A Greenhouse Gas Accounting Tool for Regional and Municipal Climate Change Management

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***Abstract*—Regional greenhouse gas (GHG) inventories support the development and monitoring of climate change mitigation and adaptation strategies as well as 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. Thus, the RCF implementation includes a database that allows calculating with top down data taken from statistics.**

I. Introduction

In May 2013, the carbon dioxide emission level passed 400 ppm for the first time since measurements began at Mauna Loa Observatory in Hawaii[1]. Several emission forecasts found that trends in GHG emissions are likely to cause global warming in the range of 3.5 degree Celsius to 5 degree Celsius by 2100[2] which is related to "dangerous" and "extremely" dangerous climate change impacts[3]. In recent years, the European Union and several countries set (more or less) ambiguous targets for GHG reductions that consequently affect policies at the regional and local level. More and more cities and regions developed climate change policies and action plans, e. g., within the framework of the Leipzig Charter on Sustainable European Cities, the Convenant 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 at the global scale, there is no consensual and consistent methodological GHG accounting standard for 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.

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

[2] UNEP 2012, World Bank 2013, IEA 2012

[3] DECC 2009: The UK low carbon transition plan: national strategy for climate and energy. London, UK: Department of Energy and Climate Change

II. Project Goals

The main goal of the project was the development of a sound methodology for greenhouse gas accounting to support regional and local decision making. According to this methodology a software tool has been designed and implemented, which calculates appropriate carbon dioxide equivalents for municipal greenhouse gas inventories. For this purpose input data from several sources needs to be collected and stored. An important part of the software is an interactive reporting module, which automates the report generation and integrates the possibility for individualization by experts.

The final report gives an overview and statistics about all emissions produced by the municipality - the greenhouse gas emission report. Based on reports of past years or other periodical measures it is possible to easily monitor resulting data and statistics and thereby track the progress of local greenhouse gas emission inventory reduction. Further extensions are currently developed and implemented. On the one hand, a package for scenario analysis to support climate action planning workshops and, on the other hand, a remote monitoring environment for municipal buildings.

III. Methodology

A. Regional Carbon Footprint - Definition

The methodology to calculate Regional Carbon Footprints refers to the indicator carbon footprint that is used to indicate the amount of greenhouse gas emissions related to 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 in CO_2 equivalents. According to the IPCC methodology for national greenhouse gas inventories (see [6]) the RCF is calculated in different sectors (see next section) according to:

$$RCF[t\,CO_2\text{-eq.}] = \text{activity rate} \times \text{spec. emission factor}\,. \quad (1)$$

The activity rate describes relevant anthropogenic or natural activities causing emissions of GHG, i. e., electricity [kWh] or process emission [kg CH_4]. The emission factor expresses the GWP of this activity.

B. Sectors considered in the GHG inventories

1) Energy, Electricity and Heat: A major share of greenhouse gas emissions is caused by energy related activities[4]. Thus, it is intended to consider all relevant conversion and consumption of energy, e. g., electricity and heat. The GHG-intensity of the activity is related to the energy carriers (coal, oil, water, wind, solar radiation given in kWh) and the conversion technology used (coal-fired steam plants, combined heat and power). Regional energy conversion with renewable energy carriers is considered as used in the region itself or elsewhere and is thus regarded as positive effect reducing the total GHG emissions in this sector.

2) Transportation: GHG emissions related to transportation are computed by taking transport mode and distance as activity rates and specific emission factors into account. Transport modes considered are:

- individual transport,
- public transport,
- long-distance traffic,
- maritime traffic and inland waterway transport,
- aviation,
- freight transportation,
- transport activities related to forestry and agriculture.

3) Industrial process emissions: GHG emission caused by industrial processes in the mineral, chemical and electronics industry and other manufacturing sectors are estimated via the number of employees (activity rate) according to the NACE-classification of industrial sectors and specific emission factors.

4) Agriculture and aggregated sources: GHG emissions related to land use and land use change are also considered in terms of activity rates, i. e., the area of a certain land use type and a related emission factor, which illustrates the carbon uptake by plants and soils resulting in a negative emission value ("sink"). Emissions from lifestock and manure (namely CH_4) are considered again with an activity rate expressing the number of animals and estimated emission of GHG and specific emission factors. Other aggregated sources referring to non-CO_2-emissions are caused by the application of fertilizers and by liming of soils and are considered using the area of land captured as activity rate.

5) Waste: Waste generation and waste management are causing GHG emissions in solid waste disposal, biological treatment as well as incineration or open burning. The quantities of emission may be derived from pollutant registers such as E-PRTR[5].

6) Atmospheric deposition: Indirect emissions of GHG (i. e. N_2O) are occurring due to atmospheric deposition of nitrogen in NO_x and NH_3. The RCF approach is modeling this by activity rates related to the estimated annual emissions of N_2O [t/a] and specific GWP as emission factors.

[4]83.5 percent according to UBA 2010, http://www.umweltbundesamt-daten-zur-umwelt.de/umweltdaten/public/document/downloadImage.do?ident=23567 (2013-07-03)

[5]European Pollutant Release and Transfer Register, www.prtr.ec.europa.eu/

TABLE I. THE TABLE SHOWS THE GHG EMISSION OF A MUNICIPALITY IN SAXONY, GERMANY IN $t\,CO_2$-EQ. PER CAPITA FOR DIFFERENT ENERGY SOURCES, I. E., ELECTRICITY, HEAT AND TRANSPORT FOR THE YEARS 1990 TO 2012. AS INDICATED BY THE LAST COLUMN, THE EMISSION HAS BEEN SUBSTANTIALLY REDUCED DURING THAT TIME.

	GHG in [$t\,CO_2$-eq. per capita]				%
Year	Electricity	Heat	Transport	Total	Reduction
1990	1.88	8.54	-	10.42	0.0
2005	1.47	2.45	3.64	7.56	27.4
2006	1.48	2.52	3.63	7.63	26.7
2007	1.17	2.31	3.53	7.01	32.7
2008	1.24	2.45	3.97	7.66	26.5
2009	1.22	2.42	4.06	7.71	26.0
2010	1.27	2.43	4.05	7.75	25.6
2011	0.87	2.44	2.18	5.48	47.4
2012	0.87	2.46	3.37	6.71	35.6

IV. CASE STUDY

The RCF methodology has been applied to compiling GHG inventories for several municipalities and cities in Germany. This section presents the case study of a municipality in Saxony, Germany with approx. 3000 inhabitants. The municipality is engaged in the European Energy Award, which is a pan-European process management system applied in more than 1000 municipalities to support a sustainable energy policy, urban development and energy efficiency[6]. As the data availability was insufficient, only three sectors, i. e. electricity, heat and transportation have been considered in the GHG inventory from 1990 to 2012.

The essential benefit of GHG inventories according to the RCF methodology is to monitor sustainability and climate mitigation policies over time. As shown in Table I, the municipality performed well in terms of GHG reduction. In 2011 (47.4 percent GHG reduction) and 2012 (35.6 percent GHG reduction[7]) the national reduction goals of 21.4 percent have been fulfilled[8]. Due to extensive growth in photovoltaic installation, the reduction in electricity related GHG emissions gained momentum. Accordingly, national German and regional Saxonian goals to achieve a share of at least 22.9 percent respectively 20.1 percent renewable electricity consumption have been exceeded by far with 58 percent. The CO_2-eq.-emission per capita of 6.71 t CO_2-eq. is substantially lower than the one for the average German citizen (approx. 10 t CO_2-eq. per capita) or the one for the average US-American citizen (approx. 19.1 t CO_2-eq. per capita)[9].

V. IMPLEMENTATION

The regional carbon footprint software, including the calculations described above, has been implemented as a prototypical web application (an official version has not been released yet). 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. The second part is the representation of the data input process and third there is a report generation module (see Figure 1). The input is based on the sectors described in Section III. Due to the persistent storage in

[6]European Energy Award, http://european-energy-award.org/

[7]Increase in GHG emissions due to technological issues with a biogas plant

[8]However, regional goals of 56 percent GHG reduction in 2010, set by the Saxonian Government, have not been met.

[9]Data taken from http://en.wikipedia.org/wiki/List_of_countries_by_carbon_dioxide_emissions_per_capita (2013-07-05)

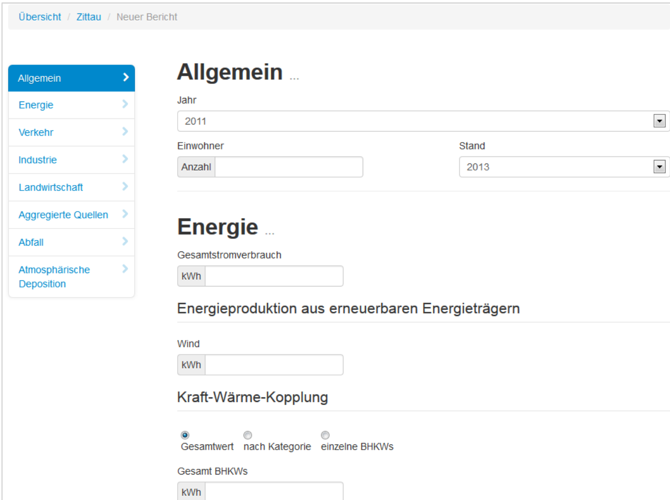

Fig. 1. The prototypical regional carbon footprint web application is intended for annual reports. Here, the input mask is based on the seven sectors, each with several required data, which needs to be provided by the municipality.

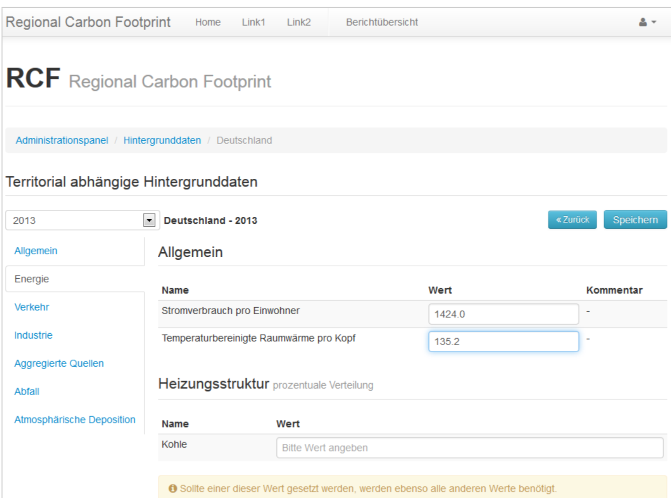

Fig. 2. For the calculation of the regional carbon footprint several statistical and background values are required on an annual base. For that purpose the software has a build-in management environment to update these values for future years.

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 (see Figure 2), to update these values for future 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 area, 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.

VI. Conclusion and Future Work

A common 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 tradeoff between scientific adequacy and good applicability of such a strategy. In the previous sections we briefly mention the different aspects of our model. The model has been applied to several municipalities in Saxony. We reported some results for one of them in a brief case study. The methodology had been implemented as a prototypical web-application. The system is tailored towards the availability of input data about specific regions or municipalities and towards the availability of necessary statistical data. The data collection turned out to be a crucial point for any methodology in the past.

Future work includes the development of methodological extensions and their implementation as supplementing software modules. In specific, the complete implementation of a scenario analysis component is needed. Scenario analysis is particularly important for fact-based decision making processes - concerning the future developments and provisions in municipalities or cities and the further reduction of the GHG emissions. Further, the direct integration of remote monitoring facilities of municipal buildings is intended.

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