MANAGING CITIES AND LOCAL COMMUNITIES: THE USE OF LIFE-CYCLE THINKING THROUGH CARBON FOOTPRINT-BASED INDICATORS

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Summary:
Cities are asked to respond to the urgent agenda of reducing emissions of greenhouse gases (GHGs). Many of these have adopted mitigation targets and developed action plans; however, these commitments have not always been followed up with sufficient actions to mitigate GHG emissions. One important issue is the lack of data with the quality and detail sufficient to identify local GHG mitigation strategies. In this paper we introduce a consumption-based GHG inventory to illustrate the vital contribution this could have to improve the data foundation decisions are based upon. Results from our case-study of selected Norwegain municipalities show that a life-cycle perspective is essential to capture the total effect of GHG reducing actions. In most cases, more than 90 percent of emissions resulting from municipalities own activities are indirect emissions embodied in the production of products and services purchased.

Key Words: Carbon Footprint, Consumption-based GHG Inventories, Environmentally Extended Input-Output Analysis, Hybrid-LCA, Case Studies of Norwegian Municipalities

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I. INTRODUCTION

Most discussions concerning the reduction of greenhouse gas (GHG) emissions tend to focus on national commitments and much too general mitigation targets. However, a shift to sub-national climate governances has emerged the last few years, especially resulting in campaigns such as the “Cities for Climate Protection” (CCP) gaining strength (Betsill and Bulkeley 2006; Koehn 2008; Wheeler 2008). With this shift, new challenges have arisen; how do we measure the success of local climate action?

Local authorities have often faced a conflict between economic and environmental objectives, and part of this conflict arises out of how the causality of emissions is addressed in current emission inventories (Bulkeley 2005; Larsen and Hertwich unpublished manuscript, 2009) It is still common to inventory emissions on a territorial basis, so that a city would be responsible for the emissions inside its municipal boundaries. The location of large point sources, such as industrial establishments or heat and power plants hence play an important role in determining the emission level of a municipality. Because large point sources usually produce for a larger set of customers than the local municipality, it is sensible to distribute the emissions among all these customers. The Carbon Footprint (CF) (Wiedmann and Minx 2007; Hammond 2007; Weber and Matthews 2008; Weidema et al. 2008) has been produced precisely for this purpose. CF methodology focuses on consumption, rather than production, and is therefore *not* influenced by fluctuation in production processes within the geographical boundaries investigated. Shifting the responsibility of GHG emissions to the consumers of products and services could be a more useful way of compiling GHG emission inventories and implies a stronger focus on the environmental impacts resulting from both private, and of particular interest to this paper; public consumption (Li and Geiser 2005; Hilson 2008; Hochschorner and Finnveden 2006; Walker and Brammer 2009; Parikka-Alhola 2008). Further, a consumption-based inventory enables the use of per capita indicators and benchmarking, yielding a wider range of possibilities to monitor the performance of a city or a municipality, and further to increase the number of policy implications to be drawn from the calculations.

The role of cities and municipalities own administrations are mainly twofold; to establish the physical environment in which its citizens live, through the construction and maintenance of infrastructure such as buildings and roads, but also as a significant actor through the activities and purchases made in order to provide local services like healthcare and education for the citizens. In this paper, we aim at showing how life-cycle thinking, illustrated through the use of CF indicators, is necessary to deal with issues relating to infrastructure investments (long life span) and the production of services (high fraction of indirect emissions yielding broad geographical system boundaries). We will especially stress the importance of the latter, as it was in this work found to be the most significant of the two, and additionally; more consistent accounted for internally (from year to year) and externally (from one municipality to another) by the municipalities. Because of this, the CF calculations made in this paper mainly focus on operational expenditures and hence exclude direct investments made by the municipalities.

The use of CF based indicators will be illustrated through a case study performed on selected Norwegian municipalities. Mainly a specific case study of the city of Tromsø (65000 inhabitants) will be used. The account system is applied to calculate the GHG emissions resulting directly from municipal activities and indirectly through the purchase of goods and services. The main part of the paper will be to develop and investigate how the different applications of the CF model and associated indicators perform in policy making and as a tool in local climate action strategies. Results on both overall measures of municipal sustainability and more detailed CFs of specific municipal activities will be provided.

II. MODELING CARBON FOOTPRINTS

CF models and calculators often apply a bottom-up perspective using a Life Cycle Assessment (LCA) of the assumedly most important activities and processes (see e.g. Barthelmie et al. 2008). Often, this is a sufficient way of developing a CF model for a specific case study, and will perform well regarding detail and responses to actions. However, a bottom-up LCA model is found insufficient in this paper as the focus is on the provision on public services, which at the local level involves significant amount of services purchases from other municipalities, government or private actors. Process-based LCA are not fit for this purpose, as described by Junnila (2006).

Therefore, to model the CFs of municipalities an Environmetally Extended Input-Output (EEIO) model is used as the main foundation. Input-Output Analysis (IOA) (Miller and Blair 1985) works well in calculating environmental impacts relating to public services as it includes non-physical flows. Also, the monetary structure of the IOA works very well in combination with the account system of municipalities in accessing data on municipal purchases. For more specific data on direct process emissions, the model is expanded by Life Cycle Inventory (LCI) data, which are included in the model using the methodology referred to as hybrid-LCA (Hertwich 2005; Heijungs and Suh 2002; Nakamura and Kondo 2002). The main step of the model is to match the comprehensive municipal annual accounts to the more standardized extended IO system, and further; to use this to develop a set of CF indicators. A simplified overview of the model is illustrated in figure 1.

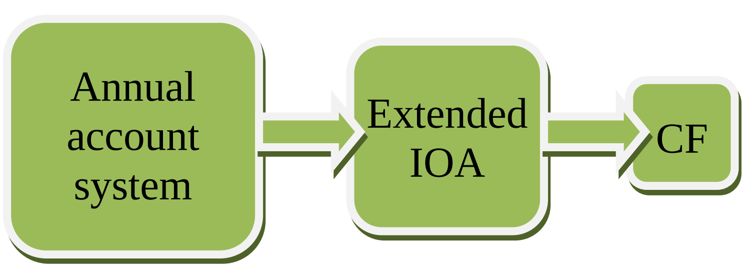

Figure 1: Overview of the municipal Carbon Footprint model

The detail in the municipal account numbers usually range from about 100 to more than 500 purchasing sectors depending on city size. These data are further available for different municipal departments. In its basic structure, the extended IO model consists of four sectors of direct process emissions (LCI data) and 58 IO sectors using the NACE (Nomenclature generale des Activitiés économique dans les Communautes Européennes) classification of Europeian economic activity. More detail on direct process emission and expansion on the IO model in general, to increase the detail of the analysis, have been performed in case studies of larger cities. To estimate the fraction of emissions embodied in imports, the IO system is divided into a domestic and imported fraction, using the procedure known as multiregional IO modeling (Peters and Hertwich 2006).

For simplicity, we assume a Norwegian production technology for both domestic and imported products, with the exception of electricity, where three different options are made available in the model; Norwegian, Nordic and an European mix of production. These options are made available for both the electricity purchased directly by the municipality, electricity used in the Norwegian economy and electricity in the foreign economy. Different sets can be used for different type of analysis (analytic or descriptive), but our base-case assumption in this paper is Nordic production technology for all production of electricity in Norway, and a European production technology of all electricity embodied in imported goods. The main reason why a Norwegian electricity mix is *not* assumed for domestic productions is because it consists almost purely of hydro-power, yielding low CF intensities. This would work well as a descriptive measure. However, focusing on policy implications, it is more relevant to use an action oriented measure; the global effect an increase or reductions in the use of electricity have on GHG emissions. For this, a Nordic mix of electricity is a fair assumption because of the high levels of trade between the countries.

More comprehensive information on the CF model applied can be found in Larsen and Herwich (unpublished manuscript, 2009). The model in this paper is modified mainly by updating the data sources; IO and emission data is now from the year 2005, while municipal expenditure data is available from the municipals accounts for 2007. Further, there is an increase of detail in the model; we now include all GHG gases: CO_2, CH4, N2O, CO, HFC, PFC and SF6. Also, work is performed on standardizing the analysis, both in the matching the account data to the IO model, but also in benchmarking results enabling comparable CF indicators between different cities and municipalities. All IO data is provided by Statistics Norway. The model is used for constructing Figur 2-7 and Table 1 and 2.

III. THE CONTRIBUTION OF MUNICIPAL SERVICES

Using the same IO system in the CF model earlier described, the total CF of all Norwegian consumption is calculated to be 70 million tonnes of CO_2 equivalents. Most of this relates to consumption by households. Also, a significant amount is caused by governmental activities (all public activities, including municipal), contributing to 15 percent of the total CF. The third significant contributor is capital. Indirect capital investments (embodied in purchased goods and services) are internalized into the IO model, and assigned to household and governmental demand respectively. Also, there is consumption of fixed capital contributing to more than 5 million tonnes of CO_2 equivalents. The municipal contribution to the CF by the public sector is not directly available in the national accounts of Norway. Therefore, a simplified analysis of all municipalities in Norway was conducted to estimate their contribution to the total Norwegian CF. This was performed by developing GHG emission intensities at an aggregated level (known as three-digit KOSTRA) of the municipal account system reported to Statistics Norway. Using the detailed analysis (five-digit KOSTRA) performed on larger municipalities like Trondheim, Bergen and Tromsø, where details on the structure of these aggregated purchasing categories are available; a set of emission intensities at the three-digit KOSTA level was developed. In most cases, developing these emission intensities at this aggregated level was fairly unproblematic. A sector like “the purchase of food” easily matches with the IO sector of “production of food and beverages”. But for some sectors, especially on “the purchase of energy”, assumption had to be made, using the mix of different energy uses (electricity, heating oil and district heating) found in the more detailed five-digit KOSTRA analysis. The main limitation of this simplified analysis performed on all 430 Norwegian municipalities is therefore the assumption of all three-digit KOSTRA sectors having the same internally distribution of sub products, services or activities for all municipalities

Using the simplified analysis describe above we calculate the contribution of Norwegian municipalities to be 3.1 million tonnes of CO_2 equivalents caused by operation and 0.3 by capital investments. This is a contribution to the total CF of approximately 5 percent. All IO data are provided by Statistics Norway for the year 2005, except for municipal account data that where more recent data from the year 2007 was provided. Municipal account data were price adjusted to year 2005 to fit the IO data, but still not directly comparable to the total CF of Norway, where consumption data is from 2005. Nevertheless this will provide a fair estimate of the contribution of municipal services to the total CF. The results are summarized in figure 2.

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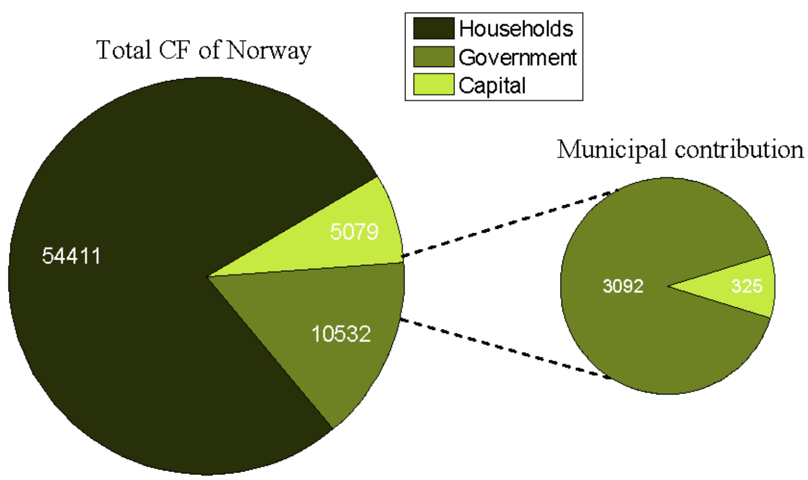

Figure 2: Municipal contribution to the total CF of Norway (1000 tonnes)

IV. RESULTS

The main aim of this paper is to indentify how the model introduced works in providing decision makers at the local level with much needed information on the performance regarding GHG emissions. The model focuses on emissions resulting from municipal activities; e.g. managing infrastructure, operation of schools, healthcare institutions and kindergartens. Since the account data of the municipalities are available for different departments, results are available both as an overall measure of the municipality, but also for single departments and even down to specific school and healthcare institutions.

1. Overall calculations of CF

In Figure 3 the CF of an average sized Norwegian city, Tromsø (65 000 inhabitants) for the year 2007, is illustrated. This indicates that the total life-cycle emissions resulting from municipal activities (excluding investments) in Tromsø in 2007 was almost 50 000 tonnes of CO_2 equivalents. This corresponds to approximately ¾ tonnes per inhabitans. The simplified analysis of all Norwegian municipalities described in chapter 3 indicated a range of CF per capita from 0.4 to as high as almost 3 tonnes of CO_2 equivalents for some specific municipalities. The national average is however just 2/3 tonnes per person, caused by all large cities/municipalities having fairly low CF per capital. With this information we identify Tromsø municipality to have an average CF per capita resulting from their own activities; less than most municipalities in numbers, but slightly more than most comparable municipalities in size.

From the CF model described, the low fraction of direct GHG emission, mainly from the combustion of fuel and heating oil, is identified. Using the multi-regionalization in the model, estimates on where indirect emissions, resulting from the upstream embodied emissions in purchased goods and services, occur, is also provided. The fraction of indirect emission in Tromsø is just an estimate based on emissions from first order supplier assumed to be localized within the borders of the city, e.g. the purchase of local transport services and construction activities.

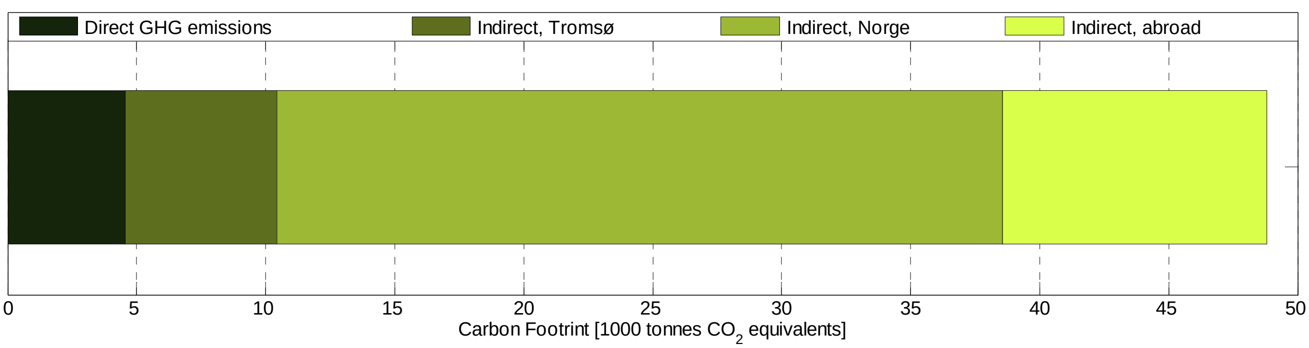

Figure 3: Total CF of municipal activities of the city of Tromsø (2007)

2. Sectorial breakdown of CF

The results for Tromsø can further be broken down to different contributing sectors, as shown in figure 4. Each sector illustrates the contribution to the life cycle GHG emissions resulting from the activity in, or purchase of goods and services from, that particular sector. E.g. for energy, the use of heating oil also include emissions from refinery and extraction of crude oil etc. Using this information, cities and municipalities are able to identify problem areas on where to focus their action. In the case of Tromsø, Energy and Infrastructure are identified as areas of particular interest.

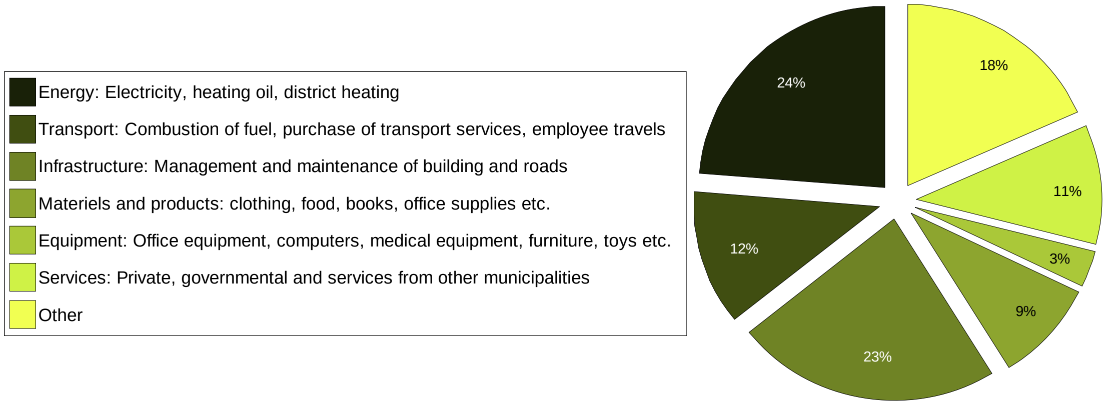

Figure 4: Composition of the total CF of municicial activities of the city of Tromsø (2007)

Results can further be broken down to the level of detail provided in the account system of the specific municipality investigated (293 purchasing categories for Tromsø). The data on the environmental performance of these will still be limited to the detail given by the extended EEIO system (in general, several account sectors will be matched to each extended EEIO sector); however, for policy making this will help decision-makers to identify which specific purchase or activity contributes to the CF. This level of detail is available for all municipal departments, exemplified in table 1, where the highest contributing activity/purchase to the CF of the school department in Tromsø, is ranked. The use of energy in school buildings is not included as it is being accounted for by the buildings department.

#	**Activity / purchase of**	CO_2-**eq.**		#	**Activity / purchase of**	CO_2-**eq.**
#1	Conveyance of pupils	763		**#21**	Materiel for arts and crafts	65
#2	Food	373		**#22**	Raw materials	61
#3	Purchase of special education	271		**#23**	Meeting and conferences	60
#4	Renting means of transportation	255		**#24**	Equipment and toys	56
#5	Books for educational purposes	254		**#25**	Hosting; Food and drinks	48
#6	Course and training	241		**#26**	Telephone services	44
#7	Travel expenses	215		**#27**	Filing req. travel expenses	43
#8	Miscellaneous services	212		**#28**	Electricity	42
#9	Purchase from municipalities	207		**#29**	Licenses and fees	38
#10	Equipment	200		**#30**	Conv. special education	30
#11	Teaching material	175		**#31**	Cleaning service	27
#12	Paper for educational purposes	135		**#32**	Welfare arrangements	20
#13	Computer equipment	134		**#33**	Books for school libraries	19
#14	Other materials	101		**#34**	Purchase from private	18
#15	Food for educational purposes	91		**#35**	Papers and literature	18
#16	Office supplies	88		**#36**	Advertising	17
#17	Renting of buildings	76		**#37**	Software	14
#18	Conveyance of injured pupils	76		**#38**	Allowance	14
#19	Renting of office machinery	70		---	Other (account #39 - #293)	216
#20	School camp activities	67		---	**SUM**	**4857**

Table 1: Contribution to the CF of the School department in Tromsø (tonnes of CO_2 *equivalents)*

From table 1 we identify a high complexity in the CF of providing educational services. Transportation and food is identified as contributing activities/purchases. Also, there is a high fraction of purchase of various materiel and equipment for educational purposes contributing to the CF. The results illustrated in Table 1 could be a very helpful tool for municipalities in determining focus areas and developing green purchasing strategies for the different municipal departments. The complexity of the school department could make this a suitable participant in applying the model to in such a strategy.

3. Breakdown of CF to municipal departments and sub-departments

As illustrated, the CF can be divided into contributing municipal departments. In table 2 the result for departments within the municipality of Tromsø is shown at the aggregated level of contributing sectors used in figure 4.

Department	Energy	Transport	Infrastructure	Materiel	Equipment	Services	Other	SUM
Political organizing	0	68	0	84	7	4	56	219
Administration	0	151	17	148	52	9	452	830
Buildings	9577	210	4852	39	86	177	2201	17141
School	42	1406	76	1434	443	502	953	4857
Kindergartens	0	144	33	473	148	2564	510	3872
Primary healthcare	27	63	16	171	36	660	432	1405
Social services	267	199	65	82	53	267	683	1 617
Healthcare services	73	1265	44	1493	246	457	1023	4 601
Child welfare	0	311	4	7	6	222	344	894
Culture	23	249	32	170	211	54	716	1 454
Roads and parks	1028	1316	5082	107	31	18	148	7730
City development	0	63	2	21	16	1	177	279
Fire & rescue	0	173	16	41	86	14	73	400
Water & sewage	536	189	835	30	22	4	277	*1893*
Other services	2	46	210	105	117	224	905	1610
SUM	11576	5854	11282	4405	1559	5177	8949	**48802**

Table 2: Contribution of different municipal departments to the total CF of Tromsø (tonnes of CO_2 *equivalents)*

Details can be taken even a step further by investigating the sub-departments of municipalities. Information on these is also provided by the municipal annual accounts, at the same format used by the CF model. This enables to calculate CF of sub-departments e.g. single school buildings, illustrated in figure 5. Here the CF of all schools in Tromsø is normalized by the number of pupils and ranked from the highest to the lowest CF. The CF is stacked by sectors found important for the school department. The result shows difference from 200 to more than 500 kg CO_2 equivalents per pupil, excluding the energy used for building purposes. This indicates a potential for improving the sustainability of providing educational services. The CF model has proven well suited for this purpose. One reason for this is the inclusion of the IO system (includes non-physical flow) to capture emissions from the purchase of services. This is a vital step, especially in comparing and benchmarking the result. The reason for this is that some municipalities, municipal departments or sub-departments purchase high amount of services from other public or private institutions and establishments. The importance of including this is illustrated by "Stakkevollan skole" in figure 5. Without adding the CF from the "purchase of services from others", this particular school would be ranked with a much lower CF. Cut-off errors, often seen in traditional LCA (Lenzen and Murray 2003; Stromman and Solli 2008), is therefore vital to avoid in order to develop indicators of sustainability in the service sectors.

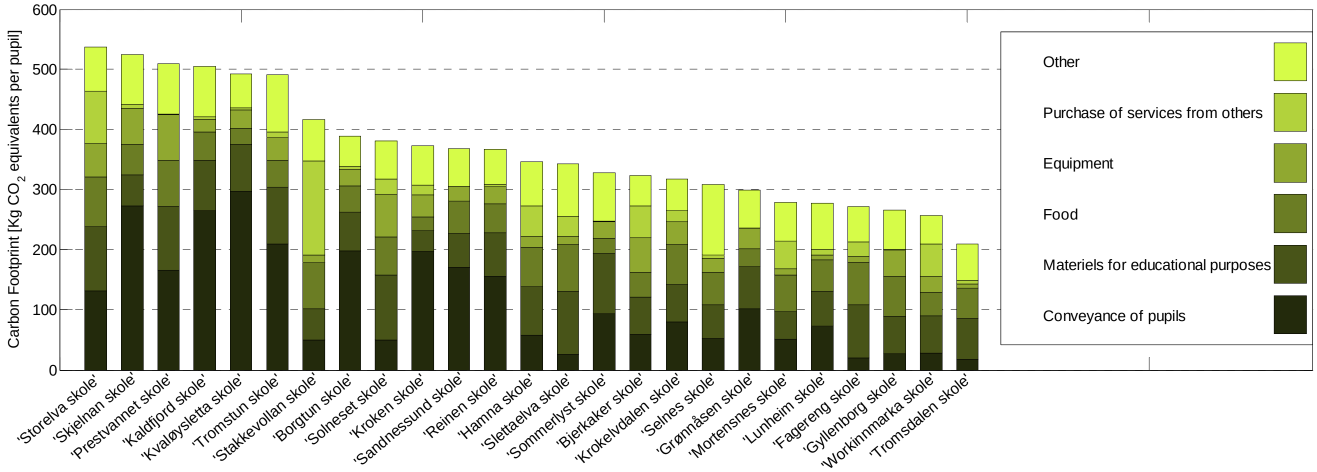

Figure 5: Normelized CF of school buildings in Tromsø (2007)

4. Benchmarking results

Providing data on the CF of municipal services is useful in identifying problem areas of, and department responsible for, GHG emissions. However, it provides limited information as a measure of overall sustainability of a municipality's provision of services. To do so, results can be benchmarked internally (developing time-series for a municipality) or externally (comparison to other municipalities). Then, municipalities are able to monitor the year-to-year situation and to compare their CF per capita GHG emissions to other municipalities. In figure 6, a CF timeserie of Trondheim (160 000 inhabitants) is developed. The sector classification used in section 4.2 is applied, and results indicate a significant increase of the CF from 2001 to 2007.

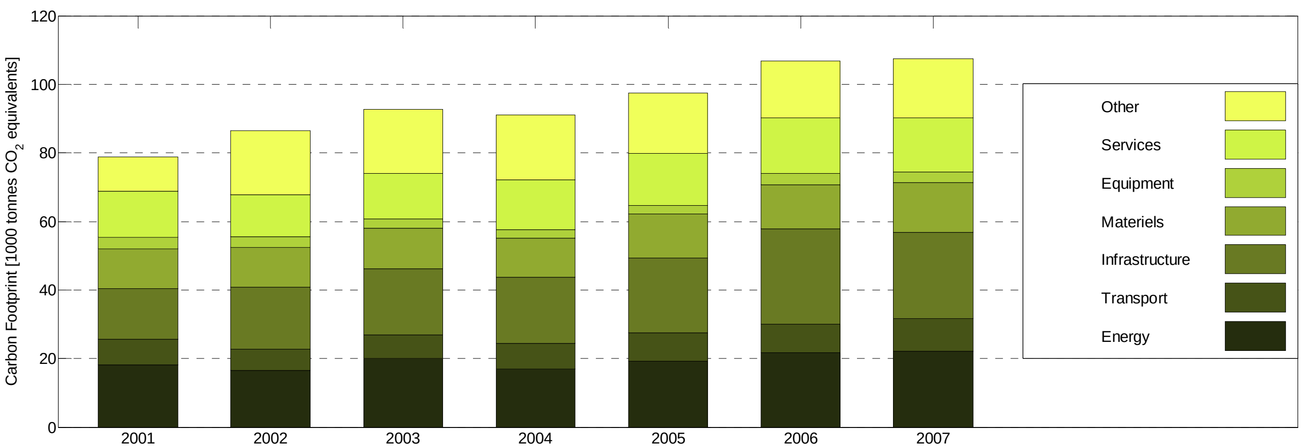

Figure 6: CF timeserie of Trondheim

To compare municipal CFs they have to be normalized by the number of inhabitants in each municipality. In figure 7 this is illustrated by the CF of selected Norwegian municipalities using the simplified three-digit KOSTRA account numbers described in section 3. The municipalities are different in size, ranging from Oslo (550 000 inhabitants) to Frosta (2 500 inhabitants). Not only can this be used as an overall measure of sustainability, but also provides a sectorial classification to be used in determining specific parts of the municipal activities that may contribute to an unsustainable procurement practice. One example worth further investigations is the high contribution of “Materiel” purchased by Kristiansand.

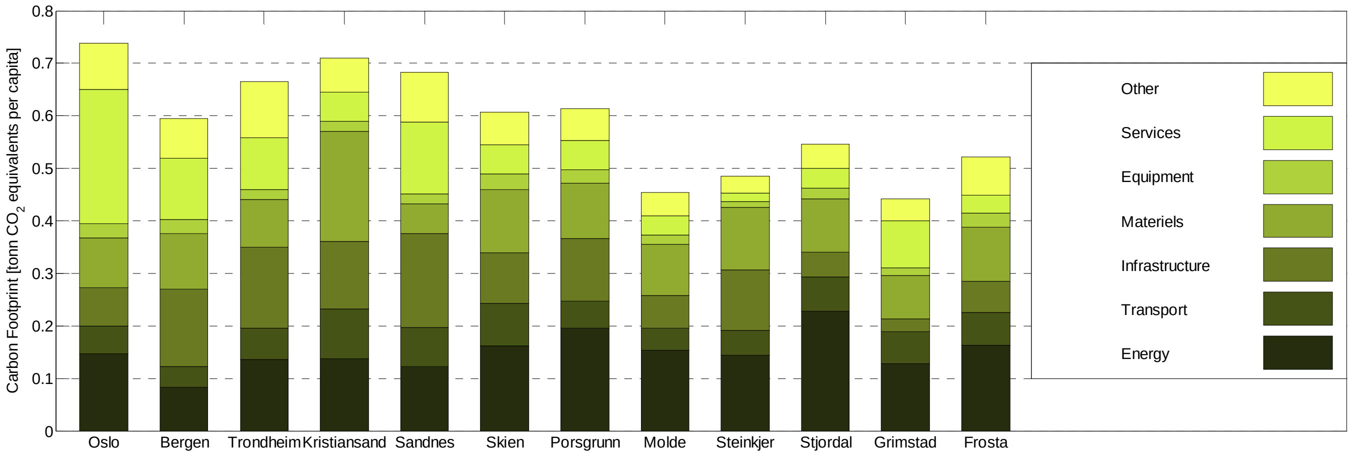

Figure 7: Normelized Carbon Footprints of selected municipalities (2007)

The results in figure 7 further indicate a difference in the composition of CFs of larger cities and smaller municipalities, especially in larger cities having a higher contribution from the purchase of services from other (municipalities, government or private actors) and Infrastructure. Smaller municipalities, on the other hand, tend to have a fairly high contribution from the energy sector. Also, in general, the larger cities (Oslo to Skien) seem to have a higher overall CF than medium-sized cities (Molde to Grimstad).

V. DISCUSSIONS

The main aim of this paper was to identify how a consumption-based inventory will work in providing local decision-makers with highly needed improved data on measures of local sustainability. The strength of the inventory developed through the use of the CF model is clearly pointed out; it identify what activity or which purchase done my which department contributes to the life-cycle emissions of GHG. Based in this, the analysis should be performed at an early stage of work on local climate action, to identify target areas.

Further, benchmarking the results provide municipal with comparable per capita indicators on how the municipality performs on both a year-to-year basis, but also compared to other municipalities. This enables municipalities to compare the developing of the different contributing sectors, and to monitor the effect of actions to reduce the CF.

However, some limitations can be identified. Most important is the aggregated data in the EEIO model. IO data works very well in avoiding cut-off errors, and will provide fair estimates of CF. Nevertheless, the detail provided is not sufficient to evaluate very specific actions, like the purchase of a different type of food. For this purpose more detailed LCI data is needed. If more detailed LCI data were provided on specific municipal purchases or activities, it would however be possible to update and modify the model to take this into account.

Further, the model used in this paper focuses on the municipalities own activities. Our calculations show that this contributes with approximately to 5 percent of the total CF of Norway, as the CF form private consumption is by far the largest contribution. However, focus on reducing the CF of municipal activities should have high priority in local climate action because; (1) it is within municipalities' own management actions most easily can be applied. (2) possibilities for synergy effects as actions can be combined towards both private and public consumption practice, and in some cases the municipality could "lead the way", generating new more environmental friendly entry markets (3) planning and managing infrastructure (building and roads) can greatly affect private behavior, and reduce their CF.

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