Regional Carbon Footprinting for Municipalities and Cities

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Abstract

This paper describes a methodology to account and attribute greenhouse gas emissions on a regional level. Regional greenhouse gas (GHG) inventories support the development and monitoring of climate change mitigation and adaptation strategies and policies for municipalities and cities. However, information and scientific expertise on climate change impacts are complex and a consensual and consistent methodology on formation of regional GHG inventories is still missing. Available methodologies and calculation tools mostly fail to balance scientific adequacy and usability from a pragmatic perspective. Within the project Regional Carbon Footprint (RCF), software that allows data management (i.e. for bottom up data) in order to calculate regional greenhouse gas inventories and to report about regional carbon footprints has been developed. Efforts needed for data collection turned out to be the main bottleneck for application from a practitioner's point of view. The RCF approach overcomes these shortcomings by closing this gap with the use of top down data taken from statistics.

1. Background

In May 2013, the carbon dioxide emission level passed 400 ppm for the first time since measurements began at Mauna Loa Observatory in Hawaii[3]. Several emission forecasts found that trends in GHG emissions are likely to cause global warming in the range of 3.5 to 5 degree Celsius by 2100 [1] [2] [3] which is related to “dangerous” and “extremely dangerous” climate change impacts [4]. In recent years, the European Union and several countries set relatively ambiguous targets for GHG reductions that consequently affect policies at the regional and local level. An increasing number of cities and regions developed climate change policies and climate action plans, e.g., within the framework of the Leipzig Charter on Sustainable European Cities, the Covenant of Mayors or the European Energy Award. However, regional and local climate change actions require observing GHG emission sources in order to identify potential reduction measurements and to monitor their implementation. While there are complex models on anthropogenic climate change available on the global scale, there is no consensual and consistent methodological GHG accounting standard for smaller regions. Various existing tools fail to balance scientific adequacy and pragmatic usability. For that purpose, the present paper describes a “Regional Carbon Footprint”-software as a basic instrument for local and regional climate change management and energy concepts.

2. Methodology

The methodology to calculate Regional Carbon Footprints (RCF) refers to the indicator carbon footprint that is used to indicate the amount of greenhouse gas emissions related to the life cycle of products or to activities of organizations, individuals or – as in case of RCF – populations. Carbon footprints refer to the global warming potential (GWP) of different greenhouse gases and are given

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[3] http://www.esrl.noaa.gov/gmd/ccgg/trends/\#mlo (2013-07-04)

in CO_2 equivalents. The GWP characterizes the effectiveness of a certain GHG in influencing radioactive forcing and absorbing infrared radiation reflected from the earth surface [5]. The conversion to CO_2 equivalents allows comparing the effect of specific GHG relative to CO_2. According to the IPCC methodology for national greenhouse gas inventories [5], the RCF is calculated in different sectors (energy, electricity and heat, transportation, industrial process emissions, agriculture and aggregated sources, waste, atmospheric deposition) according to

$$RCF[tCO_2] = activity\ rate\ \cdot emission\ factor\ . \qquad (1)$$

The activity rate describes relevant anthropogenic or natural activities causing emissions of GHG [kg CO_2 equivalents], i.e., electricity demand [kWh] per household, kilometres driven by car [pkm], renewable energy converted by PV [kWh] or production output [kg]. An emission factor is a coefficient, expresses the GWP [kg CO_2 equivalents] of this activity, i.e. GHG caused by electricity demand and so on. Emission factors are given by different institutions, while there is no convention how to select which emission factor.

2.1. System boundaries, scopes and sectors

Obviously it is necessary to define system boundaries and scopes before calculating carbon footprints. The temporal system boundaries usually enfolds the period from the recent year back to 1990. All calculations are therefore related to the year 1990, which refers as base year also in most international conventions and regulations such as the UNFCC. The spatial system boundaries are given by territory of municipalities or administrative districts. However, it is necessary to determine boundaries related to the question (i) which and (ii) whose emissions will be included in the analysis.

Ad (i): Which emissions are included?

In order to calculate the Regional Carbon Footprint, an inventory of anthropogenic emissions is needed. Although there are also natural effects, the global climate systems, e.g. clouds and water vapour, have both major effects on radioactive forcing.

Greenhouse Gas	GWP-100	GWP-100	Applications/sources
Carbon dioxide (CO_2)	1	1	combustion of fossil fuels in electricity generation and transportation, production and consumption of cement and other mineral products, production of steel and iron and ground chemicals
Methane (CH_4)	25	28	production, processing, storage distribution of natural gas, digestive processes of domestic livestock (cattle, sheep, goats), storage of manure, emissions from landfill waste and treatment of wastewater
Nitrous oxide (N_2O)	298	264	Use of synthetic fertilizers, breakdown of nitrogen in livestock manure and urine, byproduct of nitric acid production, burning of transportation fuels
Hydrofluorocarbons (HFCs), haloalkanes	124-14800	59-12400	flame retardants, fire extinguishants, insulating foams, refrigerants, propellants, solvents, and pharmaceuticals
Perfluorocarbons (PFCs)	6500-9200	7390-17700	fluoropolymers, refrigerants, solvents, medical uses (anesthetics, liquid breathing, blood substitute, contrast-enhanced ultrasound, eye surgery, tattoo removal), cosmetics, organic rankine cycle, flourous biphasic

			catalysis
Sulphur hexafluoride (SF_6)	22800	23500	tracer gas, insulator gas in high-voltage switchgears and microelectronic circuits, filling gas in insulating glass panes and sport shoes
Nitrogen trifluoride (NF_3)	17200	16100	DRAM computer memory production, manufacturing of flat panel displays, large-scale production of thin-film photovoltaic cells (Prather 2008, Tsai 2008)

Table 1: Greenhouse Gases covered by the Kyoto Protocol after Doha Amendment [6] [7]

However, only man-made emissions of greenhouse gases (GHG) covered by the Kyoto protocol are considered here. GHG originate from a variety of anthropogenic activities (see Table 1), which are classified in different sectors and subsectors:

- Energy (electricity and heat)
- Mobility and transport
- Industrial processes
- Agriculture and forestry (digestion, fertilizer consumption, land use and land use change, atmospheric deposition and aggregated sources)
- Municipal waste and waste water treatment.

The most important sectors, and therefore the ones to put most attention to in terms of feasibility of data collection, are energy and mobility. The other sectors are rather specific and not in every municipality or city applicable or of importance. Therefore, the emissions on those sectors are roughly estimated based on statistical data from national GHG inventories.

Ad (ii): Whose emissions are included?

In order to use the results of a RCF study in regional politics and decision making it remains unavoidable to become aware on responsibilities according to the “polluter-pays”-principles as well as about the possibilities, i.e. the scope and freedom of action that is given to a municipality. There are different accounting approaches in use to assign emissions to the origin or initiator [8] [9]:

- *Approach (A)* is taking into account all direct GHG gases emitted in the region based on an emission register. Imported and exported goods and related GHG emissions are, however, left unconsidered. This form of source-oriented-accounting (so called “Quellenbilanz”) is based whether on production data or emission registers such as E-PTER. It allows conclusions regarding total GHG emissions caused mainly by energy conversation, combustion of fuels or production processes in a defined territory. However, only little reference is made to opportunities mitigating climate change by political measures, as individual and collective behaviour (i.e. consumption of energy, choice of mobility modes etc.) are not considered.
- *Approach (B)* is focussing on GHG emissions that are consequences of consumption (and not production). GHG emissions are calculated based on end-user consumption, i.e. final energy consumption, electricity and heat. It is therefore an activity-based-approach (“Verursacherbilanz”), based on consumption.

The territorial approach (approach A) is common to be used in international and national statistics. However, there seem to be drawbacks as illustrated within the energy sector: If in a certain region less energy is consumed than produced, all GHG emissions are allocated to the region itself, although the electricity generated in the region is exported and consumed elsewhere. For example, a large scale coal power plant such as Vattenfall Europe’s “Schwarze Pumpe” (1600 MW) emits around 12 billion t CO2 annually[4], while the share of electricity consumed in the region is merely about 6% [10]. To avoid this castigatory allocation, it is therefore necessary to combine both methodological approaches at least in the electricity sector. Basically, it remains to be an “activity based approach”, but actual GHG emissions are considered by applying emission factors corresponding to the regional or national electricity mix. GHG are also occurring for so called low-carbon technologies such as photovoltaics or wind generators. Thus, emission factors for those technologies are applied, too. The amount of electricity from renewable sources is considered to be consumed within the region and allows distributing a “green bonus”. Citizens, regional decision makers and stakeholders only have limited potential to mitigate emissions caused for example by large power plants in the territory. Respecting the limited mitigation potential and/or the feasible scope of action of a municipality, the concept of scopes is common in GHG accounting of organisations. The following scopes are considered in this paper:

- Scope 1 compromises only GHG emissions that are directly linked to activities by the public authorities, such as energy consumption in public buildings, fuel consumption by car fleet etc. This scope is obviously.
- Scope 2 includes all direct GHG emitted in the region, including generation of electricity from fossil and/or renewable sources; inventories are developed according to approach A.
- Scope 3 includes indirect emissions which result from individual and collective activities in the region such as consumption of electricity and fuels, heating etc.

It might be useful to add another scope in order to integrate exported/imported goods and other indirect emission into a more reliable assessment of GHG emission caused by human activities. Again, the scope of action of municipal decision makers is limited as local authorities can hardly control or influence those indirect emissions caused for example by private cars or industrial production.

2.2. Sector energy

Energy conversion, i.e. combustion of fossil resources and consumption of electricity and heat was responsible for 42% of all GHG emissions worldwide in 2011 [11]. Due to this fact, climate mitigation policies focus on de-carbonisation of this sector, i.e. by fostering a fuel switch to renewable and therefore climate neutral or nuclear energy carriers and sources. According to the general formula, GHG emissions are calculated as

$$RCF_E\ [tCO_2] = \left(C_{e,mix} \cdot EF_{e,mix}\right) - B \tag{2}$$

with

RCF_E Regional Carbon Footprint, sector electricity,

$C_{e,mix}$ consumption of energy [kWh],

$EF_{e,mix}$ emission factor, electricity mix and

B bonus for electricity generation from renewables.

The activity rate represents whether production or consumption of electricity and heat [kWh] is based on specific data from local suppliers or from statistics and is then multiplied with specific emission factors. Local authorities require that local generation of electricity by renewable resources should be integrated in the calculation of the GHG inventory. Therefore a “green bonus” or “green credit” is given, that is calculated as

[4] according to E-PRTR; beside other air pollutants such as HCl, Pb, Hg, Cd, As

$$B\ [tCO_2] = \sum G_i \cdot EF_{e,i} \tag{3}$$

with

B bonus for electricity generation from renewables [t $CO_{2\text{-eq.}}$],

G_i electricity generation from renewable energy [kWh/a] and

$EF_{e,i}$ emission factor, specific for the energy carrier.

The following assumptions apply [9]:

1) Electricity generated from renewable resources which is fed into the low and mid-high-voltage grid is considered as being used in the region. An adequate bonus as green credit is given without taking into account any electrical line losses, which leads to an inherent bias, as losses depending on the voltage level amount up to 6% [12]. Taking renewables from the region into account is, however, not compliant with the approach by the Conveyant of Mayors [13], which includes only generation facilities which are owned or controlled by local authorities. Still, fostering green energies are presumably the major contribution to regional climate mitigation, though the contribution of municipal decisions is controversial.
2) If electricity generated in the region, i.e. by large scale power plants, exceeds local production, the difference is calculated with a specific emission factor, depending on the conversation technology, conversation efficiency and energy carries used.
3) If there is no large scale power plant in the territory under consideration, the difference between local production by renewables and electricity demand is considered as correlation with a national emission factor according to the national electricity mix. Double counting, i.e. local electricity generation from renewables and the share of renewables in the national electricity mix are considered as marginal [9].

GHG emissions related to the consumption of space heating occur mainly due to fossil fuel combustion (i.e. natural gas, LPG, hard coal, lignite or oil). CHP facilities within municipalities, which are producing electricity and heat for district heating systems, are also included by applying a specific emission factor $EF_{h,i}$. This emission factor comprehends different energy carriers according to a distribution formula, which represents heating systems structure in Germany,

$$RCF_H\ \ [tCO_2] = \sum C_h \cdot S_i \cdot EF_{h,i} \tag{4}$$

with

RCF_H Regional Carbon Footprint, sector heat,

C_h heat consumption in the municipality [kWh],

S_i share of energy carrier/ heat production system of total heat consumption in Germany [%],

$EF_{h,i}$ emission factor specific to the energy carrier or heat production system.

GHG emissions considered here include merely heating in buildings by small-scale heating installations and meso-scale district heating systems. However, emissions due to water heating and cooking are not included as they are considered as marginal. Process heat used in industrial processes, i.e. steam, is supposed to be provided by large scale CHP generation plants and is therefore considered in the subsector electricity.

2.3. Mobility and transport sector

The transport sector is responsible for 22% of global GHG emissions. Emissions from ground transport have increased drastically by 52% since 1990. They accounted for about 75% of all emissions in this sector in 2011. A robust assessment of mobility related GHG emissions would make it necessary to include the extent, i.e. kilometres driven by each mode of transport (i.e. ground transportation by different means such as public transport by trains, trams and busses as well as individual transport by cars and freight transport, aviation and cargo transport by ships), which is very specific to the regional context, i.e. demographic development, urban or rural region, availability and attractiveness of public transport. An empirically sound and regional specific data set would be desirable which is based on regular traffic counting. However, there are different approaches to allocation and attribution of responsibility, related different methodologies of source-oriented-accounting and activity-based-accounting. It remains controversial, how commuter transport or long distance freight transport should be attributed to different territories. In the light of controversial methodological approaches, limited availability of context specific data, and limited scope-of-action of municipalities, a more generic approach is sufficient and rational. Transport sector emissions are therefore calculated based on the number of registered vehicles N_i in the municipality, average annual mileage M_i and mode specific emission factors $EF_{t,i}$ according to

$$RCF_T\ [tCO_2] = \sum N_i \cdot M_i \cdot EF_{t,i} \tag{5}$$

with

RCF_T Regional Carbon Footprint, sector transport and mobility,

N_i number of vehicles in category i,

M_i milage in category i and

$EF_{t,i}$ mode specific emission factor.

2.4. Remaining sectors

The remaining non-energy sectors are very specific and not in every case directly related to the municipality or city under analysis. The effort for collecting data to compute emissions is comparably high, but the relevance for decision making is limited. If there is, for example, not much industrial or agricultural activity causing GHGs, it is rational to minimize efforts in quantifying the emissions. If it can be expected that GHG emissions are decreasing anyway, e.g. waste legislation in Germany prevents land filling of organic material and resulting methane emissions, it is rational to assume declining emissions in this sector without further need for action. However, these sectors should not be neglected as they are of relative importance with a share of approx. 30% [14]. Therefore the recent version of the RCF software applies a top-down method to capture GHG emissions from the following sectors:

- industrial processes, i.e. due to production of mineral products such as cement, usage of solvents, insulating foams, refrigerants or filling gases in switchgears or applications in microelectronic circuits, usage of bitumen in asphalt coating and roofing, glass and ceramic production, etc.;
- agriculture and forestry (i.e. digestion, fertilizer consumption, land use and land use change, atmospheric deposition);
- municipal waste and waste water treatment.

The specific GHG emissions in those sectors are estimated by downscaling statistical trends at national level [15] via the number of inhabitants for each year

$$RCF_x\ [tCO_2] = \left(\frac{E_{total,x}}{P_{GER}}\right) \cdot\ P_{region} \tag{6}$$

with

RCF_x GHG emissions in a sector x [t CO_2],

$E_{total,x}$ total GHG emissions in a specific sector [t CO_2].

P_{GER} number of inhabitants in Germany [N] and

P_{region} number of inhabitants in the region [N].

The main disadvantage of this top-down approach is obviously that municipalities are accounted for GHG emission also if there are no industrial facilities or agricultural activities. However, a burden-sharing-principle is executed implicitly, when the overall emission from the sectors is allocated to all inhabitants in Germany. Although credibility and accuracy of the results is therefore rather low compared to bottom up calculations with specific regional data, the estimations at least contribute to the requirement of completeness of the GHG inventories. Suggestions for a more sophisticated treatment of the sectors are given in [9].

3. Implementation

The regional carbon footprint software, including the calculations described above, has been implemented as a prototypical web application [16]. The current software prototype is basically a data management tool, consisting of three main parts. First, there is an administration environment for municipalities, including master data maintenance. Second, there is a representation of the data input process. Third, there is a report generation module. The input by the user is based on the sectors described in Section 2. Due to the persistent storage in a database, it is possible to monitor the progress over the past years and track any improvements. For calculation, there are several statistical information and background values required, which are available in the system's database for recent years. Therefore, a management environment within the RCF-software is needed to update these values for upcoming years. By finishing the input process, a comprehensive report, which is available in different formats, is automatically generated. The basic data model has a dynamic nature, so it is always possible to add additional input fields easily via the administration environment, e.g., a new type of renewable power plant. By doing so, the software adds both, the report input fields and an appropriate background value administration depending on the sector to which it was added. Thus, it is possible to adapt the elementary report to future conditions within existing sectors without further implementation effort.

4. Conclusion and future work

A capable methodology and corresponding software solutions to calculate GHG inventories are essential to achieve climate goals. In the project described in this paper, we developed a methodology to calculate regional carbon footprints. It turned out to be particularly complex to find a good trade-off between scientific adequacy and good applicability of such a strategy. The model has been implemented as a prototypical web-application and has been applied for several municipalities in Saxony.

Future work includes the development of methodological extensions and their implementation as supplementing software modules. This comprehends the implementation of a scenario analysis component in order to allow projections of potential benefits of climate action plans. Scenario analysis is particularly important for evidence-based decision making processes, concerning the future developments and provisions in municipalities or cities and for the further reduction of the GHG emissions. Further, the direct integration of remote monitoring facilities of municipal buildings is intended.

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