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Towards green business process management

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Abstract

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Towards Green Business Process Management
(Pre-Publication Draft)

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***Abstract*—There is a *global consensus* on the need to reduce our collective carbon footprint. While much research attention has focused on developing alternative energy sources, automotive technologies or waste disposal techniques, we often ignore the fact that the ability to optimize (existing) operations to reduce their emissions impact is fundamental to this exercise. We believe that by transforming the problem into the domain of Business Process Management (BPM) we can leverage the rich expertise in this field to address issues associated with identifying areas for improvement, understanding the implication and performing carbon footprint minimization. We will use the term "Green BPM" to describe a novel class of technologies that leverage and extend existing BPM technology to enable process design, analysis, execution and monitoring in a manner informed by the carbon footprint of process designs and instances. This article describes the first steps in the development of this class of technologies.**

I. INTRODUCTION

There is a *global consensus* on the need to reduce our collective carbon footprint. Due to external pressures such as legislative requirements [1], [2], as well as an increase awareness of the general public (choosing products from organizations with environmentally sustainable profile), organizations are forced to capture details about, understand and minimize their carbon footprint. We argue that by transforming the problem into the domain of Business Process Management (BPM) we can leverage the rich expertise in this field to address issues associated with identifying areas for improvement, understanding the implication and performing carbon footprint minimization. Transforming a problem into a more researched domain is a powerful principle often applied in mathematics and science. BPM is known for its focus on the understanding and improvement/optimization of an enterprise's business processes. Process modeling technology has applications beyond what we would traditionally describe as business processes. We can also model and improve manufacturing and other "physical" processes. To leverage the BPM technology we need to inform the business process design with its associated emission impact. This article shows how business process designs can be informed by capturing and utilizing the relationship between resources and activities and how this paves the way for future green business process optimization.

II. BACKGROUND

The Business Process Modeling Notation (BPMN) [3] is a mature process modeling notation finding broad acceptance in industry [4]. Business processes are represented in BPMN using *flows* (activities, events and decisions), positioned in *lanes* and linked by *connectors* (control flow links and message links). The BPMN notation captures the functional aspects of an enterprise. In general, business process modeling notations lack in the representation of qualitative attributes [5] such as the impact of carbon emission. Qualitative attributes are also referred to as non-functional requirements (NFRs) in the requirements engineering literature and capture the qualitative aspects of a system. Various studies [6], [7], [8] in the requirements engineering literature point out the importance of identifying qualitative attributes in addition to the functional aspects of a system. This trend has also found attention in the business process modeling literature [5], [9].

A qualitative attribute that is receiving great interest is the notion of an environmental performance indicator. A current environmental performance indicator that is widely accepted and used is the measure of *carbon dioxide equivalent (CO2-e)*[1] emission. We note that environmental performance is also influenced by other factors like amount of waste generated, or the amount of water consumed. CO2-e has been identified to play a key role in global warming and received great attention by international [10], [11] and national [1], [2] environmental frameworks. We will use CO2-e as a key indicator for environmental performance in this article, but note that other factors can be incorporated as well.

The reminder of the article is structured as follows. Section III introduces a machinery for accumulating emission annotations across process designs. Section IV describes how we model the relationship between resources and activities to inform the business process with its emission impact. In section V we report our first experiences of applying the framework. Section VI outlines potential approaches for carbon-driven (green) optimization. Section VII describes

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[1] Carbon dioxide equivalent (CO2-e) is an expression of other greenhouse gases in their carbon dioxide equivalent by their global warming potential (CO2 itself has a global warming potential of 1)

related work in the resource modeling literature. Section VIII concludes the article and provides an outlook of future research.

III. INFORMING PROCESS MODELS WITH CARBON EMISSION

The challenge of understanding and improving an enterprise's carbon emission performance can be transformed into the domain of BPM by informing the activities of process designs (specified in BPMN) with emission annotations. An *emission annotation* is an textual assertion associated with the activity and states the carbon emission value the activity emits when being executed. Associating emission annotations with activities is intuitive since carbon emission are either the direct *consequence of an activity* (for example fugitive emission caused by digging for coal, or the impact of cutting a tree) or the result of *consuming resources* such as using a dredge, a chainsaw, or materials like wood, oil and water. In section IV we show how a resource model can be leveraged to receive emission annotations.

In the next subsection we describe how emission annotations are accumulated across business process designs.

A. Accumulating Carbon Emission Across Process Models

The task of accumulating emission annotations across business process designs is not trivial since there might be various paths that can be traversed during process execution. We refer to each path through the process model, starting from a "start event" to a current activity, as a *scenario label*. A scenario label consists of a sequence ($\langle\rangle$) or a set ($\{\}$) or a combination of both. Sets can be processed in any order and are used to represent parallel splits, while the sequence dictates an order to account for the sequence in which the activities of a design are modeled. For example, the scenario labels for the selected activity T7 in figure 1 are the following:

$$\langle S1, T1, T2, \{\langle T3\rangle, \langle T4\rangle\}, T5, T7\rangle$$
$$\langle S1, T1, T6, T7\rangle$$

This machinery has been described by [12], [13] and further defined by [14], in the context of the ProcessSEER tool.

An *emission annotation* states the amount of carbon emissions, in terms of equivalent CO2 amounts, a activity emits when being executed. It can be directly annotated by the user or is returned by a functional call to an associated resource model (see section IV for more details). We refer to the accumulated emission annotations as *emission scenario*. The use of the word scenario is deliberate - each emissions scenario corresponds to an execution instance where the path is defined by the executed associated scenario label. An emission scenario at a given point in a process model is the sum of (cumulative) carbon annotations that would have been emitted up to that point. We accumulate emission annotations over a sequentially ordered pair of activities following the sequence of the respective scenario label. The carbon emissions at a given point in a process design is thus a set of contingent measures, each corresponding to an alternative path from the start event to that point.

Let Ti and Tj be a pair of contiguous activities connected by a control flow link. The set of (cumulative) effect scenarios at Tj consists of all distinct values $es(i) \oplus ea(j)$, where $es(i)$ is an emissions scenario associated with Ti, $ea(j)$ is the emissions annotation of Tj and '$\oplus$' is an accumulation operator. Each such distinct value constitutes an emissions scenario for Tj. We deal with AND merges (see figure 1 label *G4*) in the following manner. If Ti and Tj are the only two activities immediately preceding an AND-merge, and Tm is the activity immediately following it, the set of emissions scenarios at Tm consists of all distinct values $es(i) \oplus es(j) \oplus ea(m)$ for every distinct pair $es(i)$ and $es(j)$ such that $es(i)$ is an emissions scenario associated with Ti and $es(j)$ is an emissions scenario associated with Tj, while $ea(m)$ is the emissions annotation associated with Tm. In the preceding setting, if we replace the AND-merge with an XOR-merge (see figure 1 label *G3*), we proceed by $es(i) \oplus ea(m) = es(m')$ and $es(j) \oplus ea(m) = es(m'')$, where $es(m')$ and $es(m'')$ are distinct.

Using this technique, emission scenario for each scenario label providing us with the range of carbon emission for the process design.

B. Considering Probability

Following the described technique we are able to compute an emission scenario for each scenario label providing us with the range of carbon emission emitted for the process design. The range of carbon emission values can be very large - the highest and the lowest figure are far apart from each other. Using these values in the parent-process can result in an even wider range. Due to this potential issue and ease of communicating emission figures, it is of interest to the users to have a single emission figure for each process design. The approach of computing an average of all emission scenarios was considered. This approach essentially place equal weighting on all scenarios. However, we feel that this approach might be erroneous due to the fact that some rarely executed scenarios might skew the mean emission value. To avoid this issues, the process designs can be enriched with probability figures. This can be done for example, by evaluating process logs, which is in generally a powerful technique enabling an enterprise to evaluate and understand the performance aspect of the qualitative attributes associated with their processes. If no process log is available one can also resort on the experience of process users.[2]

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[2] We acknowledge that the knowledge of the user about the process maybe erroneous.

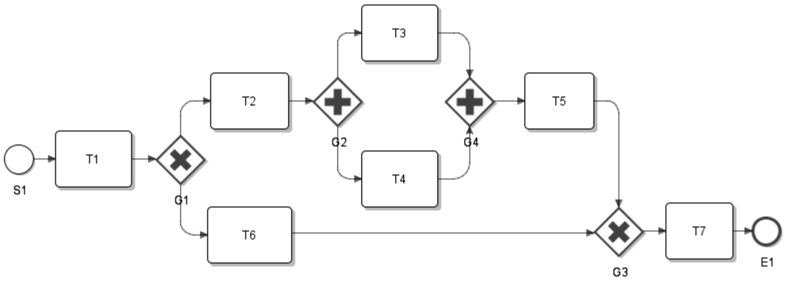

Figure 1. BPMN Model

The identified probability figures are annotated for all *outgoing exclusive gates* (XOR-split see figure 1 label *G1*)[3] of the process design. The sum of the probability annotations of all outgoings paths of a XOR-split has to be 1. We do not have to annotate sequence flows, since the probability of a sequence flow linking two activities together is always 1 - no other way can be taken. Furthermore, the probability annotation for every outgoing sequence of a parallel split is 1, since all sequences are followed for a parallel split. We accumulate the probability annotations across the process design to find the probability of executing a scenario label. In brevity, we perform the accumulation using the technique described previously, substituting addition with multiplication.

Using our machinery for emission- and probability accumulation we are able to inform the process designs of an enterprise with their environmental performance.

IV. Resource Modelling

In this section, we describe the relationship between resources and activities as well as the resulting emission impact. Furthermore, we propose a formal definition of a resource model, that emphasizes the *"usage-cost relationship"* among resources and activities.

The interrelationship as well as interplay between resources and the activities utilizing them can have a significant influences on the resulting carbon emission value. We note that also other qualitative properties of an activity like execution time, rate of failure, compliance, or monetary costs can be influenced. Our focus in this article is on the carbon emission impact.

The amount of carbon emission emitted is influenced by *what resource/type of resource is used*. Clearly driving a large SUV causes more emission than driving a small car. Another factor is *how the resource is used*. Driving a car with many accelerations causes more emission than foreseeing driving with less accelerations. Furthermore, the *intensity with which a resource is used* has an influence on the emission impact. Staying with the previous example it makes a difference whether we use a car for 100km or 200km. In addition, a resource might require another resource to be used. We refer to these resources as *sub-resource*. Consequently, the carbon emission figure is also influenced by the sub-resources used (again how they are used, with which intensity, and their sub-resources). For our example, a sub-resource could be the fuel used for combustion and the associated carbon emission for gathering and transporting the fuel to the petrol station. We sum up the influencing factors as followed:

1) What resource/type of resource is used?
2) How is the resource used?
3) With which intensity is it used?
4) Which sub-resources does it use?

Clearly there is an interplay between the resources and activities and their impact on a systems environmental performance. An approach to fathom this interplay of resources with other resources and activities is by modeling it. In the next subsection we formally define a resource model, using graphs and show how it helps us to inform the business process design with its emission impact, during design time.

A. Formal Definition

The usage-cost relationship among resources is represented by a *directed acyclic graph*, to which we refer as Resource Net. Resources are represented by nodes, which can be linked to each other over their *usage mode*. We use the notion of usage mode to account for the fact that resources can be used in different ways and that this impacts the emission and possibly other *cost types*. A usage mode is specified in the way that it associates quantified costs with a *scale* (e.g. kilometer, watt hours, piece, liter, etc.), for example 1 kgCO2-e per kilometer. A resource B requires another resource's C usage mode if there exists a directed edge from C to B. The directed edge is further labeled with the *usage intensity* value. This impacts the associated cost types. Furthermore, each usage mode is associated with a subset of the resource's *capabilities* utilized for that usage mode.

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[3] In the following we do not consider OR-gateways. Semantically, an inclusive OR can be viewed as a combination of an XOR and an AND

Formally, a Resource Net is a graph $\langle V, E \rangle$, with no cycles, such that:

V is a set of vertices, denoting the resources, described by a 4-tuple $\langle ID, UMS, C, CAP, \rangle$ where:

- ID is the unique identification of the resource.
- C is a set of cost types (e.g CO2-e, dollars, etc.).
- CAP is a set of capabilities associated with a resource.[4]
- $UMS = \{UM_1,\ UM_2,\ ...,\ UM_n\}$ is a non empty set of usage modes where,
- a usage mode UM is a 4-tuple $\langle id, Scale, cap, \Omega \rangle$, such that:
  - id is the unique identification of an usage mode.
  - $Scale$ is a 2-tuple $\langle unit, quant \rangle$ where:
    - $unit$ describes what is measured (e.g. kilometer, liter, piece, etc.) and $|unit| = 1$.
    - $quant \subseteq R^+$ quantifies the unit. [5]
  - $\Omega : Scale \times C \rightarrow \mathcal{R}^+$, is a function and quantifies the costs for the scale of a usage mode.
  - cap is a set of capabilities required by the usage mode, where $cap \subseteq CAP$.

E is a set of directed labeled edges of the form $\langle \langle u, v \rangle, \langle UM_u, UM_v, I \rangle \rangle$, such that:

- u and v are resources, where $u, v \in V$.
- $UM_u \in UMS$ denotes an usage mode of resource u.
- $UM_v \in UMS$ denotes an usage mode of resource v.
- The order of u and v, dictates that a directed edge points from u to v, subsequently the interpretation of the corresponding usage model (UM_u and UM_v) is UM_v requires UM_u with the intensity I. [6]
- $I \in \mathcal{R}^+$ denotes that $UM_v.Scale.quant$ requires $UM_u.Scale.quant \times I$.

B. A Methodology for Modeling a Resource

The following methodology provides guidance in instantiating a Resource Net graph:

1) Select a resource.
2) Identify all relevant usage modes of the selected resource by asking:
   - Is this resource used in different ways?
   - Do the costs of the identified usage modes vary considerably? [7]
3) Focus on usage modes that potentially result in high costs.
4) For a selected usage modes identify:
   - its scale - how the usage intensity can be measured.
   - all relevant cost types (e.g. carbon emission, waste, dollar),
   - quantify the cost types for the usage mode's scale (e.g. x kg CO2-e per km).
5) Identify all sub-resources required by each usage mode.
6) Repeat the procedure until all resources and their usage modes are identified.
7) Associate each resource's usage mode with the required sub-resource usage mode and specify the usage intensity.

We note that finding a required sub-resource and its provided usage mode could be partially automated by searching for appropriate capabilities, associated with an usage mode, across an list of existing resources in the enterprise.

C. Correlating Resource Nets with Business Process Models

Process designs can capture different levels of abstraction, ranging from abstract process designs to decomposed sub-processes and finally to atomic activities. Atomic activities cannot be (or are not) further decomposed. While abstract processes are generally used to provide an overview of the process environment, atomic activities are described in further detail. We suggest the following bottom-up procedure to identifying at which level of abstraction the Resource Net should be correlated with the business process design:

1) Identify all process designs.
2) Order them according to their level of abstraction. The general rule applies that processes are more abstract than their sub-processes, and atomic activities (that cannot be decomposed any further) are on the lowest level of abstraction.
3) Select the process designs at the lowest level of abstraction.
4) Check whether resources can be associated in reasonable time and effort.
5) If no resources could be found consider the next level of granularity and repeat the previous step.

Having identified an appropriate level of abstraction, we correlate process designs with a Resource Net by annotating the activities of a design with a functional call. This call states the resource, the leveraged usage mode, and it's usage intensity, for example *use(Printer, Scanning, 5 pages)*. The expression is evaluated and returns the corresponding emission figure, as emission annotation, back to the process design. Please note that the process analyst can also directly annotate the emission annotation. This is necessary in situations where carbon emission are not the result of using a resource, but rather the direct consequence of the activity (e.g. CO2-e impact of cutting a tree). The emission annotations can be extrapolated to the higher level processes (bottom-up) by repeated accumulation of the emission annotations across the process designs. This

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[4] For example a car might have the capability to transport 5 person

[5] For example 1km, 0.1L, 1piece, etc.

[6] This implies that there can be several directed edges between two resources - one for each usage cost relationship between two usage modes.

[7] We are aware that the answer can be hard to quantify exactly, but note that an educated guess can provide enough insights for the moment.

results in generating a carbon emission value at the process environment level (see figure 2) and can be the starting point for process analysis and optimization.

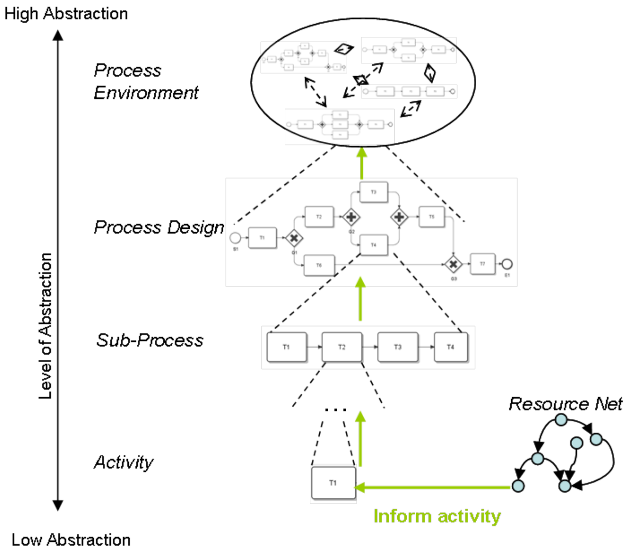

Figure 2. Processes captured on different levels of abstraction.

Although, the introduced Resource Net should be capable of modeling a wide range of resources and their usage-cost-relationships, we note that the user should focus on relevant resources that are measurable and considerably contribute to the carbon footprint of the business. The general rule applies that the more resources (starting with the most relevant) are considered and modeled, the more accurate the carbon emission figure will be. However, the more resources are modeled the higher the costs for designing the Resource Net, mainly due to the information gathering process and possible maintenance and management costs of the Resource Net. Accordingly, these two factors have to be evaluated against each other. We note that we are not in the game of accounting carbon emission, but rather seek to enable carbon-aware business process management. To identify all relevant resources, we provide the following guide:

1) Select business process design.
2) Select each activity and identify all relevant resources by asking:
   - What tools are used that require fossil fuels or electricity?
   - What materials are consumed?
3) Keep the relevant resources and drop non relevant resources by checking whether:
   - the associated costs are relevant,
   - they can be associated and quantified,
   - it can be done in reasonable time and money.
4) Identify all sub-resources of the identified resources and repeat the previous step.

In the next subsection we provide an example, showing how the Resource Net could be used and instantiated.

D. *A Resource Net Example*

The example shows how an electrical device (in this case a modern printing device) could be represented using a Resource Net. Due to space restrictions we omit a more detailed example.

The laser printer prints in black and white and provides scanning functionality. First, we identify all usage modes of the printer, being “print” and “scan”. The scale in which both usage modes are measured is piece of pages (short: “page”). For simplicity, we assume that there are no direct costs associated with both usage modes. [8] However, the printer requires other resources (sub-resources) like paper for printing and/or electricity for scanning. For simplicity we assume that the resource paper is only used for printing, resulting in the usage mode “print”. Another usage mode could have been “burn”, denoting that the paper is combusted for heat and light. The scale of the paper is also captured in piece of pages (short: “pages”). Again, to keep the example simple, we do not associate the costs of producing and delivering the paper. The resource “electricity” is more abstract and could denote an specific electricity provider and its offerings, or an average electricity provider of the country the business is located. We identify the usage modes “energy mix” “solar energy”, “atom energy”, and “coal energy”, but seek to focus on the energy mix;. The scale of the usage mode “energy mix” is Watt hours (Wh) and the costs are 2g CO2-e per Wh[9]. Note that we can also associate other cost types with a usage mode, for example monetary costs. This results in the following representation of resources (R) and their usage modes (UM):

R: $\langle Paper, \{print\}, \{\emptyset\}, \{\emptyset\}\rangle$;
UM: $\langle print, \langle page, 1\rangle, \{\emptyset\},\ 0\rangle$

R: $\langle Electricity, \{energy\ mix\}, \{\emptyset\}, \{\emptyset\}\rangle$;
UM: $\left\langle energy\ mix, \langle Wh, 1\rangle, \{\emptyset\}, 2gCO2 - e_{/Wh}\right\rangle$

R: $\langle Printer, \{print, scan\}, \emptyset, \{b\&w\ print, scanning\}, \rangle$;
UM: $\langle print, \langle page, 1\rangle, \{b\&w\ print\},\ 0\rangle$

Having specified all resources, their usage modes and the associated costs, we associate them by defining the edges:

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[8] If we would want to consider the carbon emission that have been emitted for producing the printer and transporting it to its current place, we could have done so by dividing the number of emission associated with producing and transporting the printer by the average number of papers that are printed or scanned during the printer’s lifetime.

[9] This information is generally provided by the electricity provider or by the government as an regional average.

E: $\langle\langle Paper, Printer\rangle, \langle UM_{print}, UM_{print}, 1\rangle\rangle$
To print *one* page, one piece of paper is required.
E: $\langle\langle Electricity, Printer\rangle, \langle UM_{energymix}, UM_{print}, 3\rangle\rangle$
To print *one* page 3Wh are required.
E: $\langle\langle Electricity, Printer\rangle, \langle UM_{energymix}, UM_{scan}, 2\rangle\rangle$
To print *one* page 2Wh are required.

Figure 3 shows a Resource Net instantiation (solid line), correlated with Activity "A", of the example described above. The dotted lines show possible other resources and activities using/extending the Resource Net. Activity "A" in the example uses the printer to print 15 pages and states this with the following functional annotation "*use(Printer, print, 15)*" (see bottom right corner of figure 3). The function returns the emission annotation "*90g CO2-e*", denoting that 90g CO2-e are emitted when performing the activity (assuming this is the only resource used by the activity and it does not have any further user annotated emission impact).

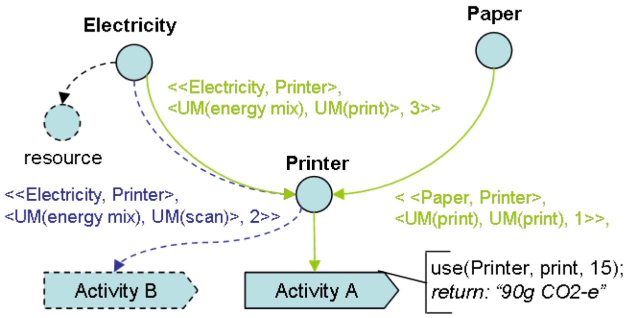

Figure 3. Resource Net example

V. EVALUATION

We applied our framework on handcrafted examples similar to the provided examples, existing models published in the literature [12], [15], [16] as well as large scale industry models. We were able to identify resources and associate these resources with their corresponding activities. Using [17] as our primary source for converting electricity consumption and fuel combustion into CO2-e, we correlated cost with the identified usage modes associated with a single activity. Finding the costs of resources that are possibly *used by several activities* at the same time (for example an information system, or the building in which the activities are executed) was somewhat more challenging, since the proportionally break-down of costs cannot be easily identified. We handled this problem by utilizing the principles of (time-driven) activity based costing (ABC) [18], which is a well known and widely applied costing approach to trace indirect costs to cost object. Specifying usage modes as cost objects made it possible for us to compute and trace indirect cost. However, alternate approaches are required. Finally, using the ProcessSEER machinery we were able to successfully accumulate the identified emission figures across the process designs.

VI. CARBON-DRIVEN PROCESS IMPROVEMENT

Building a machinery for assessing the carbon footprint of process designs, we must address the question of process improvement for carbon footprint optimization. The focus here is on design improvement - we will address instance-level optimization later. Process improvement must therefore involve process re-design to obtain processes that achieve the same (functional) goals, while minimizing the carbon footprint (and potentially other non-functional criteria as well). To achieve this, we need the following (in addition to the functionality described earlier in the article): (1) the ability to annotate process designs with detailed specifications of functional effects, (2) the ability to search for optimal designs through a space of alternative process designs and (3) the ability to assess proximity of process designs to other process designs.

The ProcessSEER system, enables us to obtain *semantic effect annotations* for process models. The functionality that ProcessSEER seeks to support is the following. Given a user-designated point in a BPMN process model, we are interested in answering the question: what effects would the process have achieved if the process were to execute up to that point? The question is significant. Process models specify coordination semantics, but typically provide little by way of information on the effects of a process in a given domain, beyond what might be inferred from activity names. Having access to such information is critical in a variety of settings where semantic analysis of process designs is required, such as detecting and resolving non-compliance [12], detecting conflicts in process inter-operation [19] or building enterprise process architectures [20]. ProcessSEER implements a parsimonious extension to BPMN, where analysts are only required to describe the *immediate effects* of process activities, which are then automatically contextualized to obtain *cumulative effect annotations* for each activity in a process.

Using semantic effect annotated business process designs and the ProcessSEER machinery we can identify the cumulative effect of the process design by pointing at the end-event of the design. The final cumulative effect annotations in a process design (or some user-designated subset of these, representing *intended effects* or goals) determine functional requirements for the re-designed processes. Consequently, any process re-design has to meet these the functional requirements. A library of process design fragments can be leveraged to (semi-) automatically search though the library and replace fragments from the library with process fragment of the as-is process design, such that the functional requirements are met, the capabilities captured in the Resource Net are identical and the carbon emission impact is reduced. A process fragment is any atomic activity, sub-process graphs with a single entry and exit point, or complex activities[21]. In the context of process improvement, there is often a requirement of *minimally change* existing process designs, i.e., maximizing process improvement while minimizing disruption to the status quo. This is particularly important if we are interested in protecting investment put in existing process infrastructure and minimizing the ancillary costs associated with any change to process designs. The requirement for minimal change could be dealt with in two ways: (1) by *design proximity* as a tie breaker when multiple alternative process re-designs achieve the same quantum of process improvement and (2) by conceiving of a state space search landscape (where each state is an alternative process design) where the quality of a design is determined by a weighted sum of a *process improvement measure* (in our setting the carbon-footprint measure) and a *design proximity measure*. Instances of proximity relations and measures can be found in [12] and [16].

VII. RELATED WORK

Capturing the resources, leveraged by a business process, through the usage-cost relationship, is an important factor for informing a business process design with its emission impact. As an overview, the current resource modeling literature does not give this relationship sufficient attention. The BPMN 1.2 specification does not consider resource models and their correlation with process designs. The *proposed* BPMN 2.0 specification [22] does, but provides no deeper insight into the aforementioned usage-cost relationship.

Podorozhny et al. [23] introduce a general approach and key concepts in resource modeling and management and applies it to activity and agent coordination. Of particular interest is the “requires relationship”, which has some similarity to the proposed usage-cost relationship. However, the “requires relationship” only specifies that another resource is required and further details such as the usage intensity are not captured or described.

Zu Muehlen [24], [25] describes the role of resources in the context of workflow systems. A resource is considered to be a workflow participants which can *actively* contribute to the goals of an activity. Passive resources like material or information are explicitly not considered.

On the other hand Kwan and Balasubramanian [26] have a more abstract definition of a resource, also consider passive resources. They define a resource as an entity that is involved in the execution of a activity. This view is aligned with ours.

Russell et al. [27] lists the various ways in which resources are represented and utilized in workflow systems. A resource is described as an entity that is capable of doing work. The authors distinguish between human and non-human resources, where a non-human resource can be durable or consumable. To identify when a consumable resource is completely consumed, the concept of “rate of usage” for a consumable non-human resource is introduced to the resource meta-model.

VIII. CONCLUSION

One of the key challenges of organizations today is to understand and optimize their environmental impact. We argue that by transforming the problem into the domain of business process management, we can leverage on the rich expertise in this area and access its ability to help organizations understand and optimize the way they do business. We believe that this can be done by informing a business process design with its environmental performance, measured in carbon dioxide equivalent. Process designs in general and the modeling notation BPMN specifically focus on the functional aspects, resulting in a poor (not existing) representation of qualitative aspects. We showed that BPMN can be enriched and further informed with qualitative annotations such as the emission annotation. Furthermore, we introduced a machinery for accumulating emission annotations across process designs to compute the carbon emission value of the whole process design. In this task, we also described the role of probabilities in receiving more accurate emission figures. Showing the usage-cost relationship between resources and activities as well as providing a way to model this relation using a Resource Net graph, we do not only provide an approach to determine the emission figures but also contribute to a better understanding of the reason behind the numbers. We further outlined the necessary steps for green business process optimization.

In future work, we further seek to investigate how a library of process fragments can be leveraged for process re-design and optimization. For example, how can we avoid an exhaustive search through the library and checking each library fragment with the fragments of the process design of consideration and how can we ensure that the process re-redesign can be executed with the existing Resource Net. In addition, we seek to perform “accumulation” in a more abstract manner, by constructing an abstract algebraic framework to perform this task. We already indicated that resources utilized by a process can also have an impact on other qualitative attributes, besides the carbon impact. This approach will not only enable us to accumulate effects, emission and probability annotations across process designs in a more structured and informed manner, but also other qualitative attributes such as execution time, reliability and security.

We believe that carbon-aware (green) business process optimization is the next logical step towards Green BPM.

REFERENCES

[1] European Commission, "Monitoring, reporting and verification," http://ec.europa.eu/environment/climat/emission/mrg_en.htm, 2009, last checked 01.03.2010.

[2] Australian Government Department of Climate Change, "About the national greenhouse and energy reporting act," http://www.climatechange.gov.au/reporting/, 2009, last checked 01.03.2010.

[3] Object Management Group, "Business process modeling notation (bpmn) 1.2," http://www.omg.org/spec/BPMN/1.2/PDF, 2009, last checked 21.02.2010.

[4] J. Recker, M. Indulska, M. Rosemann, and P. Green, "Do process modelling techniques get better? A comparative ontological analysis of BPMN," in *Proceedings of the 16th Australasian Conference on Information Systems. Sydney, Australia*, 2005.

[5] S. Gorton and S. Reiff-Marganiec, "Towards a task-oriented, policy-driven business requirements specification for web services," *Lecture Notes in Computer Science*, vol. 4102, p. 465, 2006.

[6] L. Chung, P. Leite, and J. Cesar, "On Non-Functional Requirements in Software Engineering," in *Conceptual Modeling: Foundations and Applications*. Springer-Verlag, 2009, p. 379.

[7] E. Yu, "Towards modelling and reasoning support for early-phase requirements engineering," in *Proceedings of the 3rd IEEE International Symposium on Requirements Engineering (RE'97)*, 1997, p. 226.

[8] B. Paech and D. Kerkow, "Non-Functional requirements engineering-Quality is essential," *REFSQ04*, 2004.

[9] C. Pavlovski and J. Zou, "Non-functional requirements in business process modeling," in *Proceedings of the fifth on Asia-Pacific conference on conceptual modelling-Volume 79*. Australian Computer Society, 2008, pp. 103–112.

[10] Global Reporting Initiative, "Sustainability reporting guidelines," http://www.globalreporting.org/, 2009, last checked 01.03.2010.

[11] The Green House Gas Protocol Initiative, "Programs and registries," 2009.

[12] A. Ghose and G. Koliadis, "Auditing business process compliance," in *Proceedings of the International Conference on Service-Oriented Computing (ICSOC-2007)*, 2007.

[13] A. Ghose and G.Koliadis, "Pctk: A toolkit for managing business process compliance," in *Proc. of the 2008 International Workshop on Juris-Informatics (JURISIN-2008)*, 2008.

[14] K. Hinge, A. Ghose, and G. Koliadis, "Process seer: A tool for semantic effect annotation of business process models," in *Proc. of the 13th IEEE International EDOC Conference (EDOC-2009)*, I. C. S. Press, Ed., 2009.

[15] A. Ghose, G. Koliadis, and A. Chueng, "Process Discovery from Model and Text Artefacts," in *IEEE Congress on Services*, 2007, pp. 167–174.

[16] E. D. Morrison, A. Menzies, G. Koliadis, and A. K. Ghose, "Business process integration: Method and analysis," in *Proc. Sixth Asia-Pacific Conference on Conceptual Modelling (APCCM 2009)*, 2009.

[17] Australian Government Department of Climate Change, "National green house accounts (nga) factors," http://www.climatechange.gov.au/workbook/pubs/workbook-jun09.pdf, 2009, last checked 01.03.2010.

[18] R. Kaplan and S. Anderson, "Time-Driven Activity-Based Costing," *harvard business review*, p. 1, 2004.

[19] G. Koliadis and A. Ghose, "Semantic verification of inter-operational business process models," in *Proceedings of the 2007 IEEE Services Computing Conference (SCC-2007)*, 2007.

[20] G. Koliadis, A. Ghose, and S. Padmanabhuni, "Towards an enterprise business process architecture standard," in *Proc. of the 2008 IEEE Services Congress Sympposium on SOA Standards, IEEE Computer Society Press*, 2008.

[21] B. Weber, S. Rinderle, and M. Reichert, "Change patterns and change support features in process-aware information systems," *Lecture Notes in Computer Science*, vol. 4495, p. 574, 2007.

[22] Object Management Group, "Business process modeling notation (bpmn) ftf beta 1 for version 2.0," http://www.omg.org/cgi-bin/doc?dtc/09-08-14.pdf, 2009, last checked 21.02.2010.

[23] R. Podorozhny, B. Lerner, L. Osterweil, R. Podorozhny, B. Lerner, and L. Osterweil, "Modeling resources for activity coordination and scheduling," in *Proceedings of Coordination 1999*, 1999, pp. 307–322.

[24] M. Muehlen, "Resource modeling in workflow applications," in *Proceedings of the 1999 Workflow Management Conference*, 1999, pp. 137–153.

[25] M.Muehlen, "Organizational management in workflow applications–issues and perspectives," *Information Technology and Management*, vol. 5, no. 3, pp. 271–291, 2004.

[26] M. Kwan and P. Balasubramanian, "Adding workflow analysis techniques to the IS development toolkit," in *Proceedings of the Hawii International Conference on System Science*, vol. 31. IEEE Institute of Electrical and Electronics, 1998, pp. 312–321.

[27] N. Russell, A. Ter Hofstede, D. Edmond, and W. van der Aalst, "Workflow resource patterns," in *in the 17th Conference on Advanced Information Systems Engineering (CAISE05). Porto, Portugal*, 2005, pp. 13–17.