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Counting Carbon: Contextualization or harmonization in municipal GHG accounting?

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Abstract: This article conducts an assessment of what should be considered best practice in municipal GHG accounting, contrasting the call for increased global harmonization with the need for local relevance and applicability. Taking as its point of departure an analysis of GHG accounting methodologies applied by local governments in Denmark, we identify eight Danish methodologies and assess them based on international good practice criteria. We observe a high degree of convergence among the Danish approaches in the application of data sources, quantification approaches, and scope, identifying data availability as the key barrier to improving the specificity and dynamic properties of local GHG accounts. In furthering an international best practice, the Danish approaches indicate that relevance to local planning necessarily involves an adaptation to the context of local systems and data sources, and that best practice guidelines should acknowledge limitations in inventory quality and provide guidelines for weighing trade-offs and exploring synergetic improvements. In Denmark, synergies can be found in improved data quality and regional cooperation on account development, which may improve relevance, quality, and comparability simultaneously, and act as an adaptive approach to methodology harmonization, without thereby reducing inventory relevance.

Keywords: Greenhouse gas inventory, mitigation, best practice, monitoring, municipalities

1. Introduction

A growing number of local governments (LGs) across the world are addressing the global problem of climate change through the development of climate action plans (CAPs) aimed at mitigating local drivers of greenhouse gas (GHG) emissions (Wilbanks & Kates, 1999: 610ff; Broto & Bulkeley, 2013: 92). Outlining mitigation action usually involves the development of a comprehensive inventory, accounting for the GHG emissions associated with the local authority (Kennedy et al., 2010: 4828; Ramaswami et al., 2008: 6455; Ibrahim et al., 2012: 224). In this study we aim to discuss the inherent trade-off between international standardization and contextual relevance in the growing field of GHG accounting.

A GHG inventory can be defined as an account of all GHGs emitted to the atmosphere for a given entity in a given period of time (Boswell et al., 2012: 87). This account has a number of applications, acting as the basis for planning action, reporting progress, and benchmarking performance (While, 2011: 47f; Corfee-Morlot et al., 2009: 35). A distinction can be made among three different scales of GHG accounting, developed for application to different scopes of emission-driving activities (Belassen & Cochran, 2015: 5). Accounting on the **territorial scale** includes all emissions occurring within a given geographical area, such as a

country, for which the International Panel on Climate Change (IPCC) guidelines, adopted by the United Nations Framework Convention on Climate Change (UNFCCC), is the accounting and reporting standard (Corfee-Morlot et al., 2009: 66f; IPCC, 2006; Belassen & Cochran, 2015: 5; Ibrahim et al., 2012: 223).

Accounting on the **entity scale** includes emissions related to the operation of a given entity, such as a company or organisation (Belassen & Cochran, 2015: 5). At this level the GHG protocol developed by the World Resource Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) acts as a harmonised reporting approach, in which the IPCC guidelines have been adapted for use on a different scale of activity (Corfee-Morlot, 2009: 67; WBCSD & WRI, 2004). Accounting on the **project scale** includes emissions stemming from a specific project, usually an emission-reduction project focused on a particular activity (Belassen & Cochran, 2015: 5). At this level, offsetting projects operating through the Clean Development Mechanism (CDM), or voluntary offsetting through, for example, the Gold Standard, provide the primary application of accounting methodologies (Belassen & Cochran, 2015: 5; GSF, 2015: 7; UNFCCC, 2014: 5).

Local governments account for both their organisational (entity) and community emissions. Accounting for **community scale** emissions primarily follows the territorial scale in attributing emissions to a spatially defined area, regardless of ownership; however, as this often includes emissions occurring outside the area as a result of activities inside the area, elements of an entity scale approach are used as well (Kennedy et al., 2011: 28). A number of different standards have been developed for local government GHG accounting, including ICLEIs International Local Government GHG Emission Analysis Protocol (IEAP), the Covenant of Mayors Strategic Energy Action Plan (SEAP), and the Global Protocol for Community-Scale GHG Emission Inventories (GPC) (ICLEI, 2009; EU, 2010; WRI et al., 2014; Rauland & Newman, 2015: 122f). None of these, however, has achieved the same widespread application as national and organisational accounting and reporting standards (Ibrahim et al., 2012: 224; Yetano Roche et al., 2014: 526). As a result, numerous studies have identified significant variations in the quality and scope of local GHG inventories (Rice, 2013: 333; Boswell et al., 2012: 6; Kousky & Schneider, 2003: 363; Bulkeley, 2013: 53; Corfee-Morlot et al., 2009: 67).

Given the increase in local action and the key role of GHG accounting in planning and monitoring mitigation activities, some authors argue for the need to establish a 'best practice' in this new field of planning to improve the overall quality and applicability of local GHG accounts (Boswell et al., 2012: 6; Corfee-Morlot et al., 2009: 65; Kennedy et al., 2011: 48; Ibrahim et al., 2012: 236). Defining a best practice for local GHG accounting will necessarily involve the definition of a number of criteria, by which different approaches can be assessed and compared. Taking as a point of departure the guidance on national inventory preparation published by the IPCC, one can emphasize a number of good practice indicators for ensuring inventory quality: transparency, completeness, consistency, comparability, and accuracy (IPCC, 2006: 1.7; Corfee-Morlot et al., 2009: 67). These criteria have been widely applied as basic reporting principles in various standards and guidelines on GHG reporting, with one recurring

modification: comparability has been replaced with the principle of relevance (ISO, 2006: 6; ICLEI, 2009: 7f; WRI et al., 2014: 25f). The broad dissemination, acceptance, and applicability of these criteria make them an ideal starting point for an assessment and discussion of approaches to local GHG accounting.

The search for a best practice in municipal GHG accounting has generally coincided with a call for inventory harmonization founded on the desire for comparability among local GHG accounting systems (Kennedy et al., 2010: 4828; Kramers et al., 2013: 1285). The key argument is the possibility of comparing, and thereby benchmarking, performance across locations, reporting on progress to local government networks, and providing measurable and verifiable emission reductions that are eligible for certification and may thus allow access to carbon finance (Corfee-Morlot et al., 2009: 10, 65ff; Ibrahim et al., 2012: 237). These are relevant and well-argued drivers for a standardization of accounting approaches; however, the substitution of comparability with relevance in the adaptation of national reporting requirements to smaller scales could be an indication that the utility of local GHG accounts should be evaluated using a broader understanding of relevance than the ability to benchmark performance. The methodologies applied are often adapted to the individual needs and contextual factors of local governments (Cochran, 2015: 76). The key task for a best practice on municipal GHG accounting, then, is to improve the quality and possibly the comparability of local accounts without reducing the operational applicability and relevance.

The purpose of this article is to contribute to the development of such a best practice for local government GHG accounting within the community scope. Based on a comparative assessment of all methodologies used by Danish municipalities, we aim to discuss the practical application of good practice criteria, the inherent trade-offs involved, and opportunities to improve the relevance of local accounts for planning mitigation action. We believe that Denmark is a highly relevant case country for this study, as Denmark in many ways can be considered a frontrunner on local climate planning. Having undergone a significant decentralisation of energy production since the mid 1970s, Denmark is currently endowed with the largest distributed generation capacity in the industrialised world, and confer significant autonomy to local energy actors (Sperling et al., 2011: 1339f; Chittum & Østergaard, 2014: 466f; Sauter & Bauknecht: 156). In addition, recent studies show widespread climate action planning among local government actors (Damsø et al., 2016: 76f; Hoff & Strobel, 2013: 6).

2. Methodological approach

2.2. Concept definition

A number of different concepts regarding GHG emissions and methodologies for GHG accounting have been used in this article, for which initial clarification is provided to avoid undue confusion.

A **GHG source** is a physical unit or process that releases a GHG into the atmosphere, whereas a **GHG sink** is a physical unit or process that removes a GHG from the atmosphere (ISO, 2006: 1). GHG emissions and removals are traditionally divided into **sectors**, constituting main groupings of related

processes, sources, and sinks. Each sector comprises a number of individual **sub-sectors** (categories) and **subcategories** (IPCC, 2006: 1.5; WRI et al., 2014: 30). A **GHG inventory** is a full account of all relevant GHG emissions and removals (from GHG sources and sinks) for a particular entity within a particular period of time - in this instance, a municipality and a calendar year. A GHG inventory is generally constructed by estimating emissions and removals at the subcategory level and then summing up emissions and removals, as this is how IPCC methodologies are set out (IPCC, 2006: 1.5). An additional distinction can be made among different aspects of the GHG accounting process, often referred to as MRV (Monitoring, Reporting & Verification). **Monitoring**, or measuring, refers to the scientific part of the process, i.e. measuring or estimating emissions from the different sources. **Reporting** covers the aggregation, recording, and reporting of emissions to the relevant authority, while **verification** involves a third-party assessment of compliance with the relevant guidelines (Belassen & Cochran, 2015: 4). This study is focused on the first part of the MRV process, using reporting requirements and guidelines only insofar as they affect the applied methodology for quantifying emissions. The IPCC provides an **approach** to the quantification of GHG emissions at the subcategory level, combining information on the extent to which a human activity takes place (called **Activity Data**, AD) with coefficients that quantify the related emissions or removals per unit of activity (called **Emission Factors**, EF): Emissions = AD * EF (IPCC, 2006: 1.6; ISO, 2006: 9). It follows that a particular **quantification approach (QA)** will use two sets of **data sources**: a set of activity data, and an emission factor. Each quantification approach will correspond to a particular subcategory. Some QA's apply other approaches, such as dividing national emissions based on inhabitants or mass balance methods; however, the clear majority of QAs follow the above-mentioned IPCC approach (IPCC, 2006: 1.6). In this study, a **methodology** is a collection of approaches used for the quantification of emissions from all subcategories deemed relevant to a GHG inventory. A methodology can be codified via a **manual** (procedural written guidance) and/or a **calculation tool** (software application).

2.3. Data collection (methodology identification)

In identifying methodologies applied to GHG accounting by LGs in Denmark, we have applied a multi-strategy approach, combining two different methods of data collection that complement each other in uncovering all available accounting methodologies (Bryman, 2004: 455).

First we conducted a comprehensive **cross-sectional literature review** in which all publicly available action plans for all Danish LGs were included. The study includes 436 plan documents, spanning 103 cases (98 municipalities and five regions) in Denmark (Damsø et al., 2016). The data was collected using web-based search engines combined with website reviews, and additional e-mail enquiries for the LGs that did not appear, from the original search results, to have an action plan. Subsequently the data was processed using a quantitative content analysis technique, by which key characteristics have been codified in accordance with a predetermined coding manual. The content analysis identifies applied methodologies, first by mapping identifiable methodologies directly, and subsequently by mapping third-party actors involved in plan development and

assessing whether they apply a distinctive (latent) methodology not available in the original results.

Second, we conducted a **survey** aimed at collecting information on the cross-municipal ‘Strategic Energy Planning’ (SEP) projects funded by the Danish Energy Agency (DEA) that have not yet been widely disseminated (DEA; 2015a, 2015b, 2015c). As the projects are cross-municipal, a total of 14 projects cover almost all Danish LGs. The limited number of projects made it possible to use an e-mail survey following a predetermined template, relaying a specific set of questions on applied tools and approaches, as well as requesting relevant documents from each project lead (Andersen, 2010: 142f). Of the 14 projects, nine returned a complete response, resulting in a response rate of 64 per cent. A total of eight different methodologies, briefly summarized in table 2, have been uncovered and included in the study.

2.4. Data processing and analysis (methodology review)

The eight methodologies identified have been reviewed following the above-mentioned criteria of transparency, completeness, consistency, accuracy, comparability, and relevance. The review has been subdivided into four studies corresponding to the three levels in the methodology hierarchy (methodology, quantification approach, and data source) followed by a crosscutting discussion on relevance and comparability as well as our contribution to an international best practice. The reason for this is that some criteria relate to the full methodology, whereas other criteria relate to the individual quantification approach or data source. A definition of the criteria and their analytical application in the article has been summarized in table 1.

Table 1: Criteria definition and application

Criteria	Definition	Analysis			Discussion
		Methodology	Quantification Approach	Data Source	
Transparency	Sufficient and clear documentation is disclosed.	X			
Completeness	All relevant GHG emissions and removals are included.	X			
Consistency	Emission calculations are consistent in approach, boundary and methodology.		X	X	
Accuracy	Bias and uncertainty is reduced as far as is practical.		X	X	
Comparability	GHG inventories are reported in a way that allows for comparison.				X
Relevance	GHG sources, data and methodologies are appropriate to the needs of the intended user.				X

Definitions are selected from the sources providing the most precise and applicable description of each criterion: Transparency, completeness, accuracy and relevance from ISO (2006: 6), consistency from WRI et al. (2014: 25) and comparability from IPCC (2006: 1.8).

3. Analysis

The following analysis has been subdivided into a section on methodologies, quantification approaches, and data sources, using applicable criteria for each.

3.1. Methodologies

We have identified eight unique methodologies applied to local GHG accounting in Denmark. Three have been developed for public agencies with the purpose of providing tools and methodologies for municipalities and other public actors in mapping emissions and planning transitions (CO2-calculator, SEP Guidelines & TEMA model). Two have been developed independently by other public actors for application to municipalities in a specific region (RUC & DST approaches). The remaining three are applied by consultancy firms (PE, Rambøll & COGITA approaches). Each methodology has been briefly described in table 2.

Table 2: Methodologies applied to local GHG accounting in Denmark

Methodology	Anchorage & application	Typology	Availability
CO2-calculator	A tool for mapping GHG emissions and planning action, developed for the Ministry of Climate and the Environment in 2009. Utilized by 33 Local Governments (LGs).	A software application (calculation tool) and written guidance and documentation.	Freely available for Danish LGs.
Strategic Energy Planning (SEP) Guidelines	Guidance document on strategic energy planning, commissioned by the DEA to underpin LG energy planning in 2012. Guidance on mapping energy consumption, supply, baseline projections and mapping transition potentials. Utilized by 3 LGs.	Guidance document and a spreadsheet for estimating a local energy balance	Freely available. Spreadsheet freely available for all Danish LGs.
TEMA model	TEMA is a calculation model launched by the Ministry of Transportation, for calculating energy consumption and emissions from transport. Can calculate emissions from personal and cargo transportation, utilizing and combining different modes of transport. Utilized by 1 LG.	Software application with written guidance and documentation.	Freely available.
Roskilde University (RUC) methodology	Developed by researchers at RUC in 2011 for CAP development in the Region of Zealand (DK). Utilized by/for 17 LGs.	Guidance document.	Documentation available.
Statistics Denmark (DST) methodology	Developed by DST in 2011 for CAP development in the Southern Denmark Region (DK). Utilized by/for 3 LGs.	Methodology documentation.	Documentation available.
PlanEnergi (PE) methodology	Methodology for developing local energy balances, developed and applied by the independent consultancy PlanEnergi (PE). Utilized by/for 16 LGs	Methodology documentation.	Documentation available.
Rambøll methodology	Distinct approach applied by the consultancy firm Rambøll, combining the IPCC guidelines and the Long Range Energy Alternatives Planning model (LEAP). Utilized by/for 10 LGs	Calculators, models and guidelines.	Documentation unavailable.
COGITA methodology	Distinct approach applied by the independent consultancy firm COGITA. Utilized by/for 1 LG	Methodology documentation.	Documentation available.

Sources: COWI, 2010: 3f; DEA, 2012: 8; 2015d, 2015e, 2015f; Guldborgsund, 2009: 6; Herning, 2008: 6; Kjær & Damsø, 2011; MCE & LGDK, 2008; Nielsen et al., 2009: 9; Olesen, 2011; Olsen & Rørmose, 2010; 2011; Ringsted, 2010. Abbreviations defined in the table.

As can be seen in the table, the three methodologies developed for public consumption provide free software and guidance, with some restrictions on availability to non-public actors (due to data restrictions). Four of the remaining methodologies provide detailed documentation of the applied approaches along with the account, whereas the final methodology is briefly described in the introduction to published GHG accounts and has accordingly been derived from its application in these reports (Guldborgsund, 2009; Herning, 2008). In addition, a new publicly financed calculation tool is currently under development (2016) with the purpose of replacing the CO₂-calculator (ViegandMaagøe, 2015: 1). As it has not been released, let alone been utilized by any municipality, it is excluded from this study. It will however contain a number of features aimed at improving the current practices, including automatic data sourcing and export modules for the SEAP format of the Covenant of Mayors and the GPC format of the Compact of Mayors, greatly increasing the feasibility of fulfilling the reporting requirements of these networks (ViegandMaagøe, 2015: 1f).

3.1.1. Transparency

As defined in table 1, the methodologies can be assessed in regard to their transparency and completeness. Looking first to transparency, one sees that this principally relates to the GHG inventory and not the methodology (as does all good practice criteria), and specifies that sufficient and clear documentation should be disclosed so that actors other than the inventory compiler can understand how it was done and assess whether it is in line with good practice (IPCC; 2006: 1.7). In the cross-sectional analysis we observed that very little documentation on methodology, data sources, and assumptions is made available in local inventories, in line with the findings of Boswell et al. (2010: 459). The clear majority of inventories indicate the overall methodology applied, leaving further documentation of approaches to the methodology guidance documents. This lack of transparency could reduce the overall credibility of GHG accounts, as in the case of corporate GHG inventories in Canada (Talbot & Boiral, 2013: 1080f).

Although the clear and sufficient documentation of protocols and software for LG GHG accounting has made the quantification of emissions a largely technical exercise, with little room for data manipulation, some flexibility exists, as a number of methodologies include several approaches for each GHG source, with different levels of precision (Boswell et al., 2010: 459). Transparent GHG accounts should at the very least include information on the methodology applied, approaches and data sources used, and justification of exclusions and partial accounting. This presupposes that methodology documentation is available, which is the case for all the publicly developed tools but less so for the methodologies applied by private consultancy firms. While proprietary methodologies are a necessary part of the business model for consultancy firms, this does limit the transparency of GHG accounts, and complicates subsequent monitoring without continuous support from external parties.

3.1.2. Completeness

Turning subsequently to the criteria of completeness, this requires that all relevant categories of sources and sinks be included in the inventory (IPCC, 2006: 1.8). For methodologies, this can be assessed by determining whether the methodology includes approaches for all GHG sources and could thereby be said to offer complete coverage. This assessment has been summarized in table 3.

Table 3: Methodology coverage (completeness)

Sector	Energy						IPPU		AFOLU			Waste	
	Electricity	District heating	Individual heating	District cooling	Process energy	Transportation	Industrial processes	Product use	Livestock	Agricultural lands	Land use	Landfills	Wastewater
Subsector													
CO2-calculator	2	2	7	0	2	16	18	2	1	3	9	3	2
SEP guidelines	2	2	3	2	2	7	0	0	0	0	0	0	0
TEMA model	0	0	0	0	0	1	0	0	0	0	0	0	0
RUC methodology	1	1	1	0	1	6	11	1	1	1	1	1	1
DST methodology	1	1	1	0	1	1	1	0	1	1	1	0	0
PE methodology	1	1	1	0	1	6	0	0	0	0	0	0	0
Rambøll methodology	1	1	1	0	1	5	0	0	1	1	0	1	1
COGITA methodology	1	1	1	0	0	2	0	0	1	1	0	2	0

The table shows sectors and subsectors in the first two rows and then the eight methodologies, mapping coverage for each methodology on each subsector. Coverage is indicated with a light blue fill colour and the number in each cell indicates the number of quantification approaches available for a methodology within a particular subsector. Abbreviations: AFOLU: Agriculture, Forestry and Land Use, IPPU: Industrial Processes and Product Use.

Looking at the table, it should be noted *first* that the district-cooling subsector included in the SEP guidelines has only recently become a relevant category with the introduction of district cooling in Denmark (individual cooling using electricity is included in the electricity category). *Second*, it should be noted that the exclusion of particular sectors in the Rambøll approach is both intentional and described in each account, as industrial emissions and land use change are considered marginal sources that make limited contributions that are not addressed in the action plan and are therefore excluded from the GHG inventory (Guldborgsund, 2009: 5f). As such, the Rambøll approach may include these sources in the event they are deemed relevant in another municipality; lacking full documentation for the methodology, an assessment of whether it allows for this inclusion is difficult to complete. *Third*, the term ‘relevant’ allows for some flexibility, as the different methodologies have been developed with different intended applications. The TEMA model, developed explicitly for the quantification of transportation emissions, for instance, is not intended to offer complete coverage; similarly, the SEP guidelines and the PE methodology are energy planning approaches, and therefore account only for emissions from the energy sector. The result is necessarily a lack of completeness in the GHG accounts, creating some risk of sub-optimization in planning mitigation action, as not all sources are included. The shortfall may, however, be a result of an initial prioritization of the sectors, focusing on the areas in which municipalities exert the largest influence and have the best chance of implementing mitigation activities, as in the case of the Rambøll accounts.

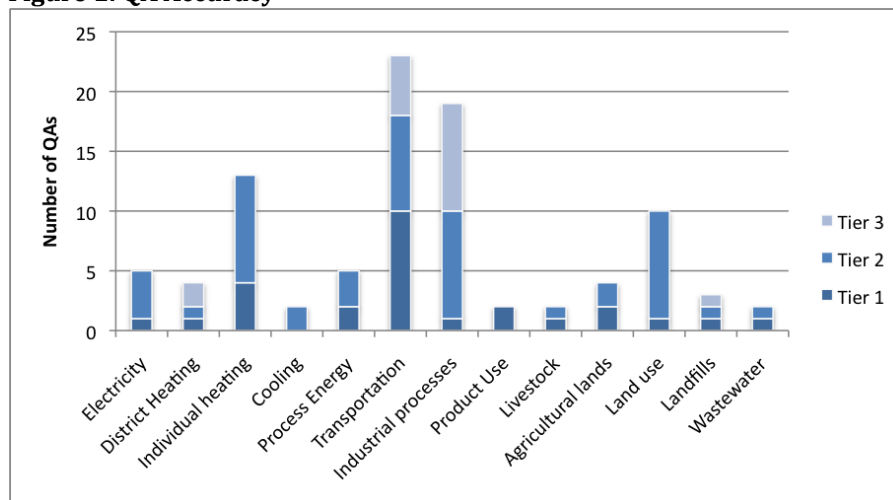
3.2. Quantification approaches

A Quantification Approach (QA) is an approach used for the calculation of emissions from a particular GHG source, traditionally done by multiplying GHG activity data with GHG emission factors (ISO, 2006: 9; IPCC, 2006: 1.6; Rypdal & Winiwarter, 2001: 108). An assessment of consistency and accuracy of municipal GHG accounting methodologies relates more closely to the particularities of the QA application than the overall methodology. Additionally, as there are eight methodologies but only 96 QAs applied for 43 emission-source categories, there is a significant convergence in applied QAs for the different methodologies. We will thus proceed by assessing the different quantification approaches applied, and discuss differences in methodology application only where relevant.

3.2.1. Accuracy

Accuracy has been defined above as the reduction of bias and uncertainty as far as is practical (ISO, 2006: 6). The IPCC has introduced the concept of **tiers** as a means of distinguishing different levels of methodological complexity, and, as a result, different levels of accuracy in GHG accounting (IPCC, 2006: 1.6; Kennedy et al., 2011: 26; Nielsen et al., 2009: 8f). Higher-tier methods are generally considered more accurate, but also require more effort in obtaining data, creating a trade-off between the effort involved and the accuracy of the results (ICLEI, 2009: 23; WRI, 2014: 83). The choice of approaches will depend on available resources, and LGs are generally advised to use the highest practicable tier, and in particular to focus resources on applying higher-tier methods to key sources (ICLEI, 2009: 23; Nielsen et al., 2009: 9). Accuracy relates directly to the applicability of the GHG inventory. An account should map the activities actually driving emissions, and thereby point to activities addressing those drivers, in particular for the sectors in which they intend to implement mitigation projects. The QAs applied in Denmark sorted by subsector have been assigned a tier level according to the above-mentioned distinction: scaling approaches as tier 1, the combination of local activity data with generic emission factors as tier 2, and the use of local activity data and local emission factors as tier 3. The results have been summarized in figure 1.

Figure 1: QA Accuracy



Quantification Approaches (QAs) have been sorted into tiers based on the following criteria: All top-down/scaling methodologies defined as tier 1, methodologies utilizing local AD and generic EF as tier 2 and methodologies utilizing local AD and local EF as tier 3.

As can be seen in the figure, there is wide variation in regard to the number of QAs available for each subsector and the division of approaches on tier levels. The number of QAs is partly a result of the number of subcategories within a subsector; for example, individual heating has three additional subcategories, transportation six, industrial processes 11, and land use 10 subcategories. Of the 96 QAs, 29 are tier 1 approaches, 50 are tier 2 approaches, and 17 are tier 3 approaches. As can be seen from the figure, tier 3 methodologies are available for only four of 13 subsectors. The lack of higher-tier methods is likely a direct result of data availability, as tier 3 approaches will require local activity and emissions data, which may be difficult to obtain for a number of sectors at the local government level. The majority of methodologies include only one QA for each emission source covered, whereas the CO₂-calculator and the SEP guidelines provide approaches on different tier levels for each GHG source category, thereby reducing comparability but increasing flexibility in methodology use.

3.2.2. Consistency (scope)

A goal of consistency suggest that emission calculations be consistent in approach, boundary and methodology (WRI et al., 2014: 25). As both methodology and approach have been touched upon, the boundary definition is the key aspect under consideration in this section. Boundary definition involves a decision regarding what activities to include in the account. Although it might seem self-evident to include activities within the local government's geopolitical area and exclude activities outside the area, this is far from always the case (Kramers et al., 2013: 1278; Kennedy et al., 2011: 28). There is wide variation in how LGs define the scope of local activities included in their accounts, which will likely result in the double-counting of some emission sources and a shortfall in the accounting of other sources, leading to some activities being excluded altogether while others are included in several accounts (Kousky & Schneider, 2003: 362; Kennedy et al., 2011: 16ff, 27; Cochran, 2015: 79; Yetano Roche et al., 2014: 526; Munksgaard & Pedersen, 2001: 329). The scope of a local inventory can be defined in a number of ways; however, aside from the distinction among territorial, entity, and project accounts, the distinction between **emission scopes** is by far the most widely applied means of distinguishing a system boundary (ICLEI, 2009: 12f, 15; Kousky & Schneider, 2003: 363; Yetano Roche et al., 2014: 522). This particular distinction was introduced in the 'GHG protocol' to delineate direct and indirect emission sources, thereby improving transparency and utility for different types of organisations (WBCSD & WRI, 2004: 25). The concept has subsequently been adapted for application at the community level, in which a distinction is made among emissions physically within the municipality (scope 1), emissions occurring outside the municipality as a result of activities within the municipality (scope 3), and emissions from the production of grid-supplied energy consumed in the municipality that may or may not cross municipal boundaries (scope 2)(WRI et al., 2014: 11; Kennedy et al., 2010: 4829; Bulkeley, 2013: 49; Boswell et al., 2012: 100). Generally, LGs are expected to include at least all scope 1 and 2 emissions to obtain an adequate

coverage (ICLEI, 2009: 20; Cochran, 2015: 80). Danish GHG accounting methodologies apply a hybrid accounting principle, merging key aspects of a production and a consumption principle, with the inclusion of scope 1 and 2 emissions, in line with similar findings by Cochran (2015: 80). Almost all methodologies account for local fuel consumption in heating, process energy, and transport, and the methodologies developed for GHG accounting generally include local emissions from industrial processes, agriculture, land use change, and waste, and include emissions from grid-supplied electricity and heat. Additionally, with the introduction of district cooling in Denmark, the supply of district cooling has been included in more recent accounts. None of the major methodologies includes scope 3 sources, and only a limited group of Danish GHG accounts includes upstream effects of local consumption. The use of a hybrid accounting principle introduces a number of issues related to double counting, most importantly in the area of transportation. There are two predominant methods for estimating emissions from transportation applied in a Danish setting: the geographic approach, focusing on travel occurring within the territorial boundary, and the resident activity method, quantifying the transport activities of city residents - in both cases coupled with scaling approaches for non-road transportation (Kennedy et al., 2010: 4831; WRI et al., 2014: 77f). The consistency issues are fairly self-evident, as the mixing of geographic and resident activity methods will result in some transportation being counted twice and other transportation being excluded altogether. This, however, is not an issue solely if some LGs apply one approach and other LGs another; within each account, some LGs apply a geographic approach to accounting for road transportation, and, subsequently, a resident activity or scaling method in accounting for aviation and waterways. This variation results in difficulties in regards to comparing local accounts. In addition to the consistency issues outlined above, this may limit the transferability of national goals to the local level and the utilization of local accounts in national reporting. Some may view this as a significant limitation, we would however argue that this limitation relates directly to whether comparability or local relevance is considered the key objective of the GHG accounting in LGs, a point we will explore further in the discussion.

3.3. Data sources

Turning finally to the data sources used to estimate GHG emissions, we have identified a total of 46 different data sources applied to local GHG accounting in Denmark.

3.3.1. Accuracy

As mentioned for the QAs, accuracy relates to the reduction of bias and uncertainty as far as is practical (ISO, 2006: 6). For data sources in local GHG accounting, the key aspect of accuracy is local specificity - the degree to which data sources are locally specific and reflect adequately the emission sources they are set to quantify. The specificity of the primary data sources has been illustrated in figure 2. The ideal data source would naturally be direct measurements of GHG emissions; however, for the clear majority of emission sources LGs will have to estimate emissions using activity data and emission factors (WRI et al., 2014: 47). All data mentioned in figure 2, with the exception

of measured emissions from industries, uses an AD*EF structure, distinguishing among data for which the data sources are 1) locally measured, 2) estimated based on local surrogate data, 3) estimated applying generic or national factors, or 4) scaled from national emissions (WRI et al., 2014: 49; IPCC, 2006: 2.7). In addition, the data sources are colour-coded based on their dynamic properties; regularly updated data sources are blue, rarely updated data sources are red, and data sources for which the dynamic property is unclear are green.

Figure 2: Data specificity and dynamic properties

	Electricity	Heating	Process	Transportation	IPPU	Agriculture	Land Use	Waste
Local Measurement	AD: Local electricity consumption EF: Local electricity production	AD: Local consumption (DH & NG) EF: Local production (DH)	Local emissions (EU ETS) AD: energy consumption (green accounts)		Local emissions (EU ETS) AD: industry information (green accounts)	AD: Livestock data AD: agriculture area data		AD: Local waste data AD: Local wastewater data
		Building statistics Chimney sweep statistics Housing statistics	Industry statistics	Local traffic analysis VKT local survey Traffic model			Local data on land use	
Local Estimate								
Generic & National	National EF	National DH EF		VKT data by city size TEMA model	National EF			
		Fuel specific EF						
Scaled	National consumption	National DH consumption		Registered vehicles Length of rail track		Area data Livestock data	Area data	
	Inhabitants, employment, housing and regional national statistics used as general scaling factors							

The figure is split into eight major sectors on the **horizontal axis** and four data specificity categories on the **vertical axis**: Scaled, generic/national, local estimate and local measurement. For each dataset a box has been placed in the matrix based on their sector/data specificity and subsequently ranked within each field. Within the category of local measurement an additional distinction is made between locally measured emissions, activity data and emission factors. The boxes are **colour-coded** based on their dynamic properties where blue boxes are updated annually/periodically, red boxes rarely/never and for green boxes the dynamic properties are unclear. Abbreviations: AD: Activity Data DH: District Heating, EF: Emission Factor, EU ETS: EU Emissions Trading Scheme, NG: Natural Gas, VKT: Vehicle Kilometres Travelled.

The key challenge in regard to data specificity is availability, and the difficulties in obtaining data are well-known and -referenced (cf. Bulkeley, 2013: 51; Cochran, 2015: 81ff; Yetano Roche et al., 2014: 523, 526). As can be seen from the figure, there are a number of locally measured data sources; however, the availability of these data sources is highly sector-specific. The transport sector poses a particular problem in terms of data availability (Yetano Roche et al., 2014: 528). Local fuel sales data is proprietary and generally considered inaccessible. Local traffic analysis, traffic models, and surveys of resident activity (VKT) can be purchased from data developers, but data sources available freely to local planners include only generic assumptions about resident activity and scaling

approaches, generally considered highly inaccurate. Similarly, for heating, locally measured data is usually available for district heating; when it comes to individual heating, however, data on fuel sales is proprietary and can only rarely be collected (and even then almost exclusively for natural gas). The alternative is housing or chimney-sweep statistics, which are fairly precise but not regularly updated. And finally, regarding process energy and IPPU emissions, EU ETS data is, at best, available for the largest sources, while data on local industries through national statistics (green accounts) is only mandatory for a small group of industries, not nearly covering the spectrum of industrial emissions. Overall, the availability of locally specific data sources for a number of key sectors is a significant limitation to the utility of local GHG accounts.

3.3.2. Consistency (*monitorability*)

A key facet of the IPCC definition of consistency is the temporal aspect—that is, that inventories for different years be made in the same way so that differences in inventories reflect actual changes in emissions (IPCC; 2006: 1.8). This relates to the monitorability of the GHG inventory: Whether we are able to monitor changes annually and show the effect of local policies is an obvious and integrated part of all climate action planning processes and a key aspect in motivating action (Boswell et al., 2012: 193). Regarding data sources, continuous monitoring is dependent upon the two aspects included in figure 2:

- **Local specificity:** whether the data sources are directly related to local emission drivers (vertical axis).
- **Dynamic properties:** whether the data will change over time, corresponding to the changes in emissions (colour coding).

Both aspects are key, as locally specific data without dynamic properties does not allow for *monitoring* change and dynamic data without local specificity does not allow for monitoring *local* change. Looking at figure 2, one sees that the transportation and individual heating sectors generally apply surrogate data, much of it static, indicating that this data may be suitable for estimating base year emissions but not for monitoring change. Additionally, all scaling approaches are inherently problematic, as they do not respond accurately to local changes in use or behaviour (ICLEI, 2009: 24). In fact, the most effective way of reducing emissions following tier 1 approaches would be a migration of inhabitants, thereby reducing the scaling factor.

4. Discussion

The remaining criteria of comparability and relevance are intrinsically tied to each other as well as to the discussion of what should be considered best practice in municipal GHG accounting. As a result, they are treated in unison in the following.

Comparability stresses the need to report in a way that allows for cross-comparison of accounts (IPCC, 2006: 1.8). The call for increased harmonisation of approaches is largely based on the desire to compare emissions among LGs, aggregate them to the national level, and allow for a more systematic assessment of mitigation performance (Corfee-Morlot et al., 2009: 10, 69). There is a clear harmonization of approaches within some sectors in Danish LG GHG accounting. This is the case for non-energy-related emissions, in which the CO₂ calculator has established a de facto standard, and for some subsectors in the energy sector

for which only one applicable dataset exists (electricity consumption and district heating). However, for other subsectors, most notably transportation, no such convergence can be identified, and the variety of methodological approaches significantly inhibits the comparability of inventories (Cochran, 2015: 76). In an analysis on updating the CO₂ calculator, it is argued that the possibility of choosing different tiers should be eliminated, to increase benchmarking among municipalities; and recent documentation on the new calculator indicate that this will indeed be the case (NIRAS & ViegandMaagøe, 2014: 3; ViegandMaagøe, 2015). While this development would likely increase the comparability of local accounts, it would do so at the cost of significantly reducing flexibility in the local application of the calculator.

The **relevance** criteria state that GHG sources, data, and methodologies should be appropriate for the needs of the intended user (ISO, 2006: 6). This basically implies that GHG accounts should have some qualities that make them applicable to addressing the source of GHG emissions. This means that GHG accounts should identify key emission drivers, as well as provide the proper policy incentive to address those drivers (Kennedy et al., 2011: 49). This is inherently a context-specific matter. Defining what constitutes a high degree of policy relevance is significantly more contextualised than, for example, defining what constitutes a high degree of accuracy or completeness. This implies that a best practice for municipal GHG accounting should move beyond a simplistic theoretical or rational set of unrelated criteria, to address the contextual challenges inherent in applied GHG accounting. Some would argue that inventories should be globally consistent and at the same time locally pragmatic (cf. Ibrahim et al., 2012: 236), and while this would be the ideal we would argue that the inherent trade-offs between the two in applied accounting praxis should be addressed.

In a Danish context there are some limitations, or barriers, to ideal-rational GHG accounting on the municipal scale. *First* among these is the limited capacity for plan development in a context that does not provide unlimited resources for GHG accounting (cf. Pitt & Bassett, 2013: 291; Corfee-Morlot et al., 2009: 39, 46; Salon et al., 2014: 76f). *Second*, municipal GHG accounting in Denmark is subject to significant limitations of data availability. This is mainly due to the system scope under consideration. National-level accounts have fairly accurate statistics of fossil fuel import, export, and use, and organisational accounts are closely linked to the financial flows of the company under study; municipal community accounts, however, do not have the same convergence of data and system boundaries, and are therefore challenged in terms of data availability. In addition to creating challenges for mapping emission sources, this results in major challenges for continuous monitoring of emissions.

An international best practice for local GHG accounting should point toward improving the relevance of local GHG accounts, or, more specifically, relevance in the practical application of GHG accounting methodologies. The Danish experience assessed above can provide some insights into ways of doing so.

First, a best practice should accept the presence of trade-offs among the different criteria, and provide guidelines for balancing competing concerns. The majority of these relate to the limited capacity for plan development, which will necessitate weighing between things like completeness and accuracy. Two

strategies for focusing resources can be found in the literature. The first is the concept of *materiality*, or focusing on key categories, which, simply put, implies that fewer resources should be spent on smaller emission sources (Belassen et al., 2015: 528; Ibrahim et al., 2012: 239). The second is a focus on *policy relevance*; as LGs have different levels of influence pertaining to different emission sources, it could be argued that attention should be granted to sources within their major sphere of influence (Lazarus et al., 2013: 565). A combination of these concerns is often appropriate, and key Danish examples of this can be found in the sectoral focus of the SEP guidelines and the PE methodology, as well as in the possibility of choosing scaling methodologies for minor sources in the CO₂-calculator, thereby focusing on the application of higher-tier methods to key categories. Some trade-offs, however, are more inherent in the competing concerns embedded in the criteria, as is often the case for comparability and relevance. Whereas increased comparability would involve methodological harmonization, policy relevance generally favours flexibility in choosing the approach most suitable to providing policy incentives for the particular municipality. One key example of this is the choice between a geographic and resident activity approach in the transportation sector. While a geographic approach provides a significant incentive to act for municipalities with large amounts of in-border traffic, as is the case for major city centres, the resident activity method provides a more useful policy incentive for municipalities with a large amount of outgoing commuting. Harmonization would necessarily result in a reduced policy incentive for one group. Different accounting approaches may give different insights, and thereby serve different purposes for local decision-making. Whereas consumption approaches focus on the final use of goods and services and, as such, on consumer behaviour, production approaches provide more valuable information on local energy systems, and may better support local system transitions (Yetano Roche et al., 2014: 531f). The purpose of local GHG accounting is to reduce local emissions. This requires contextually embedded mitigation action, and we would argue that a best practice should favour methodological flexibility insofar as it improves the applicability of action plans in reducing GHG emissions. It should be noted, however, that increased flexibility must be accompanied by increased transparency, in order to facilitate quality assurance and avoid allowing flexibility to become a means of creative carbon accounting.

Secondly a best practice should point to areas in which improvements to GHG accounting methodologies can be made, without inherent trade-offs, by addressing the underlying challenges of the contextual limitations. In a Danish context, these limitations are data availability and plan development capacity. In terms of data availability, we can observe a high convergence of methodological approaches for categories in which a particular data source provides significantly higher specificity and has greater dynamic properties than the alternatives. It follows that making high-quality data sources, and associated quantification approaches, easily (and freely) available will likely lead to simultaneous improvements in accuracy, relevance, comparability, and consistency, as a large number of municipalities will likely apply them. The automatic data sourcing included in the upcoming new calculator, may be a means of such synergetic improvements (ViegandMaagøe, 2015). In terms of

plan development capacity, a number of Danish municipalities are overcoming resource limitations through economies of scale, by combining resources with neighbouring municipalities to produce regional-scale accounts with municipal resolution (Cochran, 2015: 84; Belassen et al., 2015: 520ff). Danish examples include a region applying the PE methodology and another the RUC methodology in developing both municipal- and regional-level accounts, as well as the aforementioned cross-municipal strategic energy planning projects (Damsø et al., 2016, Region Zealand, 2011: 2; Olesen, 2011: 3; DEA, 2015b). This will improve the completeness, consistency, comparability, and likely the accuracy of local accounts, while reducing overall costs.

A best practice for local GHG accounting should be more than a mechanical application of theoretical criteria; it should provide guidance on challenges facing the practical application of GHG accounting methodologies. In advising on the weighing of trade-offs, a ranking of criteria that recognises the value of flexibility in adapting to the policy context may prove useful, and identification of contextual barriers to improved GHG accounting practice may serve as a measure to identify levers for improving current practices. In the short term, this will come at the cost of harmonization; however, the Danish experience indicates that a focus on improving the relevance of methodologies may act as an adaptive approach to data standardization, as municipalities tend to coalesce around the best available approaches over time (CDP, 2015: 14).

5. Conclusion & Policy implications

In this study we have assessed how municipal GHG accounting in Denmark complies with international good practice criteria, what should be considered best practice in Denmark, and how Danish performance can inform the development of an international best practice in this growing field.

Eight reasonably autonomous methodologies have been surveyed and assessed, none of which acts as a unifying best practice in Denmark. Conversely, the Danish best practice is composed of different contributions from several of the eight methodologies. Overall, Danish methodologies provide a high degree of transparency in documenting approaches, but lack proper documentation of methodology application. There is an acceptable completeness in sector coverage, marked by the fact that some methodologies are developed exclusively for energy and transport planning, leading to some variation in coverage, and lower overall coverage for the non-energy sectors. The methodologies exhibit a high degree of scope consistency, applying a combined production and consumption principle for GHG accounting by including scope 1 and 2 emissions but generally excluding all other upstream emissions (scope 3). The methodologies on average apply tier 2 approaches, with few higher-tier approaches available, due to significant data limitations. The specialised energy planning tools provide the most accurate approaches for the energy sector, whereas the general-purpose CO₂-calculator provides the highest-tier methods for the non-energy sectors. The key challenge for local GHG accounting in Denmark is data availability. Locally specific and dynamic data sources are only available for a limited group of GHG sources, inhibiting the accuracy of GHG accounts as well as the possibility of monitoring change. The policy relevance of

GHG inventories appears to be the primary focus for municipal GHG accounting in Denmark, resulting in significant variation and flexibility in the choice of methodology, with only limited harmonization of approaches. Recent initiatives, however, indicate a change in favour of increased harmonization of at least the publicly developed approaches.

We find that an international best practice should improve the policy relevance of municipal GHG accounting, which is closely linked to the contextual application of GHG accounting. This implies accepting that trade-offs among the different good-practice criteria will be a necessary part of practical GHG accounting, and providing guidance on how to conduct such weighing should be a key part of any international best practice. Based on the realities of limited funding and data availability, we propose materiality and policy relevance as key indicators in focusing GHG accounting development. By identifying key categories for which accuracy, local specificity, and the dynamic properties of data sources are optimized to improve policy relevance, the application of scaling methods with a lower degree of accuracy should be accepted for the remaining categories to free up the necessary resources. This must necessarily lead to the conclusion that we should promote methodology flexibility over harmonization, and local policy incentives over academic accuracy. However, increased flexibility should be accompanied by a similar increase in methodological transparency to facilitate quality assurance. In addition, there are areas in which improvements can be made without the inherent trade-offs, by addressing contextual barriers for GHG accounting. In Denmark, improved data availability at the municipal level, as well as overcoming resource limitations by cross-municipal cooperation on account development, provide a basis for synergetic improvements.

We argue that an international best practice should address concerns in practical accounting, not simply provide theoretical guidance on ideal accounting. This would improve the applicability, and thereby the application, of the criteria, and while methodological flexibility may inhibit harmonization in the short term, a focus on improving the relevance and availability of data and methodologies may act as an adaptive approach to standardization, and thus improve the theory and practice of municipal GHG accounting in the long run.

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