Modeling and Analyzing the Carbon Footprint of Business Processes

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Abstract Many corporations and individuals realize that environmental sustainability is an urgent problem to address. In this chapter, we contribute to the emerging academic discussion by proposing two innovative approaches for engaging in the development of environmentally sustainable business processes. Specifically, we describe an extended process modeling approach for capturing and documenting the dioxide emissions produced during the execution of a business process. For illustration, we apply this approach to the case of a governmental Shared Services provider. Second, we then introduce an analysis method for measuring the carbon dioxide emissions produced during the execution of a business process. To illustrative this approach, we apply it in the real-life case of an European airport and show how this information can be leveraged in the re-design of "green" business processes.

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1 Introduction

The increasing awareness for the necessity of sustainability in living and working has put "green" or "sustainable" practices on the radar screen of organizations. Environmental constraints are increasingly imposed on organizations, and demand new levels of operational compliance.

In this context, colloquial terms such as Green IT (Poniatowski, 2009) have emerged to acknowledge information systems and the surrounding business processes as contributors to environmental problems as well as potential enablers of green, sustainable solutions. Yet, while organizations around the globe increasingly realize the demand and potential of the transformative power of information systems (Watson, Boudreau, & Chen, 2010), to date, few examples of such approaches have been reported in studies.

In this chapter, we contribute to the emerging body of research on sustainability in two ways:

- We describe an approach for documenting the carbon footprint of business processes in an extended business process model.
- We describe an approach for measuring the carbon footprint of business processes in an extended activity-based costing model.

With these two approaches, we extend the current body of knowledge in Green Business Process Management specifically in two stages of the process lifecycle, viz., modeling and analysis. This way, we set a platform for future contributions that can (a) extend our work to other stages of the business process lifecycle (e.g., improvement and implementation), or (b) work on the integration of the approaches (e.g., how the extended models can be leveraged in process analysis or improvement).

We proceed as follows: Following this introduction, we review existing research on sustainability and briefly discuss existing approaches to measuring carbon footprints in organizations. Next, we describe specific extensions to process modeling notations to allow for the documentation of carbon footprint information in a process model. We then apply our modeling approach to the case of a Direct Invoicing process at an Australian Corporate Services provider. Then, we introduce a method for measuring the carbon footprints of business processes. We apply our measurement approach to the case of a European airport. Finally, we conclude this chapter with a review of contributions, limitations and implications.

2 Background

Sustainability is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987, p. 43). Our interest specifically is on environmental aspects of sustainability. The most important environmental sustainability challenge is known as the problem of *global warming*, the increase in the average temperature of Earth's near-surface air and oceans. Global warming is primarily caused by greenhouse gas (GHG) emissions, in particular through Carbon Dioxide produced collaterally through human-triggered actions, such as business travels, paper production, manufacturing and others. Therefore, these actions are manifested also in the execution of organizational business processes.

Of course, we are not the first to examine environmental issues and organizational performance. Contributions on environmental quality, lean production, regulatory mechanisms, environmentally benevolent activities, and sustainable initiatives have been made in operations research, organizational science, behavioral psychology or econometrics, to name just a few. Yet, few contributions exist that examine the contribution of an organization's business processes to environmental sustainability.

We believe that Business Process Management can assist in the endeavor to extend our perspective on processes and the wider organizational performance. This is because Business Process Management tools and techniques assist organizations in their efforts to (re-) design the organizational processes in light of compliance regulations, operational agility, or other business imperatives such as time, quality or costs (Reijers & Mansar, 2005). The dedication of BPM approaches to eliminate waste under the "paperless office" paradigm indicates its potential for making processes more environmentally sustainable. We believe that it is possible to extend and adopt Business Process Management tools such that they also allow organizations to manage and improve the organizational processes in light of environmental considerations.

This work is an important move forward because, nowadays, global warming has raised attention about so-called eco-friendly business activities, defined as those processes that produce less carbon dioxide as a main cause of global warming. In this context, it is often referred to the *carbon footprint of business processes* as a measure for the carbon dioxide production alongside organizational operations such as paper-intensive processes (e.g., a bank's mortgage process), fuel consuming processes (e.g., business travels) or a process that produces waste materials and unnecessary power sources (e.g., defect processes, quality rectification processes).

Carbon footprint is commonly understood as the amount of carbon dioxide (CO_2) emitted through the combustion of fossil fuels during daily activities – in the case of a business organization, the amount of carbon dioxide emitted either directly or indirectly as a result of its everyday process operations. It is expressed as grams of CO_2 equivalent per kilowatt-hour of generation (g CO_2 eq/kWh), which accounts for the different global warming effects of other greenhouse gases.

To facilitate the improvement of the carbon footprint of business processes, appropriate steps have to be taken alongside the complete business process lifecycle (Mendling, 2008), viz., in the stages design, implementation, enactment and evaluation. Because within this lifecycle, the design and evaluation phases are important because they allow for the development of (green) business processes as well as for their analysis, we will concentrate our discussion on these two stages. To that end, in the following we firstly describe an approach to facilitate the documentation of the carbon dioxide emissions alongside a business process.

3 Modeling the Carbon Footprint of Business Processes

3.1 An Extended BPMN Notation

Process modeling is one of the key tools used within Business Process Management to describe the activities, tasks, and processes of an enterprise (Mendling, Reijers, & Recker, 2010). Process modeling is essentially a cognitive design tool, and the role of process modeling is to understand what you do now, and what you might want to do in the future. Because process modeling encompasses IT systems, information, activities, actors and business rules and other documentation, it appears an adequate tool in designing sustainable processes (Seidel, Recker, Pimmer, & vom Brocke, 2010), especially since resource consuming activities can be captured.

Process models are designed using so-called process modeling languages (sometimes called notations or techniques), i.e., sets of graphical constructs and rules how to combine these constructs. At present, the Business Process Modeling Notation (BPMN) denotes the industry standard for process modeling (Seidel et al., 2010), and it is this standard that we now seek to extend to present appropriate modeling constructs to capture carbon footprint information relevant to a business process.

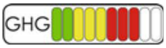
BPMN can help to gain better understanding of which activities that produce green house gases, most importantly carbon dioxide (CO_2). By defining an extended notation to indicate the activities which impact on the process emission of CO_2, a BPMN process map can be used to design processes on basis of sustainability considerations.

Activities that produce CO_2 can be characterized by the base of their *emission source* and their *method of producing* CO_2. For instance, paper, electricity or fuel can be defined as main source of CO_2 production in a business. Furthermore, activities such as unnecessary business travels, or redundant tasks may accumulate superfluous CO_2 on basis of these emission sources. The same level of concern can also be directed towards alternative means for reaching the same goal, such as alternative modes of transportation or similar measures.

Therefore, to allow for process design decisions that incorporate carbon footprint information as an important design consideration, we introduce the following BPMN notation extensions to capture activities, carbon dioxide emission sources, and flow of CO_2 in a BPMN process model (see Table 1).

Figure 1 gives an example of how these notation extensions can be used in conjunction with the BPMN specification. In the example, activities are characterized by defining which activity falls into which resource consumption group (e.g., fuel, paper). By calculating the amount of GHG emission for each activity, the example also displays the overall GHG emission levels. The indicator notation elements assign to each activity the exact amount of produced GHG, which allows calculating the GHG emissions per pool, and subsequently for the overall process.

Table 1 Suggested BPMN notation extensions

Construct	Notation	Specification
Fuel consuming activity		This notation is attached to an activity that produces CO_2 by using fuel as main source. Examples include business travels, transportation, and others
Paper consuming activity		This notation is attached to an activity that produces CO_2 by using paper. Examples include creating paper invoice, filing paper report, and others
GHG emission indicators	 or 	These notation constructs can be assigned to each pool or swim lane to indicate the level of GHG (mainly CO_2) emission in the relevant (part of the) process. Color coding can be used to display the overall level of GHG emission in the process. Else, the precise amount of GHG emission produced can be specified
GHG flow		The GHG flow construct is used to show the flow of GHG in a process and to connect emission producing activities to the GHG emission indicators

With these simple notation extensions, processes can be documented in light of their contribution to the carbon footprint of an organization. Such modeling enables process designers to identify on an appropriate level of detail the sources and main drivers of carbon emission alongside the value chain of an organization, and to use this information in the design or re-design of organizational processes that comply with environmental considerations or legislator demands.

3.2 Case Study: The Direct Invoicing Process

We applied our modelling approach in a case study with Seamless Service Provision (SSP), an Australia-based organization that offers financial and human

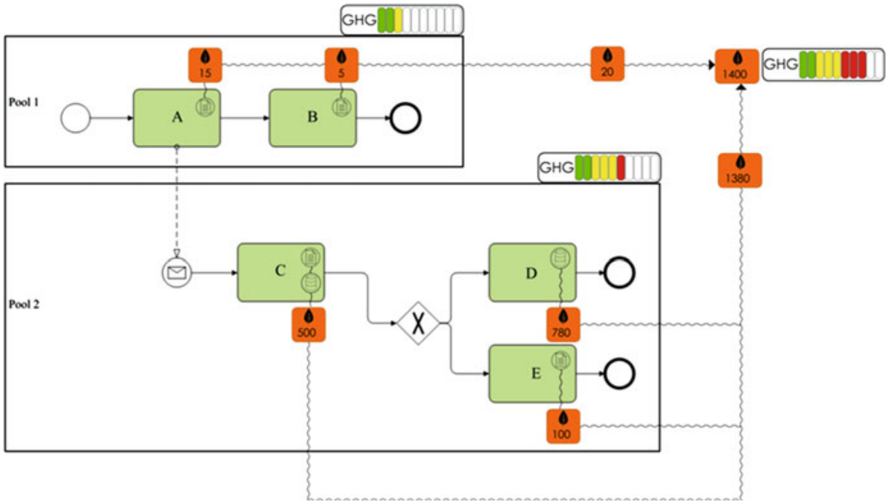


Fig. 1 Sample extended BPMN model including carbon footprint notation elements

resource services to organizations in the private and public sector. One of these services is the payment of so-called direct invoices for its clients. A direct invoice is an invoice without a corresponding purchase order.

SSP receives between 15,000 and 25,000 paper-based invoices per month. The invoices arrive in the incoming mail centre in the city centre (Office 1). Invoices are screened, entered into a system and then forwarded to Data Entry Officers at Office 2 in the north of the city (10 km distance from Office 1). Incomplete or incompliant invoices (10% of all invoices) are sent back to the client via postal mail with the request to complete the invoice.

The data entry officers then manually attach vendor master records to the invoices. The internal mail collects these forms and takes them to the master data entry department. The master data entry department creates SAP master data (takes 1–5 days) and then the invoice is ready to be entered in the SAP system by Data Entry Officers.

Validation Officers sort the invoices and print 10-page reports per 100 invoices (60 min for a batch of 100 invoices). Invoices are now ready for payment. The Payment Office runs a payment process every week. This is a highly automated process, at the end of which a report is generated. This report will be sent via mail to the individual clients to inform them about the successful payment of the invoice. Also, it will be sent to SSP's Accounts Receivable Department at Office 3 located 3 km away from Office 2. This department generates monthly invoices for SSP's clients. Third, the payment report will be sent to the Registry (same building). The employee in the Registry selects the paper-based invoices that have been paid and archives the invoices. Sometimes, vendors or clients have an issue with the payment and in these cases it is required to track down the original paper-based invoice together with all information on the invoice entry form. Such requests occur about five to ten times per month.

On the basis of this information, we were able create an extended process model of the process, modelled in BPMN (Recker, Rosemann, Indulska, & Green, 2009) together with our notation extensions. The model details the process in terms of 43 individual activities, ten involved departments within SSP, plus required data, paper, forms and other inputs to, and outputs from, the process. While we omit details about the modelling process due to space limitations, we show the final extended BPMN model in Fig. 2. Note how this model, in addition to the regular process flow, captures and illustrates the flow of CO_2 accumulations along the process.

We note that one of the main challenges in modelling an extended BPMN model is, obviously, the collection of adequate and reliable data about CO_2 accumulations during the execution of the process. Still, this data gathering challenge is not dissimilar to the traditional requirements gathering challenges in process design, and there is ample literature on methodologies and guidelines that readers can refer to, e.g., (Davies, 1982; Gulla & Brasethvik, 2000; Lauesen & Vinter, 2001; Nuseibeh & Easterbrook, 2000).

Having modelled the process in the extended BPMN notation, we posit that a visual inspection of the process model now guides an environmentally-focused analysis in at least three ways:

- It graphically visualizes the total CO_2 accumulations alongside a business process, thereby integrating quantitative data from a process analysis in the graphic representation of a process.
- It pinpoints graphically the key CO_2 emission drivers within a business process, thereby providing a scoping focus for a root-cause analysis.
- It visualizes graphically the activity-individual and overall extent to which a process can be considered green (through the GHG emission indicators), thereby allowing for simple judgment of the need for environmentally-oriented process change.

4 Measuring the Carbon Footprint of Business Processes

Of course, documenting the carbon footprint of business processes through extended process modeling is but one step of making process sustainable. Indeed, the modeling extensions introduced in Sect. 3 above are predominantly of interest to the lifecycle stage of process design. For holistic and comprehensive sustainable (re-) design of business processes, however, the (re-) design of business processes should be preceded by appropriate analyses of the "greenness" of the existing (or future) business processes. Specifically, we believe an analysis should be able to provide measurements of *carbon emissions*, and *carbon emission drivers*. To that end, we describe in the following an approach to measuring the carbon footprint of business processes.

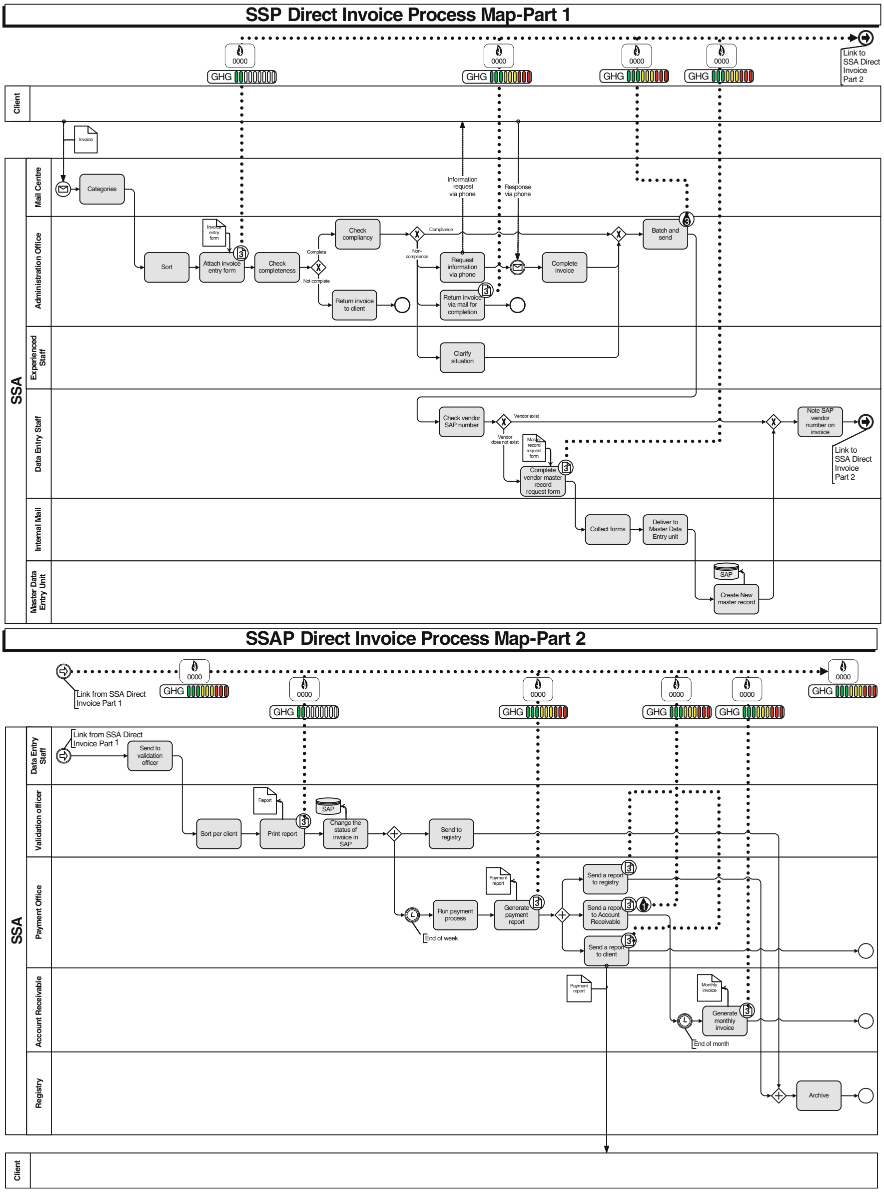


Fig. 2 Extended BPMN model of the direct invoicing process

Carbon footprint measurement is not a new topic. In fact, it has become a topic of interest to many business organizations, and has led to the development of several measurement approaches to calculate the footprint of a business as an organizational entity (see, for instance, http://www.carbonfootprint.com/).

Traditionally, calculating the carbon footprint of an organization can be done via three approaches (Hendrickson, Horvath, Joshi, & Lave, 1998): bottom-up – based on Process Analysis (PA) (Smith Cooper & Fava, 2006), top-down – based on an Environmental Input–output (EIO) analysis (Pan & Kraines, 2001), or through a combination of both (Heijungs & Suh, 2006). Still, these approach are focused on understanding input–output relations on either a system (Smith Cooper & Fava) or a broader institutional (Heijungs & Suh) or economical level (Pan & Kraines). We argue, therefore, that an understanding of carbon emissions on a *business process level* would create further opportunities on a meso and micro level to make quick and effective adjustments to an organization with a direct impact on its environmental image.

Our argument rests on a tight linkage between carbon emission measurement and Business Process Management (vom Brocke & Rosemann, 2010), through which an organization can create competent processes that function cost efficiently, with greater precision, reduced errors, and improved flexibility. While typically, process management has focused on the documentation, analysis and improvement of performance objectives such as cost, time, quality or flexibility (Reijers & Mansar, 2005), we will in the following extend a typical process management tool, namely *Activity-Based Costing* (Bromwich & Hong, 1999), towards the inclusion of environmental measures.

4.1 Activity-Based Emission (ABE) Analysis

Activity-Based Costing (ABC) is a collection of financial and operational performance information dealing with significant activities of the business (Bromwich & Hong, 1999). Key to this approach is the consideration of actual usage of equipment and resources (e.g. machinery and human resources) in the activities that constitute a business process. This approach takes a stance, therefore, on the operational level of a business process, which, through multi-level process architectures, thereby allowing for composition of the measures to a meso- or macro-organizational level.

Originally, ABC describes a costing model that identifies activities in an organization and assigns the cost of each activity resource to all products and services according to the actual consumption by each: it assigns more indirect costs (overhead) into direct costs (Kaplan & Bruns, 1987). In this way, an organization can precisely estimate the cost of individual processes (for both products and services) so they can identify and eliminate those that are unprofitable and lower the costing and pricing of those processes that are overpriced.

In ABC analysis, direct labor and materials are relatively easy to trace directly to processes, but it is more difficult to directly allocate indirect costs to organizational processes. Where processes use common resources differently (e.g., rooms, common machinery, resources involved in multiple processes), some sort of weighting is needed in the cost allocation process. The *cost driver* is a factor that creates or drives the cost of the activity (Ray & Gupt, 1992). For example, the cost of the activity of bank tellers can be ascribed to each process by measuring how long each process' transactions (cost driver) takes at the counter and then by measuring the number of each type of transaction.

ABC analysis is a key analysis tool in process management and has enjoyed considerable uptake (Innes & Falconer, 1995), also in complementary use with graphical process models (Tornberg, Jämsen, & Paranko, 2002). Therefore, following the basic premises of ABC Analysis, we argue that *Activity-Based Emission (ABE) Analysis* can be conducted for a process to determine the emission of CO_2 for each activity as well as the overall process. We believe that ABE allows the calculation of CO_2 emission more accurate than PA or EIO approaches by focusing on every step of a business process, by identifying the so-called *emission drivers* (the equivalent to a regular cost driver) and by considering the impact of alternative resources that facilitate the process execution. In fact, estimating and measuring the CO_2 outturn of each activity, the CO_2 emission of all services and products across all business processes of an organization can be calculated. In turn, ABE analysis can provide a more precise and specific insight into the actual processes, activities and resources within, that directly contribution, positively or negatively, to the carbon emission of an organization. This is because ABE helps to distinguish operations and resources based on their CO_2 emissions, and thus allows embedding an environmental view in the decision-making related to process (re-) design.

Further benefits from an ABE approach include that it can also be used within other business analysis tools such as Pareto analyses, to further examine the relation between cost, time and emission of CO_2 for a business. We foresee the combination of ABE with other analysis tools as a key step in defining organizational areas which require an improvement in light of sustainability considerations.

4.2 Stage Model

Similarly to a regular ABC analysis (Cooper & Kaplan, 1991), an ABE can be conducted within five main steps:

- Identify the product or service process to be considered. This step is typically supported through process modeling activities. At this stage, analysts may use an extended (or even regular) BPMN model of the process under consideration.
- Determine all the resources and processes that are required to create the product or deliver the service, and their respective CO^2 accumulation. To that end, typically, semi-formal graphical models of the business process are considered as documentations of the tasks that have to be performed, the actors and other resources that are involved in the execution of these tasks, relevant data and sources (transportation means, papers, forms, systems and technology) of the data, and the business rule logic that describes the logical and temporal order in which tasks are to be performed (Recker et al., 2009).

- Determine the "emission drivers" for each resource. In analogy to a cost driver (Ray & Gupt, 1992), an emission driver is any activity that causes a GHG emission to accumulate. A regular BPMN model, for example, details all tasks to be performed in a process (activities), all human and organizational resources involved (swimlanes and pools). An extended BPMN model using our notation extensions, additionally, would identify and document emission drivers for CO_2 accumulation – under the assumption that this information was properly identified prior to modeling.
  - *Scope1: direct GHG emissions* – emissions that occur from sources that are owned or controlled by the company. Examples include emissions from boilers, vehicles, electric generators and so forth.
  - *Scope2: electricity indirect emissions* – emissions that originate from consuming electricity, heat or steam purchased by the company.
  - *Scope3: other indirect GHG emissions* – emissions that are the results of the activities of the company but arise from sources not owned or controlled by the company. These include emissions from product materials produced by suppliers (newsprint/paper, ink, etc.), contractor delivery vehicles, employee commuting to/from work and business air travel.

  To measure the CO_2 accumulations, data will have to be collected, at least, about three important CO_2 emission types, *consumed electricity, consumed paper,* and *consumed fuel.* Arguably, there could be other emission types that could also be taken into consideration when identifying emission drivers.

  In identifying emission drivers, we draw upon recommendations from the Greenhouse Gas Protocol (GHG Protocol) for Sustainable Development (www.ghgprotocol.org), develop in late 1997 by the World Resources Institute and the World Business Council. The GHG Protocol is providing series of accounting tools to understand measure and manage green house gas emissions. In this protocol, three scope levels are defined to define organizational boundaries to enable differentiating between GHG emitting activities (the emission drivers) that are owned by organizations, and those that are not. These scope boundaries categories owned emitting activities in to three different scopes which is distinguishes between direct and in direct GHG emitting activities:
- Calculate CO2 emission for each activity by gathering Activity Data for each process and resource and define the emission type for each Activity Data. The GHG Protocol enables the calculation of the CO_2 emissions for each defined source of emission (the emission driver) in step 3 through GHG Protocol calculation tools. Examples for the three selected types of emissions include the following:
  - *Fuel (scope3):* For calculating the CO_2 emission of scope3 activities (e.g., business travel between two offices), the GHG protocol provides the formula*: Distance travelled* $\times$ *emissions factor incorporating default fuel efficiency value* $=$ *CO_2 emission*

  - *Paper (scope3):* For calculating the CO_2 emission of scope3 activities (e.g., transporting paper forms between two offices), the GHG protocol provides the formula*: Weight of paper × emissions factor for manufacture of paper = CO_2 equivalent emissions*
  - *Electricity (scope2):* CO_2 emission of purchased electricity can be calculated by using the GHG Protocol calculation tool for purchased electricity, which is based on the formula*: KWh of electricity used by organization × emission factor = CO_2 emissions*
- Use the data to calculate the overall CO^2 emission of the process. This is achieved by summing up all CO_2 emissions across all activities and scope levels. This analysis will then enable a sixth step (out of scope for this paper) – the actual act of making eco-aware process re-design decisions, and selecting those process and resource variants that help to reduce the carbon footprint during run-time execution.

4.3 Case Study: The Taxi Process to and from the Airport

4.3.1 Case Description

In this case study we applied our ABE approach to the taxi processes at a major airport in northern Europe. National environmental regulations force this airport to keep track of, and limit themselves to, a certain level of the CO_2 emissions that the airport is directly and indirectly responsible for. A direct emission is an emission created by operations within the airport an indirect emission is an emission created by a process that moves people or goods to and from the airport. All emissions from these activities are summarised into a total that may not exceed the emission roof determined by the national environmental agency.

The airport has approximately 17 million air passengers a year. Some of these passengers are passengers in transit who use the airport as a transit to reach a final destination. Buses, trains, and cars transport passengers to and from the airport. On average 2.2 million taxi trips are required each year in order to transport passengers and visitors to and from the airport.

The selected service process in this case is transport by taxi from and to the airport (see step 1 above). In order to reduce the environmental impact from taxis, the airport introduced the concept of eco-taxis in the middle of 2005. Specifically, a separate queue for eco-taxis was established in front of the ordinary taxi queue, promoting this eco-friendly transportation option to travellers. This way, the number of eco-taxis increased at the airport from 1% in 2005 to more than 80% in 2010.

In March 2010 a new system was introduced for coordinating taxi movements at the airport. This new Dispatch System uses a sophisticated algorithm to priorities the taxi's in the queue based on the emission level that each of the taxis have. The more eco-friendly a taxi is the more points it is awarded and hence prioritized in the dispatch queue. The system also gives prioritization points to taxis that have dropped off passengers at the airport upon arrival and assign waiting points to the taxis in the taxi remote so that taxis do not leave the airport without passengers from the airport. Taxi companies that serve the airport must register their taxis in the system in order to be able to pick up passengers from the airport. As a fourth step in this eco-based development related to taxi transportation, the airport has declared that only eco-taxis are allowed to operate from the airport by July 2011. This will change the requirements for the taxi operators radically and is also intended to reduce the CO_2 emissions from the taxi processes radically. As base for an evaluation of the impact we were allowed to perform an ABE Analysis on the taxi processes at the airport.

4.3.2 Case Analysis

To calculate the carbon footprint of the taxi trips at the airport, we created processes models of the flow of taxis to and from the airport, modeled in the extended BPMN notation. The models detail the process in terms of 29 individual activities, two involved actors (the taxi company and the passenger), information flows and other inputs to, and outputs from, the process. This information was important to step 1 of our ABE analysis, viz., the identification of important activities, as well as to step 2 (identifying the involved human and organizational resources relevant to the execution of the process). We omit the model from this chapter due to space limitations.

In the third step, we selected fuel as a CO_2 emission type of the process as it propels the resources in these processes (the taxis) and divided it in to the five most common types of engines propelling taxis at the airport:

- Petrol: 206 g/km (non-eco taxi).
- Eco-diesel: 120 g/km (eco taxi)
- Biogas: 77 g/km (eco taxi)
- Ethanol: 81 g/km (eco taxi)
- Hybrid: 104 g/km (eco taxi)

With these types of emissions, we were able to identify the five most common sub-types of resources acting as emission drivers in the taxi processes at the airport. These emission drivers are to be seen as scope 3 types of emissions as per the GHG protocol. In the fourth step (see above), we identified the sources (the data) for the emission. Emissions depend on traveled distance as well as the volume of taxi moments for each type of trip (eco trip vs. non-eco trip). In this forth step, we collected data from the new Dispatch System: the volume of taxi movements to and from the airport, in total for 2010 2,156,412 trips (1,149,819 trips from the airport and 1,006,593 trips to the airport). A total of 792,600 trips *from* the airport were made by eco taxis (i.e., with a car either propelled by Eco-diesel, Biogas, Ethanol or Hybrid). Similarly, 658,498 trips *to* the airport were carried out by eco taxis. We also collected data about the total volume of non-eco taxis and eco taxis, as well as eco taxis divided on different engines in order to break down the eco resources used in these two processes. In addition, we used the average distance for taxi travelers generated from a survey that the airport does every year with approx. 100,000 passengers. The average distance for taxi travelers was reported to be 43 km.

In the fifth step, we calculated the CO_2 emissions alongside the process for each type of trip (non-eco taxi trip vs. eco-taxi trip to and from the airport). In the calculation we assumed that the proportion of eco-trips divided on eco-resources equal the proportion of different types of eco-resources. We also used the emission factors provided by the National Environmental Protection Agency in the country where the airport is located. The reason for this is that the airport uses these factors for measuring the CO_2 emissions for land bound vehicles and emissions factors from GHG for calculating CO_2 emissions for airplanes. With this data we calculated the overall CO_2 emission of the Taxi Process at the airport, as described in Table 2. The data was calculated using the calculation schemes described in Sect. 4.2, and perusing the calculation tools defined and provided by the GHG protocol (www.ghgprotocol.org).

To summarize, the service processes transporting travelers by taxi from and to the airport has been selected (step 1). This process has been described in terms of traveler related activities (emission drivers) as well as involved actors (taxi companies) and resources (especially different kinds of taxi vehicles) used for

Table 2 ABE analysis of taxi trips to and from the airport in 2010

Type of taxi trip		Description	Number of trips per year	CO_2 emission per trip (kg, rounded)	CO_2 emission per year (kg)
Non-eco taxi trips from airport		31% of all taxi trips from the airport are non-eco taxi	357,219	**8.858**	3,164,245.90
Non-eco taxi trips to airport		35% of all taxi trips to the airport are non-eco taxi	348,095	**8.858**	3,083,425.51
Eco taxi trips from airport		69% of all taxi trips from the airport are eco taxi			
	Eco-diesel	0.6%	5,130	**5.160**	26,471.33
	Ethanol	21.1%	166,961	**3.483**	581,526.35
	Biogas	55.3%	438,157	**3.311**	1,450,737.59
	Hybrid	23%	182,352	**4.472**	815,476.48
Eco taxi trips to airport		65% of all taxi trips to the airport are eco taxi			
	Eco-diesel	0.6%	4,262	**5.160**	21,992.55
	Ethanol	21.1%	138,713	**3.483**	483,136.44
	Biogas	55.3%	364,024	**3.311**	1,205,283.63
	Hybrid	23%	151,499	**4.472**	677,503.97
Total emission per year (kg) from the taxi process					**11,509,799.75**

realizing these service processes (step 2). Emission drivers have been identified for each variant of resource utilized in the activities where other indirect GHG emissions (scope 3) has been characterized for each type of engine powering the taxi vehicles transporting the traveler (step 3). These different types of engines were then used to calculate the CO_2 emission divided into two different types of taxi rides (non-eco taxi trips vs. eco-taxi trips) (step 4), which then formed the basis for calculating the overall CO_2 emission for the selected processes (step 5). Since two processes (taxi to and from the airport) were selected this also gave rise to comparison.

5 Conclusion

In this chapter, we described two important steps forward towards the eco-friendly management of business processes. Specifically, we introduced two approaches relevant to two distinct stages of the business process lifecycle, viz., modeling and analysis.

By being able to *document* or *measure* the environmental impact of a business process, analysts and managers are empowered to account for environmental information in their decisions to execute or change business processes. Our documentation and measurement approaches both work for as-is (as in our service provider case) as well as for to-be scenarios (as in our Airport case) and can therefore be used to make informed decisions about "green" processes and the improvement of the processes towards environmental as well as classical business objectives. Specifically, the airport case demonstrates how the ABE analysis can be a useful tool to monitor and evaluate several incremental steps in the development towards sustainable to-be processes (here: more eco-friendly transportation system using taxis).

Our work surrounding the two approaches contains some limitations. Notably, we focused on two distinct stages of the business process lifecycle, and only sketched how the two approaches – extended modeling and ABE analysis – can be integrated. We showed how an extended BPMN model serves as a useful data input to step 1 of the ABE analysis; but still, theoretically, it is possible to conduct an ABE analysis without modeling the process beforehand.

Second, in our case studies we focused on selected emission drivers and emission sources and acknowledge that a different focus on other emission drivers or sources could yield different results. Nonetheless, our ambition was to demonstrate how existing analysis tools for organizational management could be adapted to allow for inclusion of sustainability considerations. Such work, and its application in practice, can be an important move towards "green" organizations and "green" value chains.

Following our work, future work could be carried out to develop or extend approaches for 'green' process implementation or enactment, to complete the stages of the business process lifecycle. Other work could examine the integration and complementary use of the approaches across all stages of the lifecycle. Empirical work, finally, could be carried out to examine the utility of such approaches in actual sustainability initiatives.

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