Workflow analysis of greenhouse gas (GHG) emission inventory methods for Trondheim municipality

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Preface

About LoCaL

This report was written through support from Low Carbon City Lab (LoCaL). LoCaL aims to reduce 1 Gt of CO2 and mobilize €25 billion of climate finance for cities annually by 2050. It is an innovation platform aiming to provide cities with better tools for assessing greenhouse gas emissions, planning, investing and evaluating progress. Started in 2015, LoCaL is a growing community of more than 20 organisations dedicated to unlocking climate finance for cities. This report was realized as part of the project Closing the Gap through Transformative LoCaL Action (CGTLA) under LoCaL. LoCaL is a Climate-KIC flagship programme.

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About Climate-KIC

Climate-KIC is the EU's largest public private partnership addressing climate change through innovation to build a zero carbon economy. We address climate change across four priority themes: urban areas, land use, production systems, climate metrics and finance. Education is at the heart of these themes to inspire and empower the next generation of climate leaders. We run programmes for students, start-ups and innovators across Europe via centres in major cities, convening a community of the best people and organisations. Our approach starts with improving the way people live in cities. Our focus on industry creates the products required for a better living environment, and we look to optimise land use to produce the food people need. Climate-KIC is supported by the European Institute of Innovation and Technology (EIT), a body of the European Union.

About this report

This report is part of the Carbon Track & Trace (CTT) project. The workflow analysis presented here 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. Funding for the project was provided by the Climate KIC Low Carbon City Lab (LoCal) flagship project along with additional in-kind contributions from the City of Trondheim, NTNU, Numascale, and Wireless Trondheim. The Carbon Track and Trace (CTT) project is intended to provide the City of Trondheim with a sound empirical basis for the development of more advanced greenhouse gas emissions inventory methods, including the eventual deployment of autonomous sensors and automated software to reduce the cost and complexity of conducting GHG inventories. An additional goal of the project is to help develop better methods of decision-support and planning support for municipal mitigation planning through integration into strategic planning instruments, cost-benefit assessments (CBA) and geo-spatial databases.

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Executive Summary

- *The GPC data collection workflow is complex and a simple automatization is not promising: due to the disparate data sources and lack of coherent reporting and format requirements, current practices of GHG emission inventory building and maintenance are not easily mapped.*
- *Highly complex data compilation, collection, selection, preparation, processing*
- *Given the current state of the art with GHG emission inventories, there is little automatic data transmission and integration 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 frameworks.*
- *Emissions inventories are difficult to complete and require upwards of 3-6 person months, depending on data availability*
- *Accuracy, precision, and uncertainty parameters are currently poorly defined or non-existent*
- *Workflow support is possible with improved data and knowledge management procedures, particularly with standardized meta-data tagging and archival procedures.*

Introduction

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 in greenhouse gas emissions demands a precise overview of current emissions to first identify the priority areas for interventions and second to track the success of the interventions over time. The way to formally achieve this overview is to use methods of greenhouse gas accounting to build an accounting inventory of emissions on a city level.

In line with Norwegian climate plans [NEA2014], Trondheim has ambitious reduction goals of 70%–90% of Greenhouse Gases (GHG) by 2030 compared to a 1991 baseline [TrondheimKlimaplan2010]. Of these, transportation emissions are among the largest components of the overall GHG emissions in the city [CoMTrondheim2014]. In order to provide a more sound empirical basis to support Trondheim's climate goals, the Carbon Track and Trace (CTT) project aims to deliver better GHG emission accounting for Trondheim municipality's geographical area of direct emissions with the two prioritized areas of transport and energy consumption in residential/commercial buildings.

This study is complementary to a CTT gap analysis conducted with Trondheim Kommune [CTTGap2015], which provides further detail on the Trondheim GHG emissions inventory policy background and methodology. It further incorporates some details from a CTT workshop held in Trondheim [CTTMidterm2015].

The gap analysis identified a number of challenges:

- *Calculation versus measurement is a major open issue. Currently, calculations are used that do not fully reflect the actual situation on the ground. This will be addressed by a project extension towards bottom-up measurement-based inventory compilation in Phase II.*
- *System boundaries count. Often, data is not available at the right spatial granularities and system boundaries may overlap, leading to a reduction in data quality. This will be addressed by using a reporting level of GPC BASIC+ due to a low cost-benefit ratio for Scope 3 (indirect emissions outside the city boundaries) for Trondheim Kommune. However, we also recommend here that system and geographic boundaries should be carefully noted as a part of data quality.*
- *Data quality and reliability remains an open issue. It is the most important challenge that is discussed extensively in this document.*
- *Cost and benefits of inventories are unclear to unknown: Commonly, cities are neither able to determine the costs of a Baseline Emission Inventory/Monitoring Emission Inventory nor can they quantify the direct benefits of mitigation action.*
- *Consumption-based inventories are expensive and time-consuming, prohibiting cities from conducting annual reviews of more comprehensive Scope 2/3 assessments. Even simple Scope 1 inventories can take up to 6 person months and exceed €300000 in costs.*

The main issues are uncertainty, the gap between top-down (downscaling national level statistical data) and bottom-up (local and/or real-time data) data, and the data sourcing issue.

GHG Inventories

CTT addresses the issue of using emission inventories to track Trondheim's emissions with an emergent standard for GHG emission inventory process of the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC) [GPC2014]. It defines a standardized way for cities to calculate and report their GHG emissions in a comprehensive and comparable way. The protocol mainly defines the categories of emissions to be reported as well as standardizing the adaptation and scaling of data, if available activity data does not align with the geographical boundary of the city or the time period of the assessment, and calculations for final reporting.

GPC accounting methods are based upon those found in financial accounting, with similar principles of relevance, completeness, consistency, transparency, accuracy, and measurability [Mesh2.8-15, GPC2014]. Data quality is another aspect to consider in the case of GPC because data can originate from multiple sources that may have varying quality levels [Kro13]. The CTT project focused 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.

The GPC reporting framework classifies emissions by their source using 3 levels of hierarchy in 6 sectors shows the numbers of sub-categories per sector/sub-sector, the full list of 43 emission types is listed in [GPC2014 p42]. GPC is organized along these emission sources. Emissions are further orthogonally organized into scopes, defining whether emissions occur inside or outside the city or come from grid-supplied energy. The scopes also roughly follow a complexity of emission tracking and allow cities to select a coverage of emissions that is appropriate for them.

Table 1 Emission types in the GPC

Sector	Sub-sector	Sub-categories
1. Stationary Energy	8	21
2. Transportation	5	14
3. Waste	4	12
4. Industrial Processes and Product Use (IPPU)	2	-
5. Agriculture, Forestry, and Other Land Use (AFOLU)	3	-
6. Other Scope 3	1	-

It is important to note that the GPC is designed to cover a period of one year. Therefore, a shorter update cycle is not mandated but may in some cases be attempted. On the other hand, an inventory may not necessarily be calculated every year, also bi- or triannual reporting may occur. In cases where specific emission types or sources are of particular interest, they could be tracked separately at a higher frequency.

A GPC-compliant calculation tool can be understood as a tool similar to a tax reporting software. 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. However, while the GPC establishes for the first time a global accounting and reporting standard through principals, requirements and data quality management, it only indirectly relates to how activity data is gathered in the first place. For practical application, the process of direct data collection from emitting sources and preparation is an important aspect.

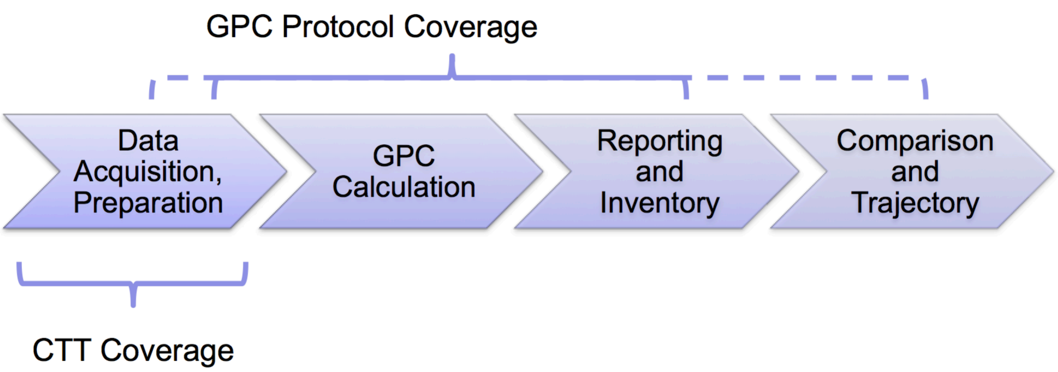

Figure 1 Coverage of GPC and CTT in an inventory lifecycle

The whole GPC lifecycle is shown in Figure 1 where we contrast GPC coverage with the coverage of the CTT project. GPC covers mainly calculation and reporting. Comparison and trajectory of reports is enabled by the standardized approach. Taking a stronger focus on input data flows, CTT assumes a GPC-compliant calculation process and complementary investigates the Data Acquisition and Preparation phase. As this is recommended, but not strictly demanded and defined, we aim to address this gap by a close reading of the GPC and of common best practices together with the practices and requirements of the municipality.

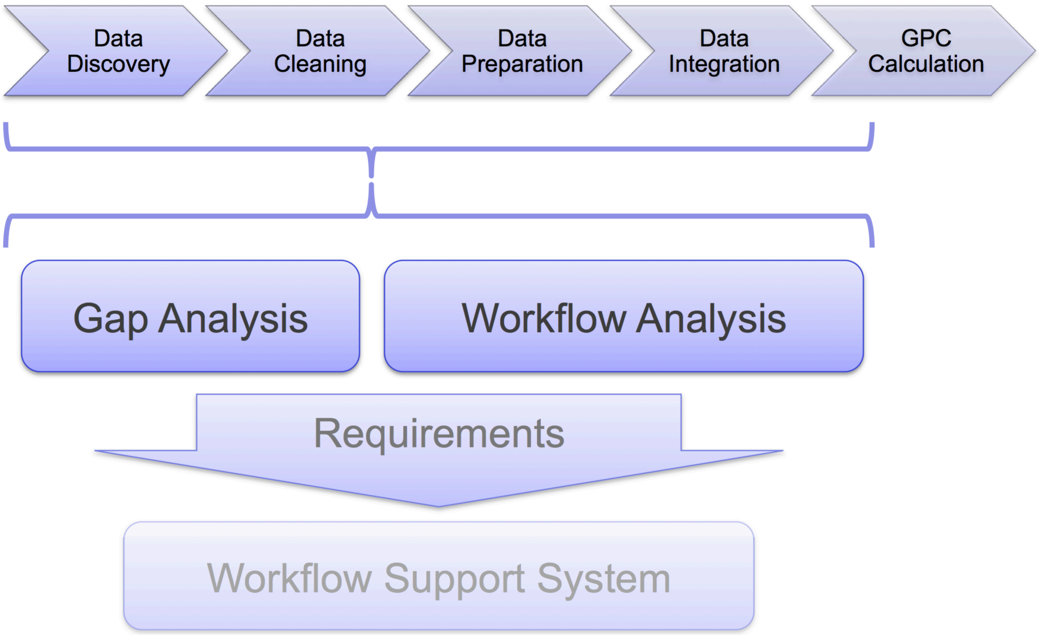

Figure 2 CTT Approach and Process Steps

The input to GPC consists of activity data for each defined category along with emission factors. Greenhouse gas emissions are defined in the form of activity data and can be reported for 7 different greenhouse gases[1], which are calculated into CO_2 equivalents. If emission values cannot be broken down into each separate gas, they may exceptionally be reported as overall CO_2e, but then need to be clearly identified and justified [GPC2014 p50]. Two main values to be made available per emission type is the actual activity data, as resource or energy use or actual emissions, and the emission factor, which acts as an adaptation factor taking local characteristics into account when transforming resource use into CO_2equivalent emissions.

Additionally, if city-level emission values are not available, scaling factors [CoMTools2010] have to be derived to scale down national values or to aggregate and disaggregate regional values that do not match the city boundaries.

[1] Reporting according to the Kyoto Protocol: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3)

Current situation

Currently, Trondheim Kommune has not yet 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, the report will be based on currently available information and some initial work on defining GPC processes. A previous study commissioned by Trondheim Kommune in 2014 to study the municipality's carbon footprint found that over 50% of direct, indirect or embedded emissions were tied to buildings and infrastructure [MISA2014].

The current practice of data acquisition and calculation is top-down with homegrown calculations and estimations. With the availability of detailed municipal statistics from Statistics Norway (Statistisk Sentralbyrå – SSB) deferred and expected in early 2016, the data situation will likely 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.

The state-of-the-art on municipal emissions inventories methods is highly variable. It can be done in a number of ways or combinations of these:

- ***Fully outsourced to a 3rd party** These are typically research institutes, engineering consultancy companies, or energy agencies. Particularly smaller communities with limited resources find it useful to enlist the assistance of expert organizations, but also larger municipalities or countries commonly outsource inventories despite in-house expertise. This is done for a number of reasons. The main explanations are: lack of staff resources, follow-up funding depended on an inventory according to a requested standard, risk of legal accountability as well as the fact that in the vast majority of European states and regions, climate action is still a voluntarily task and not bound to a resourced mandate.*
- ***Individual data gathering and calculations** Many larger cities with dedicated energy and/or environmental departments have built up sufficient in-house expertise to regularly update their emissions inventories in-house. This leads to intimate knowledge, ownership, and identification with the results as well as with the subsequent mitigation measures taken.*
- ***Regional data gathering (and calculation)** In many countries efforts are underway to join forces and collect data on a regional basis. This can be a sound way to achieve better results with shared effort. In many cases these efforts are led by regional development or energy agencies (e.g. Energy Loupe in Sweden and regional observatories established under the EU project Data4Action (http://data4action.eu/en/)).*
- ***Central data provision (and calculation)** In an increasing number of countries, the energy data needed is becoming available in a central national or regional database (for example provided by ministries, energy agencies, and so on.), sufficiently downscaled geographically as well as into market sectors (residential, commercial and industrial). In this case, minimal data collection effort is required by a municipality. In many cases these central databases even provide the conversion of activity data into CO_2 emissions. Good examples are the database provided by the Department of Energy & Climate Change (DECC) in the UK and the Klimaatmonitor provided by the Dutch Ministry of Transport and Environment. When using data from a national database, it is important to be cognizant of which data is genuinely measured activity data, and which data is scaled down from national data (top-down approach). In the latter case it is very important to recognize that purely calculated top-down data is not suitable for monitoring local actions. For example the DECC database in UK uses real measured data by municipality for electricity and natural gas, but scaled-down national data for all other fuels.*

Problem statement

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:

- *Emission sectors/sub-sectors to not necessarily directly correspond to emission sources or resource uses*
- *Emission types as input factors to GPC-compliant calculation tools are not available from any central single source.*
- *Data may not be available at all and needs to be gathered and acquired in a different way for each emission type.*
- *Available activity data may result from aggregated or national top-down data*
- *Geographical and sectorial scaling needs to be applied. As data sources do not scale uniformly, this needs to be adapted for each emission type (and possibly each GHG). Possible sources need to be investigated (c.f. [CoMTools2010]).*
- *Input factors to GPC can also be results of complex models that need to be drawn up*
- *For certain emission sub-sectors, the data collection grows into a veritable tree structure to collect all different possible constituent emissions (cf. [GPC2014 p60] for industrial emissions)*
- *On the other hand, the tree structure extends in the other direction as well, forwarding certain emission types into different final GPC emission types (cf. [GPC2014 p62] for off-road transportation activities). For example, off-road transportation within industry or agricultural operation should be accounted as stationary energy use, while the same within the transportation sector is to be reported as transportation energy use (cf. [GPC2014])*
- *Media and system discontinuity*
- *Emission impact is not always obvious. Some seemingly small sources may contribute disproportionately to GHG emissions. One example are 2-stroke engines such as found in snowblowers or lawnmowers. Another may be wood burning, especially relevant for the more than 400000 cabins in Norway compared to a little more than 2 million households.*

Additionally, more general challenges include:

- *Measurements are not available*
- *Available statistics are scaled down from national levels and may not correspond to actual city levels*
- *Verification of scaled statistics is difficult*
- *Without exact measurements, data needs to be gathered in different ways.*
- *Emission factors change and shift yearly, based on changed technology, weather conditions (e.g. temperature), percentage of renewable energy in the electricity generation mix (e.g. amount of rainfall for the year), or also based on new scientific insights.*

These challenges are addressed at different levels and with varying necessary efforts. Some are especially mentioned in the relevant literature and manuals and are thus well-known and their impact should be mentioned in the annotations and in reports.

From the data side, additional identified challenges arise based on [Mesh2.8-15 p20] regarding data availability, access, quality include:

- *Lack of knowledge where to get data*
- *Lack of skills to ask the right questions*
- *Lack of skills to process data*
- *Lack of good examples for inventories and their building process*

The Meshartility study recommendation is mostly relies on training to turn people into better domain experts, improvement of legal requirements, and better availability of resources. The CTT project will especially focus on the latter recommendation to improve municipal expertise in accessing and analyzing multiple data sources. However, training of domain experts for the tasks is also considered to be important as well.

The relevant scientific literature also offers hints towards solutions while acknowledging that in general city-level emissions inventories are extremely complex. For example, [WRL+15] gives a good general discussion of uncertainties in emission inventories, and also maps cCR (carbonn Climate Registry), ECOSPEED, GPC in terms of how they address them. [SAB15] provides a survey of guidance support frameworks and also discusses the issues of scaled-down data. [SFZB14] is a case study of an emissions inventory at an urban scale. Other work [LH10] starts with the premise that in general, emissions accounting is challenging. It proposes a measure based on carbon footprints to capture indirect emissions for the scenario of Norwegian municipalities and thus can be understood as a complementary to this study.

Tool support

This section offers a brief overview of available emissions inventory tools. To the best of our knowledge, there are currently no overall workflow tools available and as seen in the following section, this may present significant challenges.

Regarding the actual GPC emission calculation, we will briefly describe one major tool developed by ICLEI USA. ClearPath has been developed by ICLEI USA (http://icleiusa.org/clearpath/) and it is a tool that compiles and calculates GPC-compliant inventories[2]. There are two versions of ClearPath. One for communities in the United States that supports protocol-compliant government-operations and community-scale GHG inventories, and has an Inventory Module for performing calculations and reporting around the GPC. ClearPath can calculate key indicators across sectors to provide additional context and community efficiency metrics. It has integrated forecasting and planning modules that connect to the inventory data and also has an integrated monitoring module for tracking progress.

In December 2015, a new version was launched (http://clearpath.global/) for international audiences in support of the Compact of Mayors. This version of the tool is available at no cost and is more narrowly focused, only covering community-scale inventories. In the future the other modules of the tool available in the US will be adapted to the international context. Key differences in the international version include a re-organization of the categories to match the GPC, the use of exclusively metric units, and the use of combustion emissions factors on a net calorific basis.

[2] A previous tool was Harmonized Emissions Analysis Tool plus - HEAT+ (ICLEI, http://heat.iclei.org/heatplusgpc/) that is now replaced by ClearPath.

As mandated by GPC, ClearPath users can control key emissions factors for enhanced localization of results. All calculation inputs and outputs are exportable for transparency and inventory results can be exported in a format mirroring GPC Table 4.3. Each inventory record has a field for users to make notes and attach files that document activity data sources or estimation methods. We will return to this point in the following section highlighting a pressing need for clear annotation and provenance of data. ClearPath is also designed as a flexible and adaptable application for cities to manage inventory data over the long term. For example, users have the ability to select from the set of Global Warming Potential values they wish to use for all calculations in an inventory. Users can explore the impact of changing from one set to another easily by cloning an inventory and prompting a re-calculation with a different set. As cities maintain multiple inventories in the tool, they have the ability to bring all data up to date and not be locked in by past practices. A historical record of all the data from the original inventory can also be maintained.

Apart from ClearPath, there are other tools available [ICLEITools2015]. Additional tool support concerns smaller calculation tools for certain emissions or emission subcategory[3]. For example, for transportation, there is a calculation tool available with a long list of possible entries to differentiate different vehicles (which might have different emission factors). However, to even get at some basic values (such as kilometers driven), additional external models are necessary.

Workflow Analysis and Development

This section details the data gathering, input, and handling necessary to build a GPC-compliant GHG inventory. This is primarily an exercise in data integration and analysis of data flow. As noted above, accessibility 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 next-to-impossible. We therefore have altered our initial approach and instead work towards requirements for the data collection process and to understand how this workflow operates in general.

As this part is not the main focus of GPC, we analyze current and planned workflows and also derive insights in part from different parts of the GPC recommendations as far as they concern the actual data workflow. We also incorporate [Mesh2.8-15] which gives some general advice on data collection, especially accounting and reporting principles as well as considerations towards a bottom-up approach.

In its general considerations about data availability, the Meshartility study also develops a Data Process Tree of how to find suitable data sources [Mesh2.8-15 p8], which is replicated in Figure 3 to demonstrate the CTT project's initial considerations. It includes national or regional statistics offices, distribution system operators (DSO), retailers, or surveys. As shown in later examples, this needs to be extensively refined.

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[3] *http://www.ghgprotocol.org/calculation-tools/all-tools*

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." [GPC2014 p47] This means that the methods for compiling emissions data are not set. However, it contains some guidance for sourcing activity data are followed within the CTT project.

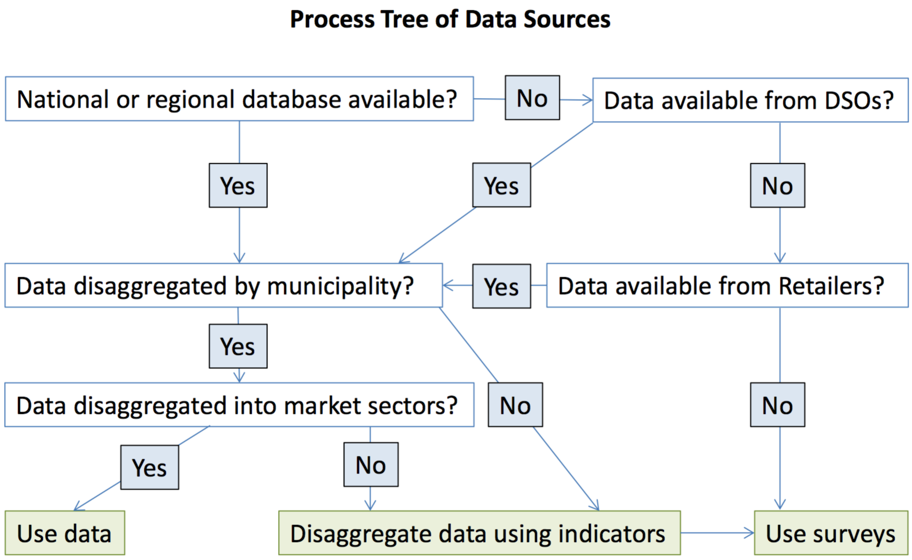

Figure 3 Simplified Data Source Selection

The overview of a complete workflow to build a yearly GPC inventory is shown in Figure 4. This is a simplified overview at a high structural level; the more detailed constituent parts are presented later. Following on 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 over the current standard and over the documentation from the previous year that can help in planning and organizing the process and the data collection. The data compilation is explained in more detail in the following figures. The GPC calculations then actually build the inventory based on the compiled data. As a last wrap-up step, all used processes, data, methods, tools, etc. need to be properly documented within the GPC report and in the general documentation to be used in following years. This will enable a learning process with a set of guidelines and best practices that make the process more easily repeatable. Following these steps, also a better automatisation of steps can become possible.

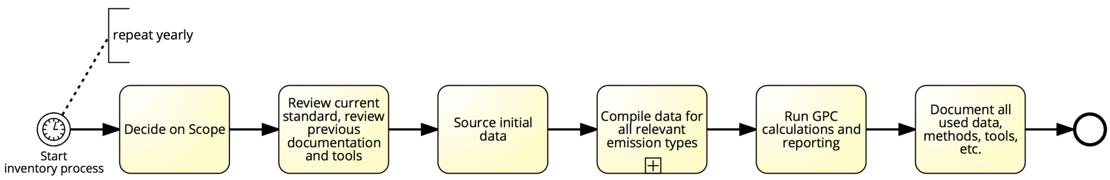

Figure 4 General Workflow for a Yearly GPC Inventory Iteration

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. Figure 5 shows this simple iterative process. The details of the emission factor determination are shown in Figure 6 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 IPCC reference factors to national factors (SSB for Norway) and possible to more specific local factors, if available (cf. Figure 3).*

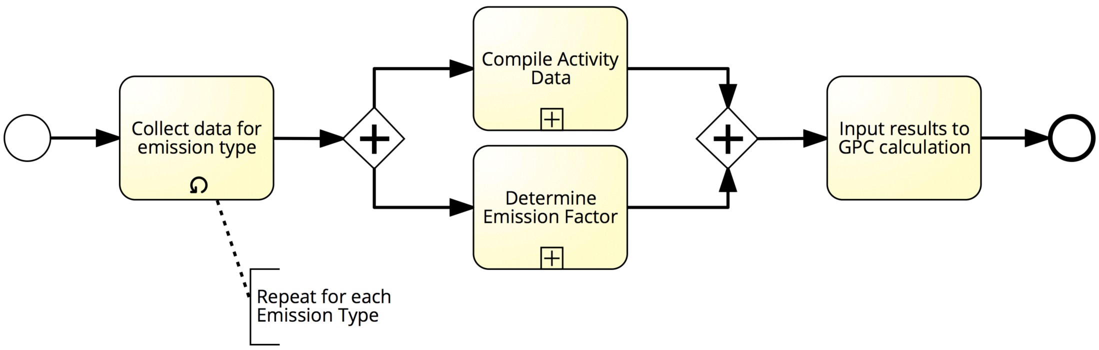

Figure 5 Workflow for Gathering Data for Emission Categories

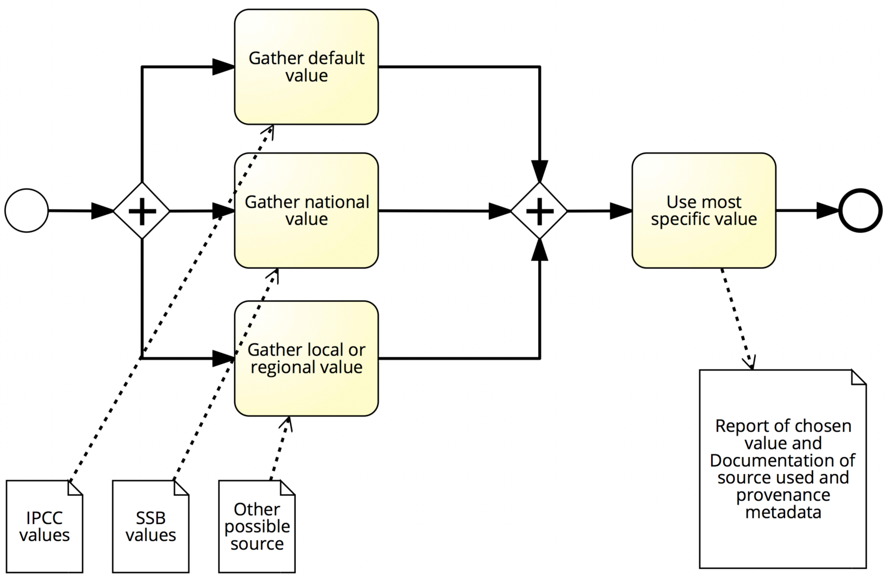

Figure 6 Workflow detail: Determining Emission Factors

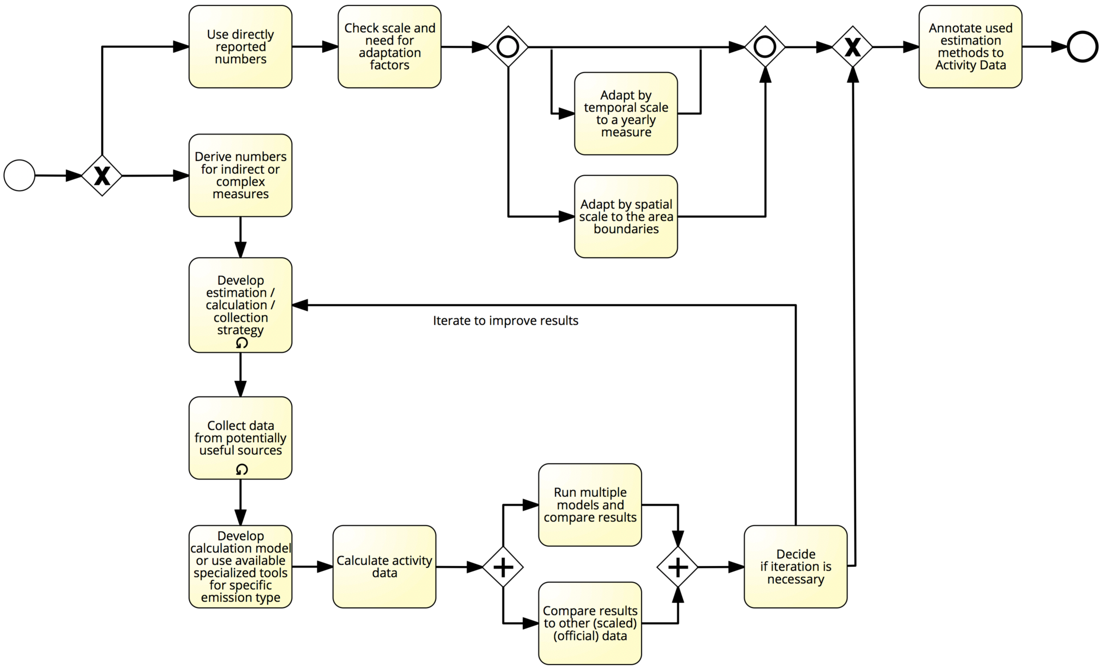

Figure 7 Workflow detail: Compiling Activity Data

The process of compilation of activity data is much more complex. Figure 7 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. This is one of the major challenges. Figure 7 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 Figure 5 and especially the determining of activity data in Figure 7 describe a basic generic workflow that will need to be adapted and extended for the individual emission subcategories, but the basic principle outlined here offers a sound guideline.

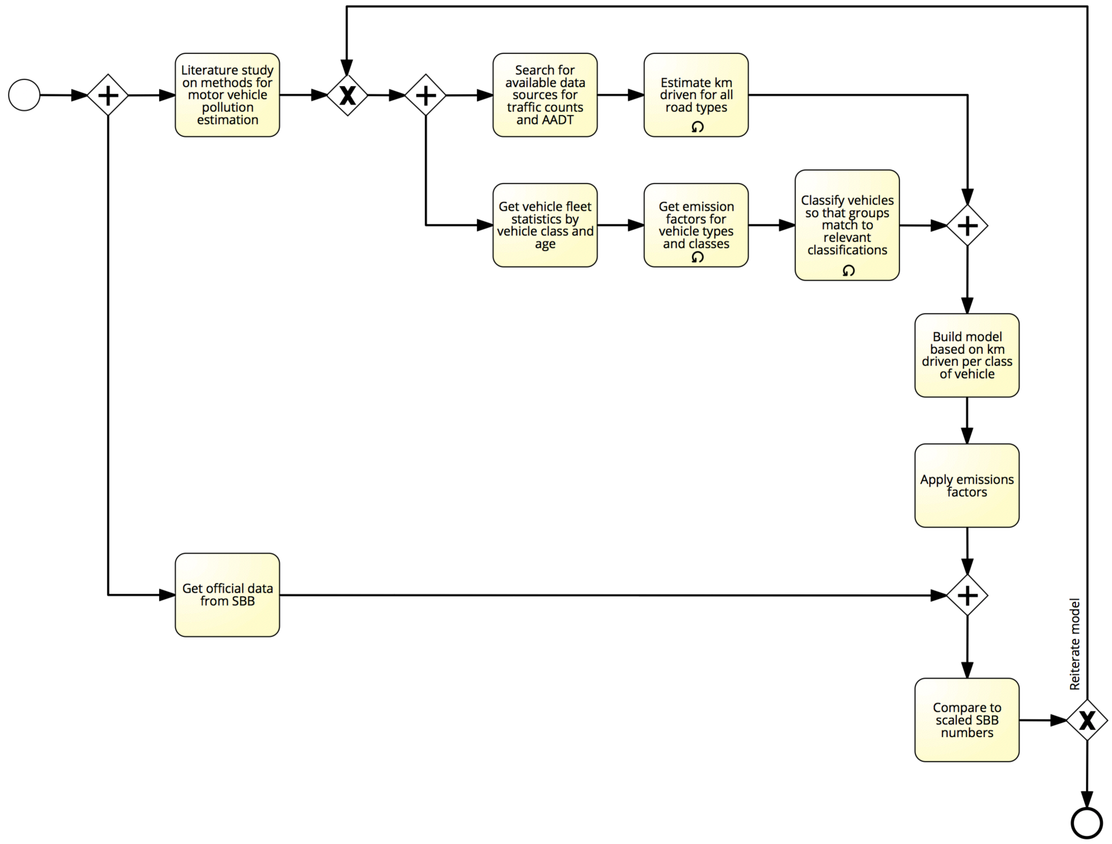

Figure 8 Determining activity data: Transportation Emission Example

The following section presents the case of transportation in greater detail to demonstrate how the workflow can be adapted for each emission sub-category and the available data. As an example, we discuss the detailed workflow steps that are used in determining transportation emissions for Trondheim.

Figure 8 shows the outline of the process steps as adapted from the previous workflows. In the following, we explain the steps in detail with additional data source information. The steps are as follows:

- *Get official emissions statistics from SSB*
- *Read up on methods used in Norway and internationally for estimating pollution from motor vehicles (for example IPCC and European Environmental Agency guidance)*
- *Search for alternative available data sources for traffic counts and annual average daily traffic (AADT) from the local Planning Office (Trondheim Kommune) and the State Highway Agency (these are now combined in a National Road Database - NVDB)*
- *Estimate kilometers driven in the city based on average AADT for different road types in the NVDB data*
- *Get vehicle fleet statistics (car registration data) for Trondheim from OFV (Opplysningsrådet for Veitrafikk) broken down by vehicle class and age*
- *Obtain emissions factors (gCO_2/km) for vehicle types and Euroclass (European Emission Standard) from diverse sources (SSB and VTT (Finland)) that to the greatest extent possible reflect city driving cycles*

- *Classify vehicles in Trondheim in such a way that groups of vehicles can be assigned a relevant emissions factor (this must be done iteratively as the vehicle classifications in the data from OFV and the various emissions factors do not match exactly)*
- *Build a model e.g. in Excel whereby total km travelled are allocated to the vehicle fleet (i.e. it is assumed that the number of kilometers travelled by each vehicle type is directly proportional to that vehicle type's share of the total vehicle fleet)*
- *Apply emissions factors to calculate total emissions and emissions per vehicle class and type*
- *Compare to SSB numbers scaled down from the national level*
- *Reiterate model.*
- *Separate models are also developed for light and heavy vehicles.*

As can be seen, the actual steps taken to gather activity data and emission factors are not easily standardized and fit into an easy universal model. Furthermore, there is a lot of manual work, data selection, model building and very domain-specific expertise and decision-making necessary.

With increasing maturity of the GPC process and support from the domain experts at Trondheim Kommune as well as increased availability of data it is estimate that process support will improve. Requirements and recommendations for a support system are presented in the next section.

Recommendations

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

Furthermore, if previous years' constituent data sources, tools, and methods are maintained it will enable easier reuse and discovery of artefacts thereby speeding up the process in subsequent years and assuring an increased consistency, validity, and quality.

The following general recommendations come from the data collection principles mentioned in the GPC itself [GPC2014 p48]:

- *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*

Some measures combine easier replication of inventory building with inventory quality measures. Incidentally, this also ties in with general inventory quality and especially verification steps. GPC *covers the option of verification by external auditors, who obviously need access to part of the process steps in preparing the input data as well. This is also tied into inventory quality and calculation checking (quality assurance, quality control) [GPC2014 p145ff]. We select and adapt the relevant aspects in the following.*

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. Additionally, methodology references for emissions sources should be archived, for example recording different approaches and methods and the type of activity data and emission factors used. 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 copies of cited references (but also a link to the actual source for refinding and reuse), the assumptions employed 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. The suggestion of version control will also be taken up.

A set of metadata for input values (extended from [GPC2014 p48]) 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 recommendations the CTT project further recommends the following metadata be captured: 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. In these cases, process and tool support to generate this complex documentation would be helpful.

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. A documentation of data sources is even more important when an inventory is outsourced to a 3rd party or if the municipal technical staff experience frequent turnover.

On an organizational level, CTT also identifies a need to involve domain experts early in the emission inventory process to understand detailed emission sources and available data within a city and capture this knowledge for future use. Then the comparability and replicability of inventories over the years can be enhanced by reusing the same methodology and same calculation methods for intermediate emission data (e.g., reuse of excel sheets or other calculations).

This implies the need for an adequate knowledge management and version control for data generated in the process. Due to the current nature of the tools that focus calculations and inventory process (cf. Tool support), this documentation for the most part will happen outside of the GPC accounting tools. Obviously, a better integration is a necessary challenge for the future development.

A domain-adapted knowledge management system (KM) would then ideally be tied into the GPC calculation system to provide better integration of the different tools. The KM system then needs to be tied to a version control and should also be able to manage not only documents, but workflows or at least the resulting numbers for integration into the calculation and inventory tools. Currently available features in ClearPath for recording notes and attaching files to each inventory record is a good start, but would need additional structure and best practices guidance for utilizing those features effectively for thorough data and knowledge management.

Future work

To follow up on the presented findings, this section gives an outlook into potential future work. It focuses on supporting, streamlining, and automating elements of GHG emissions inventory methodologies.

Within this report, it is not possible to summarize the large variation in city-level emissions inventory practices, but the CTT Phase II project will work closely both with the partner cities and ICLEI-World to further develop an operational typology of different cities' data collection methods and data gaps and then prioritize the areas where automatization is most easily done and where it will bring the most value. This will be done by a thorough mapping of the municipal emissions data collection process and deriving more detailed insights and understanding, including tailored calculations that can then be used in a future software-supported data workflow. A better utilization and integration of available tools to support certain emissions or emission subcategories will also need to be developed in parallel.

At a strategic level, [Mesh54-15, Mesh29-15] makes initial recommendations regarding energy data from utilities, many on data formats or rather structures. It does not prescribe an ICT data format, but rather describes how the data should be structured, e.g. sectorial and geographical disaggregation, reported periods and frequency of exchange. But its recommendations clearly show the important focus of the legal side, such as a call for central databases of energy use[4] and emission factors with proper access and collection possibilities.

Such a system would make a number of tasks in emissions inventory building easier since tools could directly access and ingest data that currently still needs to be collected, compiled, and processed manually. This presents an excellent opportunity to automate intermediate steps for GPC input factors. The feasibility of such automatic access and ingestion of data will be explored within Phase II of the CTT project. The data availability and quality and will be further enhanced by deploying an approach to integrate actual measurements on the ground to complement available statistical data sources.

This will include ground measurements derived from different GHG sensor systems to validate available estimates and methods and to incorporate bottom-up sensor measurements as well as satellite-based direct emissions measuring and monitoring. The data collection approach CTT Phase II will deploy is a combination of downscaled statistical calculation from existing available sources, direct columnar measurements from satellite data (where available), direct columnar measurements

[4] *Elhub may be used when available (http://elhub.no/)*

from ground-based sensor systems, and direct building- and street-level sensors. Such a system will allow a focus on priority areas (such as transport) with higher resolution and frequency and thus deliver higher value and a faster turnaround on the measurement of interventions' impact.

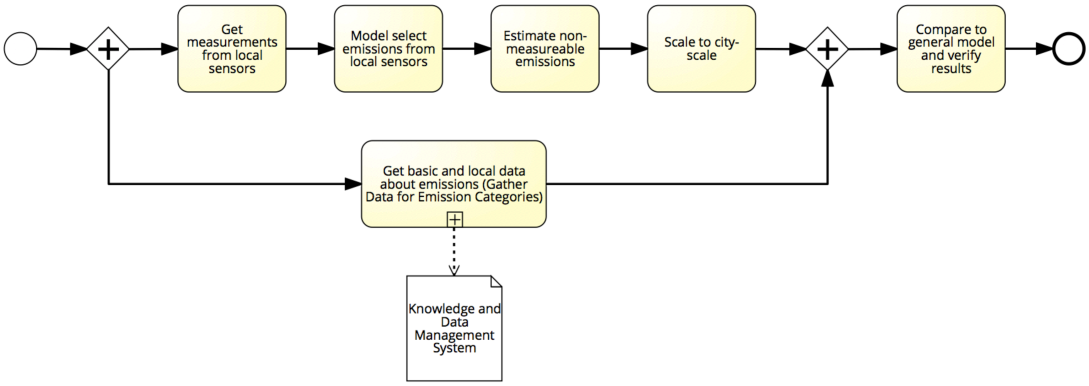

Figure 9 Future workflow with sensor integration

Conclusion

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 rather in data location, acquisition, and generation. 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.

Obviously, building a GPC inventory is not an end in itself, as it also helps a city develop a detailed overview and report about its emissions. This can serve as a decision aid in prioritizing GHG reduction measures and initiatives.

In line with this larger goal, the inventory building workflow can also 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 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.

This top-down data approach can be complemented by a bottom-up approach based on local measurements facilitated through sensor systems. This would also help to validate national statistical data and get faster turnaround time on impact of local initiatives and interventions.

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