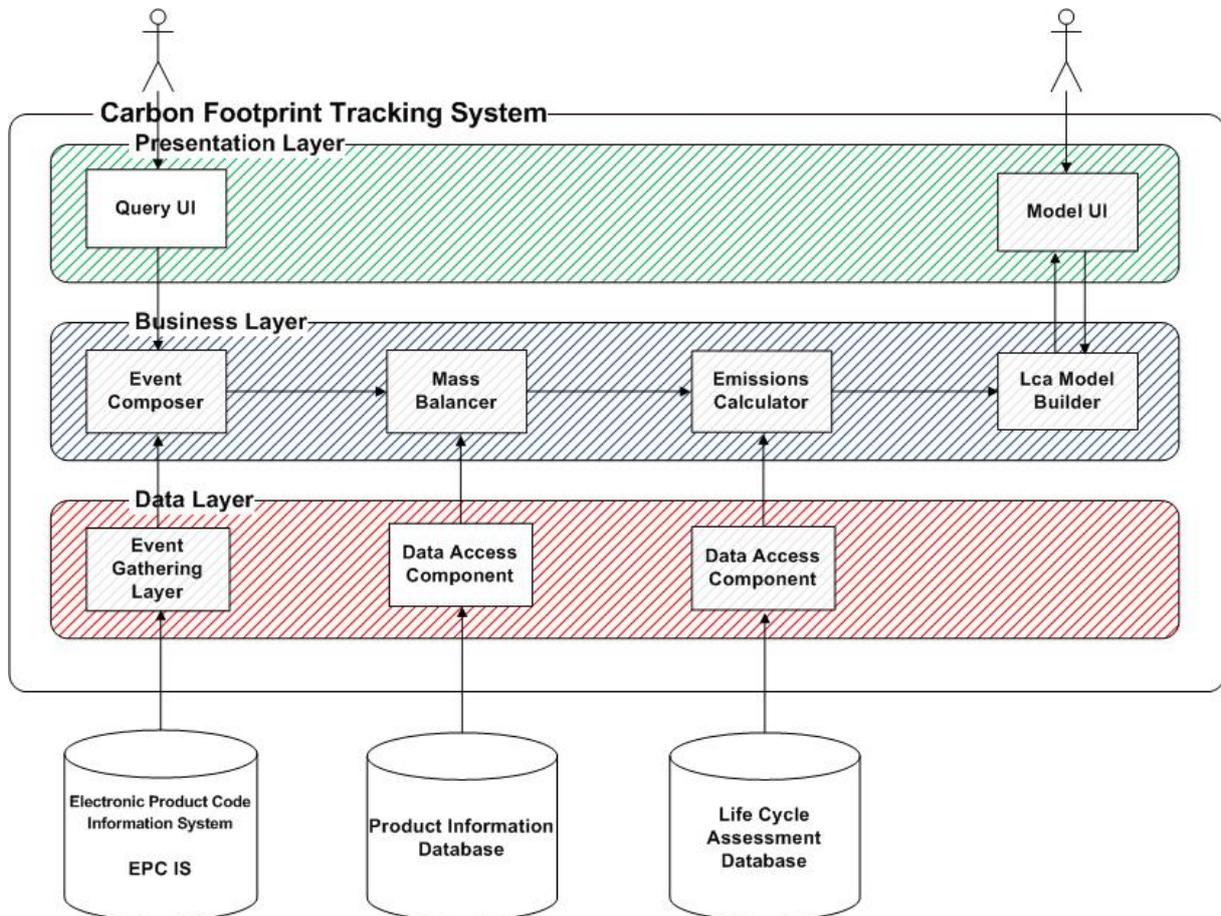


Figure 5. Screenshot of a the user interface

The transport footprint creator is the core application. Its aim is to find the transport emissions of a certain product via an automated LCA study that relies on track and trace data. The user is presented with an input interface as shown on the left pane of Fig. 5. The expected input parameters are:

- The product class, selected through a drop-down list
- The start and end date – denoting the period which the study will cover
- Whether the results are by total transported units/mass or normalized mass, e.g. of one unit.

After clicking on the OK button, the application processes the data and displays the generated LCA-model on the right pane of Fig. 5. The model shows all locations between which items were shipped, the types of transport used, as well as the amount transported in units, or kg. The resulting carbon footprint value is shown in the bottom-right corner of the user interface. It denotes the emissions due to the overall transport or due to the normalized mass depending on the selected option. It is possible to switch between the results-display options within this interface.



*Figure 6. Transport footprint creator system architecture*

The system architecture, shown in Fig. 6, is comprised of the following modules:

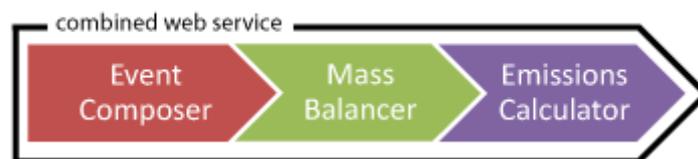
- **Query UI** accepts user input and forwards it to the event composer after validating it.
- **Event Composer** gathers all the transport events for the queried product and time period via the Event Gathering Layer. It builds a transport-model that includes each transport process.
- **Event Gathering Layer** provides the possibility to gather EPC IS events from an EPCIS repository through the EPC IS query interface. It offers the option to gather not only events for a certain item, but also for a product-class. This module was developed in the BRIDGE research project [3].
- **Mass Balancer** receives the transport model from the Event Composer. It balances the transported masses for each transport process if a normalized mass was chosen. It also gets the unit mass from the product information database to calculate the actual transported mass. The additional data is added to the transport-model.
- **Emission Calculator** determines the transport emissions. It gathers the emission factors for each type of transport from the LCA database. The emissions are summed up to one value which is added to the transport model.

- **LCA Model Builder** builds a graphical LCA-model out of the transport model data.
- **Model UI** is a user interface that comprises the graphical LCA model and the calculated transport emissions value. It provides the option to arrange the structure of the LCA-model as well to switch between different results-display options.

### 3.3.2 Transport Footprint as Web Services

The functionalities of the transport footprint application are also made available as web services that can be invoked by a client application. Providing web services allows different kinds of requests from various companies to be answered, thus leading to a more flexible, scalable, and easily deployable application. This approach also offers only certain information to users depending on the calling application's requirements. For the integrated scenario described in this document, only the transport emissions per unit of product are needed by the retailer to update its database. The logistics service provider offers a web service, based on the components already implemented, that provides this output.

The web services are based on the components of the standalone application. Each component from the business layer is transformed into an independent web service: Event Composer, Mass Balancer, Emissions Calculator, and LCA Model Builder. The mandatory first called service is the Event Composer. It builds the transport model which is the common foundation for the remaining services. Other service combinations are then called depending on the required output of the client application. For our scenario, the retailer needs the transport emissions per unit product to update its database, therefore the first three web services should be composed into a parent service that internally calls its components and returns the results (c.f. Fig. 7).



*Figure 7. Combined web service that returns the transport emissions*

This section illustrates how the tracking capabilities of the EPC Network can be extended to automate transport emission calculations, thus allowing retailers to update their carbon footprint information over web services. The next section will complete the picture by showing how consumers can access the updated information on their mobile phones.

## 4 Displaying Carbon Footprint Information

We now focus on providing the consumer with the calculated environmental impact. The first subsection provides an overview of carbon labels from recent pilots, which are the current approach to communicate this information. We then present a concept and implementation that addresses the shortcomings of physical carbon labels.

### 4.1 State of the Art Carbon Labels

An increasing number of brand owners plan to make carbon footprint information of their products available to consumers. This calls for effective labelling schemes, the most important of which are reviewed in the following.

Groupe Casino, the French retailer, has launched together with ADEME (French Environment and Energy Management Agency) a carbon labelling initiative on a selection of its own-brand products [12]. On those pilot products, Casino shows a carbon footprint scale with seven slots and provides the footprint value of the labelled product in the respective slot, thus clustering their entire portfolio by carbon footprint value (c.f. Fig. 8). This provides consumers with a tool for comparing different products. Consumer research conducted by the retailer chain showed that most consumers want to see information they can trust (thus the values), however the carbon intensity of a product should be easily recognizable (thus the scale) [11].



Figure 8. The Casino Carbon Index

The Carbon Trust offers a carbon reduction label (c.f. Fig 9) with a footprint value displayed as a mass of CO<sub>2</sub> equivalents, along with tips for consumers to help them reduce emissions during the use-phase (washing, cooking, disposing, etc). The label also shows how the product compares with less carbon-intensive alternatives of the same category (as opposed to the Casino scale that spans all categories). Optional details may be included either on the packaging or on the supporting sales material, such as an element explaining how the footprint is created [6].



*Figure 9. Carbon Trust label*

As opposed to the above examples, Climatop is labelling only the least carbon intensive products out of sample categories. The first projects were with Migros, the Swiss retailer, and currently other suppliers are going through the certification process for selected products. The climatop approach is to offer a logo as in Fig. 10 (without a footprint value) to the product with the least emissions in its category, also referred to as the “Carbon Champion”. The aim is to simplify the decision-making process for consumers [7].



*Figure 10. Climatop label*

This subsection showed that there are many differences among the labelling schemes, e.g. in the type of label and the amount of displayed information. What is common between them is that they are all applied physically onto the products, which implies the following two shortcomings: (1) they cannot be easily updated to reflect changes in the carbon emissions and (2) there is often limited space on product labels to display detailed information as some labels aim. The next subsection describes a concept that addresses these issues.



## 4.2 Visualizing Dynamic Carbon Footprint Information

This section shows how a consumer can query the carbon footprint of a product by scanning its barcode and receiving back from the retailer's database the latest environmental impact information. We first derive the requirements and then describe the usage scenario that satisfied them.

### 4.2.1 Requirements Derivation

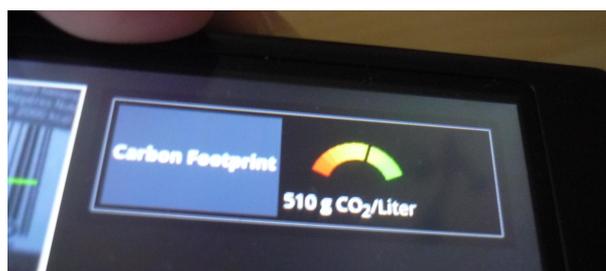
The requirements were derived from the state-of-the-art labelling schemes and input from retailers and domain experts. The reasoning and results are summarized below:

1. **Product identification.** The first decision is which product identification technology to use. An earlier prototype that we developed [8] uses RFID to demonstrate that instances of the same product can have different footprints. It became clear based on received feedback that one value per product class is crucial to avoid consumer confusion. Also, 1D barcodes still represent by far the most widespread identification feature in the consumer products industry. All this led us to decide for 1D barcodes as the identification technology of choice.
2. **Dynamic presentation.** Consumers shall be able to see the updated emission information as it becomes available to the retailer. This overcomes a major shortcoming of the current approaches.
3. **Comparative benchmarking.** The primary purpose of the application is to assist consumers in their purchasing decisions, ultimately favouring the less carbon-intensive products. Therefore, the most helpful information per product is a scale from red to green that shows how it compares with alternatives of the same category. Such a representation enables the consumer to have a quick feeling as to whether his choice is relatively green.
4. **Quick and easy interaction.** It is critical that users can scan and learn about the impacts of several products with minimal clicks per product.
5. **Support for “power users”.** For most users, minimal information is ideal because they don't have a deep understanding of the structure of carbon footprints. However, many consumers want to learn more details either to gain trust in the calculations or to educate themselves. Such power users shall have the option of a prolonged interaction with the device to achieve this.
6. **Category champions.** Labels from Carbon Trust and Climatop point to the best-performing product of a category. Our application shall also provide this feature since it helps decrease shopping footprints.

7. **Usage recommendations.** In many cases, the after-sale stage of the product life cycle is responsible for a significant portion of the total impact. We adopt the Carbon Trust practice of providing consumers with tips to reduce the use-phase emissions, e.g. when washing clothes or cooking meals.
8. **Footprint details.** Users might want to query additional details about the emission calculations, such as the methodology used and the breakdown into life cycle stages. This shall be provided as an additional view to satisfy consumers' need to trust the scientific approach used in the estimates.

## 4.2.2 Usage Scenario Description

Following is a description of the interaction scenario that realizes the derived requirements. The consumer identifies a product by scanning its barcode (req. 1). Once the product is identified, a “widget” is displayed that shows how the product footprint compares to the rest of the category (req. 3). Widgets are small web applications, designed to display in compact form concise information at maximum speed with minimal user interaction. For most consumers, the comparative scale provided by the widget (c.f. Fig. 11) is enough so they continue scanning other products. The widget is updated every time a product's barcode is successfully scanned and recognized, ensuring a quick and easy interaction (req. 4). Users that have more time, expertise, or interest can navigate to more elaborate views of the product footprint, its breakdown into life cycle stages, and how they can help reduce it (req. 5, 7, 8). Further actions are then possible from the detailed views, for example checking for the least carbon intensive alternative of a category (req. 6). All the emission values, including the transport part of the emission breakdown, represent the actual retailer's numbers (req. 2).



*Figure 11. First feedback upon scanning*

## 4.3 System Design and Implementation

This subsection provides an overview of the system implementation and shows sample screenshots of the application. We chose the established client-server software architecture. On the front-end client we use the Google Android platform to call web services and display the results to consumers. The retailer's database and the carbon footprint service are hosted by Google App Engine servers. The services are based on standard web technologies

making it feasible to reuse their visual components on any device that supports HTML, so there are no strict limitations regarding the client. An overview of the server- and client- side implementations is provided in the next paragraphs.

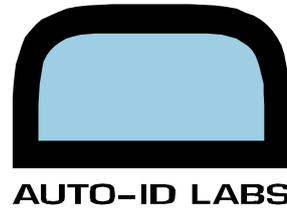
### 4.3.1 Server-Side Implementation

The server-side implementation is where most of the logic takes place. Most importantly this includes managing the product databases, storing carbon-footprint relevant data, and generating the HTML-based responses to the client queries. The Google App Engine was chosen for the implementation because of its scalability, speed, and ease of development. In addition, three main features of the Google App Engine that we use are (1) BigTable, an object database management system that enables the creation of dynamic data models, (2) Google Account API, an authentication service used to keep track of users' shopping profiles, and (3) Google Chart API, used for building carbon footprint charts and sending them to the client. The server code base is written in Python. An administration back-end interface, based on the AppEngine Admin package, is implemented to simplify the tasks of managing records in the database.

### 4.3.2 Client-Side Implementation



Figure 12. Detailed carbon footprint information



The most important activities happening on the client side are the barcode scanning, calling the web services over HTTP, and displaying the received HTML response. We chose the Android platform for implementation particularly because of its camera's auto focus functionality that leads to high performance and reliability when scanning 1D linear barcodes. The client application leverages the phone's build-in camera to scan the product codes, and builds on the ZXing open-source library designed to decode the identifiers. The displayed content is a web page built on the server side in response to HTTP GET requests.

In addition to the widget of Fig. 11, two details tabs show elaborate information as provided in Fig. 12. The emission values are based on the latest information available to the retailer. This includes the distribution (transport) part of the footprint chart on the right, which is directly calculated from EPC Network data as explained in section 3.

## 5 Summary and Outlook

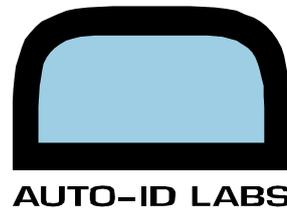
This paper presented enterprise- and consumer-side demonstrators that show the value of information technologies in determining and communicating environmental impacts of products, taking the carbon footprint as a prominent example. We showed how the EPC Network can be used to deduce environmentally-relevant parameters from the supply chain, such as vehicle types and transport routes. Our work used these real-world data to automate the currently lengthy carbon accounting process and provide more accurate results that reflect supply chain dynamics. The paper also presented a consumer-side mobile demo that leverages the automatically calculated carbon footprint values to display them to ecologically-aware shoppers. Upon scanning a product, the consumer would see up-to-date information on his/her mobile phone that helps in the purchasing decision. This overall integrated scenario connects different supply chain partners with the retailer and the consumers, thus closing the current gap between back-end emission calculation and shop-floor consumer communication.

The back-end carbon accounting logic in the presented demonstrator focuses on transport as an example product life-cycle stage whose emissions are automatically calculated. The overall picture will be complete when environmental impact from other stages is also dynamically determined. However, the leverage of the EPC Network will not be as high, especially in stages where the product is still not whole, e.g. manufacturing and raw material extraction. A combination of different information sources, such as enterprise management systems and LCA databases, should be queried for the relevant data to reach a totally automated, accurate view of the product emissions.

In addition to extending the current prototype to reach a holistic view of the carbon footprint, we also plan to perform studies on case products to determine the carbon reduction potential realizable by information technologies. The aim is to evaluate the value of IT-based solutions in terms of reduced emissions across the supply chain. Companies will use the results to determine which approach has, for them, the highest optimization leverage.

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