Supporting Municipal Greenhouse Gas (GHG) Emission Inventories Using Business Process Modeling: A Case Study of Trondheim Municipality

Dirk Ahlers[1], John Krogstie[1], Patrick Driscoll[1], Hans-Einar Lundli[2], Simon-James Loveland[2], Carsten Rothballer[3], and Annemie Wyckmans[1]

[1] NTNU – Norwegian University of Science and Technology
Trondheim, Norway
{dirk.ahlers|john.krogstie}@idi.ntnu.no
{patrick.arthur.driscoll|annemie.wyckmans}@ntnu.no
[2] Trondheim Kommune
[3] ICLEI Europe

Abstract. Business process modeling and business process management has been used to capture, support and improve a large variety of processes and practices in the private and public sector. Traditionally what is regarded as a good business process is strongly related to economic dimensions. With the increasing importance of assuring sustainable development, BPM techniques should to an increasing degree be able to be used to support the goal of sustainability of the supported or automated solution. This paper provides results from a case study in the Carbon Track and Trace (CTT) project on supporting the compilation and reporting of data on greenhouse gas (GHG) emissions on the city level in the form of GHG inventories. Although basic BPM-techniques are applicable on this levels, we have identified a number of challenges and potential improvements to represent the relevant aspects in such cases to support automated and semi-automated solutions.

Key words: Greenhouse Gas Inventories, City Services, Sustainable Business Process Modeling, Green IT, Workflow Analysis

1 Introduction

The concept of sustainability includes three dimensions: the ecology/environment, the economy, and social equity, which should all be enhanced in a balanced manner over the long run in a sustainable society. Our focus in this paper is along the environmental axis, although having in mind that measures should also be economically feasible and beneficial to human conditions in a holistic approach. Today, sustainability and climate change go hand in hand. Since the early 1990s, cities around the world have been pursuing ambitious climate mitigation targets. However, setting a course towards a low-carbon city with significant reductions

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in greenhouse gas emissions demands a precise overview of current emissions to identify the priority areas for interventions and to track their success over time. The way to formally achieve this overview is to use methods of greenhouse gas accounting to build a yearly inventory of emissions on a city level. An emission inventory allows a city to compare its emissions over time and to other cities.

In line with Norwegian climate plans [5], the city of Trondheim, Norway has ambitious reduction goals of 70%–90% of Greenhouse Gases (GHG) by 2030 compared to a 1991 baseline [1]. Of these, transportation emissions are among the largest components of the overall GHG emissions in the city [2]. In order to provide a more sound empirical basis to support Trondheim's climate goals, the municipality is building an emission inventory. It includes direct emissions within the city with the two prioritized areas of transport and energy consumption in residential and commercial buildings.

The aim of this paper is to analyse the current workflow of data sourcing for emission inventories, compare it to recommended practices, and identify bottlenecks and issues. We use Business Process Modeling as a tool towards sustainability in the context of Green BPM [21, 15]. The development process included a literature study, initial discussions at project meetings, informal interviews, and collaborative development and documentation of the used process steps towards developing the models. Through interviews and project meetings with different stakeholders from the municipality and supporting institutes, we developed an understanding of the emission inventory building process. A main issue is a large gap between mandated data input into inventories and the rather complex data sourcing. We address this gap by a close reading of the relevant GPC standard [3] and of common best practices from ICLEI [6] together with the practices and requirements of the municipality. We especially examine steps in the data gathering and compilation through interviews and iterative model development that result in a number of general models in BPMN [8] together with a list of identified challenges.

2 GPC Emission Inventory Standard

The setup of emission inventories to track Trondheim's emissions follows an emergent standard for GHG emission inventories called the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC) [3], co-developed by ICLEI. GPC defines a standardized and comparable way for cities to calculate and report their GHG emissions. The protocol defines the categories of emissions to be reported as well as adaptation and scaling of data – if available data does not align with the geographical boundary of the city or the time period of the assessment – and calculations for final reporting.

The GPC reporting framework classifies emissions by their source using 6 sectors with up to 2 levels of sub-sectors, which results in a total number of 43 emission types. Sectors are Stationary Energy; Transportation; Waste, Industrial Processes and Product Use (IPPU); Agriculture, Forestry, and Other Land Use (AFOLU); and Other Scope. Emissions are further orthogonally organized into scopes, defining whether emissions occur inside or outside the city or come from grid-supplied energy. The scopes roughly follow a complexity of emission tracking and allow cities to select a coverage of emissions that is appropriate for them.

The input to GPC consists of activity data for each defined category along with emission factors. GHG emissions are reported for 7 different greenhouse gases, which are calculated into CO_2 equivalents (CO_2e). Emissions are separated into two values per emission type. Activity data is the actual resource or energy use, or the actual emissions; the emission factor acts as an adaptation factor taking local characteristics (such as GHC emitted for electricity production) into account when transforming resource use into CO_2 equivalent emissions. Additionally, if city-level emission values are not available, scaling factors [14] have to be derived to scale down national values or to aggregate and disaggregate regional values that may not match the city boundaries. It is important to note that the GPC is designed to cover a period of one year. Shorter update cycles are not mandated but for example specific emission types or sources that are of particular interest could be tracked separately at a higher frequency, for example through better data reporting or on-the-ground emission measuring [10].

GPC accounting methods are based upon those found in financial accounting, with similar principles of relevance, completeness, consistency, transparency, accuracy, and measurability [3, 7]. It defines what input of multiple different areas is needed in which formats, defined internal dependencies and consistency conditions, and contains a calculation engine to generate reports. Data quality is another aspect to consider in the case of GPC because data can originate from multiple sources that may have widely varying quality levels [17]. We focus particularly on aspects of data quality concerning fitness for use in terms of accuracy, correctness, and completeness, with a lower interest in timeliness, currency, and provenance. However, while GPC sets up requirements and data quality management, it only indirectly relates to how activity data is gathered in the first place. Yet for practical application, the process of data collection and preparation is a major aspect and furthermore can be highly varied between municipalities, which is why this work takes the form of a case study. For the actual GPC emission calculation, the ClearPath tool[1] compiles and calculates GPC-compliant inventories. Additional specialized tools are available [23] and also tool collections of smaller calculation tools for certain emissions or emission subcategories[2]. However, to the best of our knowledge, there is currently no overall workflow tool available, prompting our study.

3 Case Description: The CTT Project

The Carbon Track & Trace (CTT) project[3] [9] is intended to provide the City of Trondheim with a sound empirical basis for the development of more advanced

[1] ICLEI USA: `http://icleiusa.org/clearpath/`, `http://clearpath.global/`
[2] `http://www.ghgprotocol.org/calculation-tools/all-tools`
[3] `http://carbontrackandtrace.com/`

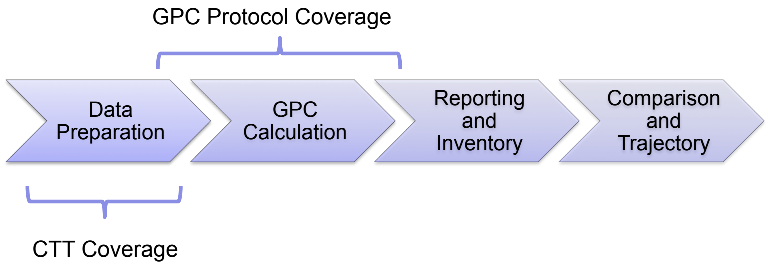

Fig. 1. Coverage of GPC and CTT in an idealized inventory workflow

Fig. 2. Detail view of the data preparation stage

greenhouse gas emissions inventory methods, including the eventual deployment of sensor systems to reduce the cost and complexity of collecting data for GHG inventories. An additional goal of the project is to help develop better methods of decision and planning support for municipal mitigation planning through integration into strategic planning instruments, cost-benefit assessments (CBA) and geo-spatial databases. This workflow analysis is the result of a research and innovation collaboration between the City of Trondheim, the Norwegian University of Science and Technology (NTNU), and ICLEI – Local Governments for Sustainability.

A simplified GPC chain is shown in Fig. 1 where we illustrate GPC coverage and the coverage of our CTT approach. GPC covers calculation and reporting and supports subsequent comparison and trajectory of reports. In our approach we take a stronger focus on input data flows and examine those in detail. We assume a GPC-compliant calculation process and complementarily investigate the data acquisition and preparation phase. This part is briefly discussed, but not strictly defined in the standard. That leaves the details up to individual municipalities, who may or may not have measures in place for them. To the best of our knowledge there are no previous processes defined.

3.1 Challenges in GHG Inventory Building

Before the workflow analysis, we briefly report on a previous general gap analysis for the emission inventory development of Trondheim [16]. The main challenges found are data uncertainty, reliability, and quality, the gap between top-down (downscaled national level statistical data) and bottom-up (local or even real-time data) data in the case of calculated instead of measured data that does not reflect the actual situation, and a strong data sourcing issues. The latter consists of non-standardised workflows, very time-intensive compilation and preparation of yearly inventories, and unclear benefits and costs of inventories. The state-of-the-art on municipal emissions inventories methods is highly variable. It can be done in a number of ways and combinations: It can be fully outsourced to a third party; it can be done individually including data gathering and calculations by a city; regional data compilation can share the effort and knowledge; and there can be central national data provision (and calculation) at city granularities.

Currently, the City of Trondheim has not yet fully completed a GHG emissions inventory using the GPC, but has embedded the methodology in their new climate action plan to be adopted by the end of 2016. Therefore, this case study is based on ongoing work on setting up the GPC processes. Previously, Trondheim commissioned external studies for the municipality's carbon footprint [4]. The current practice of data acquisition and calculation is mostly top-down with municipality-developed calculations and estimations based on national data and some available local or regional sources. The availability of detailed municipal statistics from Statistics Norway has been deferred, but it is expected that the data availability situation will improve. However, it is not yet clear how this data will be derived, whether only through scaling or through more tailored methodology taking local distributions into account. For the municipal view, it is very important to recognize that purely calculated top-down data is not suitable for monitoring local actions and allowing fast feedback loops on policy decisions. Additionally, national statistical data usually is made available with a delay of one or more years, further slowing down fast impact assessments.

A main issue in building inventories is that data, both for emission factors and activity data, are usually not directly available from a structured database or similar system. This is part of a more complex issue of multiple factors that can occur alone or in combination. General challenges include:

- Direct measurements are not available
- Available statistics are scaled down from national levels and may not correspond to actual city-level emissions
- Verification of scaled statistics is difficult
- Without exact measurements, data needs to be gathered in different ways and from multiple sources.
- No sufficient tool support for data sourcing and management
- Non-standardized handling of complexity for multiple data sources and complexity of emission composition per type

The relevant scientific literature offers hints towards solutions while acknowledging that in general city-level emissions inventories are extremely complex. For example, [22] gives a good general discussion of uncertainties in emission inventories and how different inventories address them. [20] provides a survey of guidance support frameworks and discusses the issues of scaled-down data. [19] studies an emission inventory at an urban scale. Other work [18] acknowledges that emissions accounting is challenging and proposes a measure based on carbon footprints to capture indirect emissions for the scenario of Norwegian municipalities and can serve as a complementary to this study.

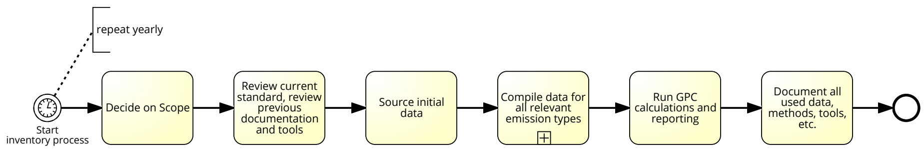

Fig. 3. General Workflow for a Yearly GPC Inventory Iteration

4 Workflow Analysis

This section details the data gathering, input, and handling necessary to build a GPC-compliant GHG inventory. As noted above, access to and readiness of data varies widely. Input values can be direct, aggregate, partitioned, or combined metrics resulting from a multi-stage process, making a streamlined approach from discovered data sources into a GPC-compliant calculation tool rather complex. We therefore work towards requirements for the data collection process and to understand how this workflow operates in general. We interviewed key players at the municipality and at ICLEI to develop an understanding of this process by analyzing current and planned workflows at the municipality and derive insights from different parts of the GPC recommendations as far as they concern the data workflow. We incorporate [7], which gives some general advice on data collection, especially accounting and reporting principles as well as considerations towards a bottom-up approach. As an additional factor to consider, the "GPC specifies the principles and rules for compiling a city-wide GHG emissions inventory; it does not require specific methodologies to be used to produce emissions data" [3]. While compilation methods are not given, the standard contains some guidance for sourcing activity data to be followed within CTT.

The overview of a complete general workflow to build a yearly GPC inventory is shown in Fig. 3. Following the GPC structure, the workflow starts with a decision on the GPC scope of emissions to be tracked. The following steps are to get an updated overview of the current standard and the documentation from previous years that can help in planning and organizing the process and the data collection and compilation. Then GPC calculations and reporting are performed. As a last wrap-up step, all used processes, data, methods, tools, etc. need to be properly documented. This will enable a learning process with a set of guidelines and best practices that make the process more easily repeatable. Following these steps, an increased automatisation of selected steps can become possible.

Compiling data for the relevant emissions is one of the major and most time-consuming steps. For each emission subcategory, it is split up into compiling the actual activity data that describes the emissions, and the emission factor which serves as an adaptation factor to transform and partition emission data into the relevant greenhouse gases or equivalents. Fig. 4 shows this simple iterative process. The details of the emission factor determination are shown in Fig. 5 with the possible sources of factors listed. Determining emission factors is encouraged to be conducted at the most specific levels. This usually means going down from

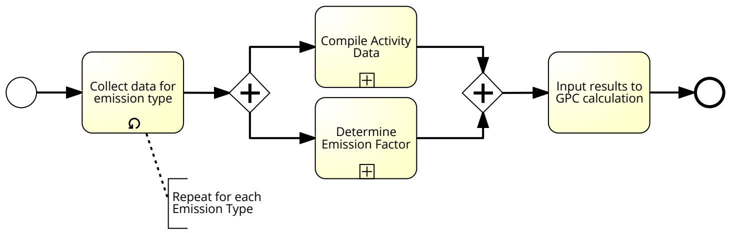

Fig. 4. Workflow for Gathering Data for All Emission Categories

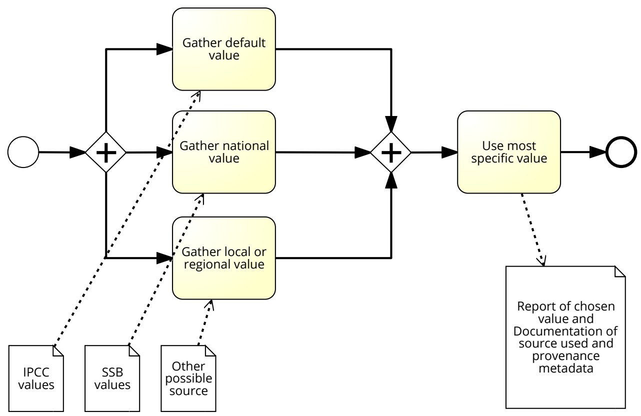

Fig. 5. Workflow Detail: Determining Emission Factors

IPCC reference factors to national factors (SSB for Norway) and possible to more specific local factors, if available.

The process of compilation of activity data is much more complex. Fig. 6 shows the outline of the steps involved. It makes the basic distinction between emissions where directly reported numbers can be put into GPC directly without any calculation or modelling. In this case, the only processing may be an adaptation of spatial or temporal scales. In the second case, emission activity data is not directly available and has to be estimated based on indirect data or complex measures. Fig. 6 gives the overview of steps to collect data and develop models to calculate or estimate activity data and to compare modelling results on multiple levels and to external models in an iterative process. This workflow for gathering data detailed in Fig. 4 and especially for determining activity data in Fig. 6 describe a generic workflow that needs to be adapted and extended for the individual emission subcategories.

Based on the problem statement and the workflow analyses, we develop a set of recommendations to enable and improve the workflow for easier repeatability over time. Due to the complex nature of the task, it is not feasible at present to develop a fully automated workflow system, but rather to select critical steps in the process to offer tailored support either through general contributions or

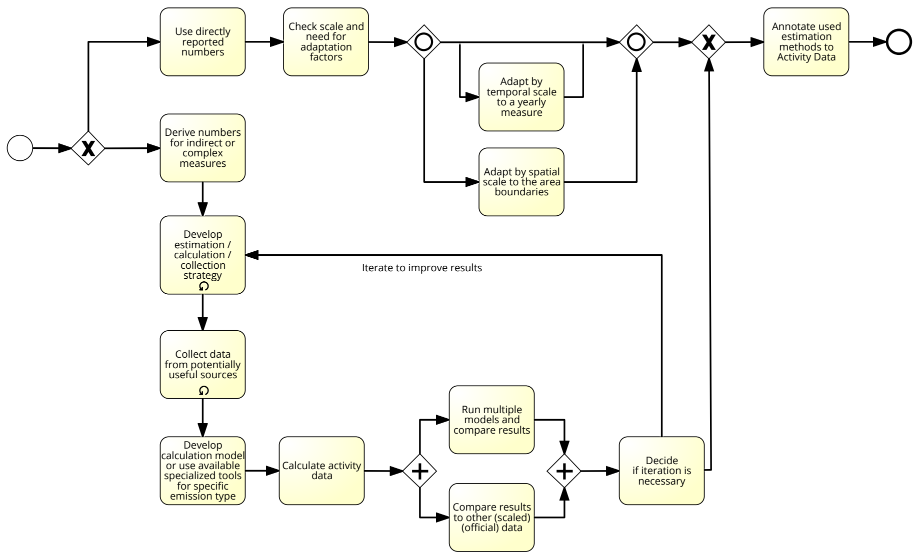

Fig. 6. Workflow Detail: Compiling Activity Data

specific focused tools. Furthermore, if previous years' constituent data sources, tools, and methods are maintained, it will enable easier reuse and discovery of artifacts, thereby speeding up the process in subsequent years and assuring an increased consistency, validity, and quality. The following general recommendations are adapted from the data collection principles mentioned in the GPC itself [3]:

- Establish collection processes that lead to continuous improvement of the data sets used in the inventory
- Prioritize improvements on the collection of data needed to improve estimates of key categories which are the largest, have the greatest potential to change, or have the greatest uncertainty
- Review data collection activities and methodological needs on a regular basis to guide progressive, and efficient, inventory improvement
- Work with data suppliers to improve the quality of the data, to better understand uncertainties, or demand better and/or more local statistics

We adapt the relevant aspects as follows. The overarching recommendation is the establishment of a management plan for the inventory process, including selection, application, and updating of inventory methodologies. The next aspect is the documentation of data, methods, assumptions, estimates, and systems. These steps then also help in maintaining quality, transparency, maintainability, repeatability and replication in following years. Furthermore, documentation should include direct data documentation, bibliographical data references, an archive of cited references, and criteria for the selection of boundaries, base years, methods, activity data, emission factors, and other parameters for the emission data. Additionally, changes in data or methodology should be documented and version control is needed.

A set of metadata for input values is defined in GPC: Definition and description of the dataset; time, period, frequency of publication; source information; information on how to access it. To these we further recommend: information on how to extract and process it; and its relation to other sources. The problem, restated, is that because of compound measures as described above, a direct annotation to the input factors is often not feasible. For example, for the transportation data discussed above, there is a complex model with multiple inputs that generates the necessary input data for GPC. A major aspect in the inventory process that is not yet covered is the need for better documentation of data sources, steps taken, and the actual process as it differs substantially between different emission categories. This implies better support for building and archiving documentation about the way information retrieval was conducted, especially which persons, organizational entities, and data sources were used and how they were accessed and converted. Data storage and processing is currently rather ad-hoc and would benefit from more attention and support as well.

On an organizational level, the comparability and replicability of inventories over the years can be enhanced by reusing the same methodology for intermediate emission data. Due to the current nature of the existing tools, documentation for the most part will happen outside of the GPC accounting tools. Obviously, a better integration is a necessary challenge for future development.

5 Future Work

Potential future work focuses on supporting, streamlining, and automating elements of GHG emissions inventory methodologies. Within this paper, it is not possible to summarize the large variation in city-level emissions inventory practices, but we aim to work with more cities to further develop an operational typology of different cities' data collection methods and data gaps and then prioritize the areas where automatization will bring the most value. A better utilization and integration of available tools to support certain emissions or emission subcategories will also need to be developed in parallel.

6 Conclusion

To summarize, the domain is categorized by a number of challenges:

- Highly complex data compilation, collection, selection, preparation, and processing.
- Little automatic data transmission and integration is possible. There would need to be large changes in current data collection, selection, pre- and post-processing, and cleaning procedures in order to automate significant parts of the GPC (or other) reporting framework.

- Emissions inventories are difficult to complete and require upwards of 3-6 person months, depending on data availability.
- Data quality aspects including accuracy, precision, and uncertainty parameters are currently poorly defined or non-existent.
- Workflow support may be possible with improved data and knowledge management procedures.

These are findings from our detailed analysis of processes in Trondheim as well as wider experiences from ICLEI. Still, situations for other municipalities may vary. From a business process modeling point of view, we note through the experience that current modeling approaches like BPMN are useful for representing and communicating the main workflow steps.

However, the main issues associated with the automation of municipal GHG emission inventory methods identified in this report are not related to inventory or workflow processes, but lie in the peculiarities of the domain as found in data location, acquisition, manipulation, and generation. A possible adaptation of BPMN to address such issues easier would be promising. As part of our ongoing work with mobile technology and services and lately IoT-solutions in Wireless Trondheim [13] we are currently working with such extensions. Frequently direct access to reliable data sources is not possible, requiring municipalities to find workarounds that are often expensive, time-consuming, and often of dubious quality. Thus also for this domain, sustainability cannot be reached by technology solutions alone, but needs a broader view incorporating organisational and other dimensions to fuel all three dimensions of sustainability. Obviously, building a GPC inventory is not an end in itself, as it helps a city develop a detailed overview about its emissions. This serves as a decision aid in prioritizing GHG reduction initiatives. In line with this larger goal, inventory building can serve as a step in organizational learning in that it aids policy learning and identification of effective practices developed by other cities. By understanding and supporting the workflow as a reflection and learning process, it can be done in such a way that the process improves over time by taking gained knowledge and lessons learned into account while still staying flexible to react to changed circumstances, e.g. data availability or quality. Then, stronger automatization can be implemented, with a special focus on high-priority areas.

Acknowledgements

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