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CHALLENGES AND SOLUTION APPROACH FOR GREENHOUSE GAS EMISSION INVENTORIES AT FINE SPATIAL RESOLUTIONS – THE EXAMPLE OF THE RHINE-NECKAR DISTRICT

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Declaration

This publication is part of a series of discussion papers by the TdLab Geographie team at Heidelberg University. Within the series, current research results are made available to the public.
The publication is based on a pilot study dealing with greenhouse gas emission monitoring for the rhine-neckar-district as a preliminary study of the climate action science project at the Heidelberg Center for the Environment (HCE) at Heidelberg University (https://www.climateactionscience.org/). The pilot study was conducted from 01/2020 to 01/2021.
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Author contributions

K. F. wrote the manuscript. The concept of the study was co-designed by N. A., S. L., A. Z. and the CAS-consortium. K. P. supported the data analysis and provided the map. N. A. and S. L. assisted with the preparation of the initial draft for the manuscript.

ABSTRACT

This discussion paper is the concluding publication of one of the pilot projects of the "Climate Action Science" research initiative at Heidelberg Center for the Environment (HCE), focusing on the Rhine-Neckar district and the city of Heidelberg. The aim of the explorative project was to generate a first overview on greenhouse gas emission data in order to initiate climate action of various actors and to provide well-founded support by using accurate information. The focus during the pilot phase was on the collection, compilation and evaluation of the quality of heterogeneous data sets and methods for a greenhouse gas emission inventory, as well as on the information preparation and evaluation of different inventory and presentation options. These should in turn be adapted to the needs of different users and fields of application. The study focused on different German approaches to greenhouse gas accounting, especially in Baden-Württemberg compared to other German states, and in detail on the City of Heidelberg compared to the surrounding municipalities in the Rhine-Neckar district. The overarching goal is to use the results beyond the case study projected here as a stimulus and preliminary work for further projects and activities in the overall "Climate Action Science" project.
Several difficulties were encountered in processing the emissions inventory and compiling various data sets on emissions in the study area. Three basic situations were identified: 1. Desired data is not available (measurements required), 2. Desired data is not freely accessible (stakeholder involvement), 3. Data generation via proxy data. In the pilot phase, we implemented a transdisciplinary approach regarding situation 2. In this way, emission maps on different information levels could be created for the study area and applied in psychological experiments. Thus, first insights into the perception and processing of emission information on the user level could be gained.

Dieses Diskussionspapier entstand als Abschlusspublikation eines der Pilotprojekte der Forschungsinitiative "Climate Action Science" am Heidelberg Center fort he Environment (HCE) mit Schwerpunkt auf dem Rhein-Neckar-Kreis und der Stadt Heidelberg. Ziel des explorativen Projekts war es, einen ersten Überblick über die Treibhausgasemissionsdaten zu gewinnen, um das Klimahandeln verschiedener Akteure zu initiieren und durch genaue Informationen fundiert zu unterstützen. Der Fokus in der Pilotphase lag auf der Erhebung, Zusammenstellung und Bewertung der Qualität heterogener Datensätze und Methoden für die Erstellung eines Treibhausgasinventars sowie auf der Informationsaufbereitung und Bewertung verschiedener Inventar- und Darstellungsoptionen. Diese sollten wiederum an die Bedürfnisse der verschiedenen Nutzer:innen und Anwendungsbereiche angepasst werden. Im Mittelpunkt der Studie standen unterschiedliche deutsche Ansätze zur Treibhausgasbilanzierung, insbesondere für Baden-Württemberg im Vergleich zu anderen Bundesländern, und im Detail für die Stadt Heidelberg im Vergleich zu den umliegenden Kommunen im Rhein-Neckar-Kreis. Übergeordnetes Ziel ist es, die Ergebnisse über die hier projizierte Fallstudie hinaus als Anregung und Vorarbeit für weitere Projekte und Aktivitäten im Gesamtprojekt "Climate Action Science" zu nutzen.

Bei der Bearbeitung des Emissionsinventars und der Zusammenstellung verschiedener Datensätze zu den Emissionen im Untersuchungsgebiet traten mehrere Schwierigkeiten auf. Es wurden drei grundlegende Situationen identifiziert: 1. Die gesuchten Daten sind nicht verfügbar (Messungen erforderlich), 2. die gewünschten Daten sind nicht frei zugänglich (Einbeziehung von Praxispartnern), 3. die Datengenerierung erfolgt über Proxy-Daten. In der Pilotphase haben wir in Bezug auf Situation 2 einen transdisziplinären Ansatz erarbeitet und erprobt. So konnten für das Untersuchungsgebiet Emissionskarten auf verschiedenen Informationsebenen erstellt und in psychologischen Experimenten getestet werden. Auf diese Weise wurden erste Erkenntnisse über die Wahrnehmung und Verarbeitung von Emissionsinformationen auf der Nutzer:innenebene generiert.

1 INTRODUCTION

Climate Action Science's mission and goals are embedded in climate action activities at the subnational level. The two states Baden-Württemberg and California have positioned themselves as key players in climate protection. Both states, along with more than 220 other regions, are moving forward with the common goal of keeping the global temperature increase significantly below 2 °C by effectively reducing greenhouse gas emissions (The Climate Group 2020). Reducing greenhouse gas emissions is a central goal of the "Under2 Coalition" founded by California and Baden-Württemberg. This coalition aims to promote climate action in international partnership by actors at the subnational level. To efficiently reduce greenhouse gas emissions, the actors need high resolution, verified, and customized information on the spatial distribution, intensity, and sources of emissions (The Climate Group 2020, UMBWL 2020).
In order to organize climate change mitigation or emission reduction "from bottom-up", subnational actors must address a new set of issues. Emission reduction strategies can only realize their potential, if they are identified, initiated, and organized through subnational partnerships that are implemented directly by the respective actors at the local level (The Climate Group 2020). Additionally, subnational climate actors face an information problem: emission inventories typically record greenhouse gas emissions on a national scale. They can be downscaled to smaller regions or cities by using convergence factors and auxiliary variables. However, "downscaling" is subject to enormous uncertainties, which can vary depending on the source of emissions and the spatial heterogeneity of emissions (The Climate Group 2020; UMBWL 2020).
The purpose of this discussion paper is to present the intent and initial conclusions of a pilot study within the Climate Action Science project. The background of the activities embedded in subnational efforts to advance climate action is presented as well as specific results from the pilot phase. In the first step, different approaches and standards for inventorying and accounting of greenhouse gas (GHG) emissions are presented. Differences between various inventories and accounting methods that lead to difficulties in comparability are highlighted. This is followed by an analysis of the inventories in the chosen study area, the Rhine-Neckar district and the city of Heidelberg, Germany. Chapter 3 presents the transdisciplinary approach of the pilot study and is described in detail in the following Chapter 4. Chapter 5 concludes with a summary and a short outlook.

2 DATA ANALYSIS FOR ACCOUNTING OF GREENHOUSE GAS EMISSIONS IN GENERAL

This chapter provides an overview of different sources, protocols, and actors related to greenhouse gas emissions inventory and accounting. Based on this overview, it becomes clear that different methods can lead to diverse results due to varying assumptions and input factors. Consequently, the choice of accounting method and input data are crucial for the comparability of results.

Inventory methods and standards exist for a variety of target groups and with different scales and levels of detail – some specify data sources others simply provide guidelines for key methodological approaches. National Inventory Reports (NIRs) are an annual accounting of greenhouse gas emissions prepared by Parties to the United Nations Framework Convention on

Climate Change (UN-FCCC). This accounting is the basis for the implementation of the Framework Convention on Climate Change and the Kyoto Protocol, as well as for emissions trading. In Germany there are three main approaches to GHG accounting and reporting based on geographic scales that correlate with the three main administrative units of the Federal Republic. These are the federal level, the state level, and the municipal level. The Federal Environment Agency (UBA) provides the German National Inventory Report. Detailed requirements of the Intergovernmental Panel on Climate Change (IPCC) regarding the form and content of the reports are intended to provide a high degree of transparency and comparability within an international framework. These guidelines are considered here as well. The reports are structured according to source groups, i.e., sectors in which greenhouse gas emissions occur, and are binding for all countries. These main source groups are (IPCC 2006):

- Energy (for example, fossil fuels)
- Industrial processes and product use (for example from the chemical industry)
- Solvents and other product use
- Agriculture, forestry and other land use (for example from animal husbandry)
- Land use change and forestry
- Waste and waste water (for example from waste water treatment)
- Others

These source groups are each subdivided further. Since the greenhouse gases have different effects, the emissions of all greenhouse gases are converted into gigagrams (Gg, 1 Gg = 1000 tons = 100 kg) of CO_2 equivalent, with the effectiveness of the gases based on 100 years. Besides carbon dioxide, other greenhouse gases such as methane or indirectly acting greenhouse gases such as nitrogen oxides are also included. In addition to the sources of greenhouse gases, especially related to CO_2, the sinks are also considered. This approach and categorization also corresponds to the structure in the IPCC reporting. For example, if one compares the transport sector in the sectorization of the IPCC with the one of the Federal Environment Agency (UBA) (Umweltbundesamt 2018), it is assigned to the energy sector in both cases. Similarly, the transport sector is listed under the subcategory "fuel combustion activities" resp. "fuel combustion". In both cases, all types of transportation are included under this subcategory: Civil aviation, road transport, rail transport, shipping, and other transport. Additionally, in the IPCC sector, the sub-item "Off-Road Transportation" is included (IPCC 2006; Umweltbundesamt 2018).

Although there are some basic similarities in the structure of the reporting, there are also significant differences. While the federal NIR-compliant GHG inventory methodology for Germany uses a source-based approach, the BISKO municipal accounting standard proposed by UBA is based on consumer emissions (Gugel et al. 2020). This methodological inconsistency must be taken into account when comparing inventories at different scales. The BISKO standard is largely consistent with other international municipal inventory frameworks such as the Greenhouse Gas Protocol - Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GHGP-GPC) (Gugel, Rechsteiner & Dingeldey 2019; Gugel et al. 2020). Due to its specific design, BISKO allows more detailed specifications and proposals for concrete emission factors for the application limited to German municipalities.

In addition to the general standards, other data sources and data suppliers for greenhouse gas balances must be considered in individual cases to insure complete reporting: Individual municipal reporting, data from energy suppliers, public offices, climate consulting agencies, public authorities, and many more. For the Rhine-Neckar district, the region where the City of Heidelberg is located, the municipal CO_2 footprint (except for the city of Heidelberg itself) is prepared annually by the Heidelberg Climate Consulting Agency (KLiBA Heidelberg) (Kliba Heidelberg 2020). The data is published with a delay of two to five years. The focus is on the creation of an inventory, building on existing balances in order to process them further. The IPCC methodology and guidelines (IPCC 2006) serve as a template and orientation for further tools such as BISCO, BICO2-BW (BICO2-BW is a BISKO-compliant methodology specified for the state of Baden-Württemberg and a tool for municipal GHG accounting.) or GHGP-GPC (World Resources Institute 2014; Gugel, Rechsteiner & Dingeldey 2019; Gugel et al. 2020). Therefore, when setting up a full inventory, several aspects and sources of error have to be considered. In general, the respective methods or standards have to be adapted to the data availability in each case. The first step is to define and determine the data needs and then identify possible data sources. Access to these can be complicated and heterogeneous. The IPCC NIR guidelines provide methods for dealing appropriately with data bottlenecks in terms of availability or accuracy (e.g., different levels of data with appropriate decision criteria).

Even though inventory standards and methodologies exist for a variety of scales and regions, most of them refer to political administrative actors in two ways. First, the process of calculating GHG emissions is often carried out by administrative actors. Consequently, issues of data availability, quality, and privacy are addressed assuming the capabilities of these actors. Second, the proposed inventories themselves present results that are intended to be relevant to the same policy makers and administrators. As a result, both, the available methods and the inventory data generally do not refer to actors other than companies (e.g., GHGP Corporate Standard) or administrations (BISKO, GHGP-GPC), and thus do not consider the full range of possible climate actors, such as schools and universities, associations, and other civil institutions.

2.1 EXAMPLE: CLASSIFICATION OF ENERGY AND GHG BALANCES FOR THE MUNICIPALITIES OF THE RHINE-NECKAR DISTRICT

Various calculations show that the choice of accounting method and the data used can have a significant impact on the results. So far, there is no nationwide standardized methodology for municipal GHG accounting in Germany (Kliba Heidelberg 2020). Therefore, the accounting method for municipalities in the Rhine-Neckar district by KLiBA Heidelberg is explained here as an example to show which processes and factors have to be considered. These results of the GHG balances were used in the pilot project and adapted to be applied in psychological experiments (section 4.3).

Since May 2012, the IFEU Institute Heidelberg (IFEU), together with the Climate Alliance and the Institute for Decentralized Energy Technologies, accompanied by the Federal Ministry for the Environment, has been developing a standardized balancing regulation for municipalities (BISKO) (Ifeu 2014; Gugel, Rechsteiner & Dingeldey 2019; Kliba Heidelberg 2020). This is also the basis for the BICO2-BW calculation tool provided by the state of Baden-Württemberg, which was also developed by IFEU (Ifeu 2014; Gugel, Rechsteiner & Dingeldey 2019). For the

individual municipalities, this calculation tool, including the revised practical guide "Climate Protection in Municipalities" from the German Institute of Urban Affairs (Difu) from 2011, is used (Difu 2018).

The energy and GHG balance information for municipalities is based on the final-energy-based territorial principle. According to this principle, all consumption occurring in the district is balanced at the level of final energy and allocated to the various sectors. Grey energy (e.g., energy contained in products) and energy consumed outside the district boundaries (e.g., hotel stays of residents spending nights outside the area due to holidays or business trips) are not considered (Difu 2018; Kliba Heidelberg 2020). On the energy supply side (provision of electricity and heat), all energy conversions in the district are also considered for the heating sector and are included in the balance sheet. When balancing electricity consumption in the Rhine-Neckar district, the GHG emission factors of the federal mix are used for the calculation of GHG emissions. In addition, the "REGIO" territorial balance is also drawn up, which shows the role of regional electricity supply for climate protection in the Rhine-Neckar district (compared to the federal mix) (Kliba Heidelberg 2020). KLiBA categorises the balance sheets of municipalities in the Rhine-Neckar region according to the following stationary sectors:

- Private households: Energy consumption of private final consumers.
- Manufacturing (industry): all manufacturing companies with more than 20 employees covered by the State Statistical Office.
- Municipal real estate in the cities and municipalities: all consumption data of administrative buildings, schools and day-care centres.
- Municipal properties for the district's overall balance sheet, for example waste management company (AVR) or own operation “construction and assets” (EBuV) and others
- Industry and others: all energy consumers not included in the other sectors. It includes trade, commerce and services, smaller industrial companies (with less than 20 employees) and agriculture.

Further details on the methodology can be found at http://klimaschutz-rnk.de/klimaschutz-rnk/start and the Difus provided there (Kliba Heidelberg 2020). In addition to raw emission data, a number of other data must be included in the balance to provide context: population figures, number of households, types of heating and combustion plants, and many more. These are partly available through public institutions such as the state statistical offices (Ifeu 2014; Gugel, Rechsteiner & Dingeldey 2019).
In general, all data and their suitability must meet specific criteria to be used in calculation of GHG balances, including: long-term availability, institutionalization of data provision, proper documentation, implementation of quality control and assurance measures by data providers, reporting of uncertainties, representativeness of data, and completeness of data (Umweltbundesamt 2018). The quality of the data is also decisive for its informative value. To differentiate among the quality criteria in this study, we have classified the data quality as A-D. Regional primary data have high informative value (data quality A), while the lowest validity (data quality D) is based on nationwide indices. Data quality B means the calculation of the balance on the basis of regional primary data, supplemented by extrapolations. With data quality C, the calculation is based on regional parameters and data. "In most balances, it is likely that the data quality for the overall balance is better than for the individual sectors” (Gugel, Rechsteiner &

Dingeldey 2019). It should be noted that access difficulties increase with data quality and spatial resolution (Umweltbundesamt 2018). Downscaling via auxiliary data and model assumptions can therefore be a helpful step.
The municipal balance can thus be estimated as follows: Using standard metrics as a starting point, a modification with local consumption data is performed. By determining existing consumption data in parallel and filling the data gaps with key figures and estimations, municipal energy or CO_2 balances can be determined from two directions (Ifeu 2014; Umweltbundesamt 2018; Gugel, Rechsteiner & Dingeldey 2019). In order to achieve a broad data basis, it may be necessary to request data from different data owners (institutions or actors). This requires an exchange or a network to get access to helpful and needed data. For the development of these contacts and networks a transdisciplinary approach is recommended. Stakeholders can be involved in the process of data discovery and by doing so, the access to data can be simplified and accelerated by a constant cooperation. In the pilot phase, we implemented the transdisciplinary approach described in the following chapter.

3 TRANSDISCIPLINARY ASPECTS

Transdisciplinary approaches at the interface of climate change research, geoinformatics, and society combine science and case-specific relevant findings and develop knowledge for a practical solution of problems oriented towards the common good (Pohl 2008; Strohschneider 2014; Adler et al. 2016; Pohl & Hirsch-Hadorn 2017; Pohl, Krütli & Stauffacher 2017; Pohl et al. 2021).
In general, knowledge transfer between the research project and external partners such as state agencies and community stakeholders, had a dual function that is transferable to other cases. First, external knowledge was made available to the project, for example, by providing information on emissions processes at state and municipal agencies. It was expected that this knowledge (transport, gas distribution networks, district heating, waste and wastewater, industrial sites and sectors, household emissions) is heterogeneous and needs to be translated into quantitative emission rates. Second, we needed to identify and assess the information requirements of climate actors and integrate them directly into the research process. This input provides prerequisites for improving targeted and efficient modelling. Other authorities or stakeholders, such as agricultural enterprises or operators of energy plants, also have access to information on land use and emitters, which enables a better understanding of greenhouse gas processes and additionally increases the informative value of the generated visualizations (Fig. 1). This way the results obtained not only addressed the specific requirements of climate actors, but have been made tangible for civil society. To generate an appropriate presentation of the data in order to achieve the desired effects was a further dimension of the project.
Local stakeholders, such as agencies covering the fields of environment, energy, urban and regional planning, identified particularly relevant areas and provided corresponding information. In cooperation with local partners and municipal environmental authorities, a comprehensive inventory of carbon dioxide emissions was drawn up for the study region.

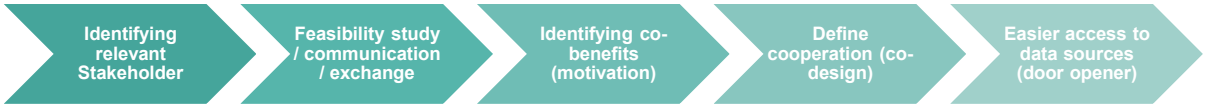

Fig. 1: Transdisciplinary approach via stakeholder exchange: Necessary transdisciplinary intermediate step to develop data sources via stakeholder involvement.

4 DESIGNED EXPLORATORY APPROACH OF THE PILOT PROJECT

As part of the pilot study for the Rhine-Neckar district and the city of Heidelberg, we investigated the concept of high-resolution mapping and visualization of greenhouse gas information and its use for citizens and climate actors. The overall goals of the project and thus the steps in the pilot phase were a) to gain an overview of emissions and b) to provide a user-friendly presentation of the information with the aim of initiating or reinforcing climate action (b1), but also to provide explanatory approaches for measurement science (b2). Several fundamental problems and questions arose in this context:

1. How were emissions recorded and how were they reported (according to the territorial principle or the polluter-pays principle)? Depending on the individual case, both approaches offer advantages and disadvantages.
2. Data was not available at the required thematic, temporal, and spatial resolutions to generate the perspective for the different user groups.
3. How can the data be presented in order to achieve the stated goals, such as initiating climate action?

First, the various data sources and their formats of representation and resolution had to be merged. For this purpose, it was necessary to inventory the data in order to reflect the perspectives of the user groups. This included classifying whether the required data was generally available, could be made available (monetary incentive or stakeholder process), or can only be generated through new measurements. Data sets should generally be available in a certain spatial and temporal resolution and should have a temporal dynamic as high as possible. The level of detail required and achievable therefore had to be balanced against the goal of providing climate stakeholders with the most appropriate information for climate action.

During the project, we placed one focus on traffic data. More generally, the traffic volume, the traffic mix, and the respective emission factors can be recorded for the determination of traffic emissions. The challenging task was that the calculation and visualization of the emissions on linear traffic routes does not provide an adequate allocation to the emission sources (driving around the heavily frequented routes does not reduce the emissions). Modelled traffic data are therefore not "real" measurement data. Regardless of how the data is generated, the primary obstacle remains how it is perceived by the user. Consequently, integrating these types of data into a Google layer or within a specific app to affect individual climate action is conceptually challenging and might be misleading with respect to the perceived message. Therefore, a number of further important questions need to be clarified: What are the actionable areas and sectors? Where do individuals make their personal, private decisions? (Ecological Footprint UBA) vs. areas of political preferences and decision-making. What is the highest possible sectoral allocation, if energy, industry, transport, agriculture, buildings or private households, waste, and consumption decisions cannot be separated uniformly and clearly depending on the methodology (territorial vs. polluter pays principle)? Furthermore, the allocation of emissions to sectors had to be defined.

During the pilot phase, two methods for calculating traffic emissions were applied and compared with the aim of estimating emissions at street level. In a first approach, the existing total

emissions of 2017, as published in the Statistical Yearbook 2018 of the City of Heidelberg (Stadt Heidelberg 2017), were disaggregated by downscaling to road-related mileage data from 2014. In a second approach, the 2014 mileage data were corrected for the mean mileage trend within Germany. This step was necessary to approximate realistic mileage values for 2017 and thus improve the comparability of the two approaches. A Heidelberg-specific emission factor was calculated using fuel consumption data (Grabolle & Loitz 2007) and the ratio between different vehicle types as registered by the Federal Motor Transport Authority (KBA 2020).

For the energy data, a thematic limitation to data from the energy/heating sector, i.e., electricity and heating, was conceivable. However, these were difficult to obtain on a small scale in order to quantify the energy consumption of private households. The mission and process of the Team Data/Visualization in the pilot project therefore was to identify free data, inaccessible data, and non-existing data.

4.1 SELECTION OF SECTORS (ORIENTATION ON METHODOLOGIES AND REPORTS)

During data collection, some challenges were identified regarding aspects such as data availability, data access, complications regarding data privacy, multiplicity of sources, and data owners, data formats. Based on the identification of many challenges, a new approach was developed.
Three basic situations were identified: 1. The desired data is not available: Measurements are necessary to generate data, 2. Desired data are available but not freely accessible (privacy, motivation, etc.): Transdisciplinary approach via stakeholder exchange required, 3. Own data generation via proxy data: Indirect data generation via free data, but not possible across the board (Fig. 2).

Fig. 2: Explorative approach in the pilot study: Identification of three basic situations (components) and their possible solutions.

The team “Data/Visualization” provided the input for situations 2 and 3. Situation 2 deals with the transdisciplinary approach via stakeholder exchange. This transdisciplinary intermediate step was necessary in order to develop data sources through the involvement of stakeholders, e.g., on local public transport or CO_2 balancing in municipalities. Data filters were to be considered with regard to restrictions by data protection or similar. The steps are typically carried out in the following order: Identification of relevant stakeholders; feasibility study, communication and exchange; identification of co-benefits (motivation); definition of cooperation (co-design), and finally, to open up the data sources with stakeholders as door openers. For example, a local stakeholder from the field of energy consulting provided relevant information on municipal CO_2 accounting in the process drawn up: It is relatively easy to obtain data on gas consumption among the energy sources, whereas emission data derived from wood or oil is generally more

difficult. Possible further data sources can also be chimney sweepers. However, various energy agencies have been trying for several years to create a process structure to centralise this data and make it continuously available. The main obstacles to this, so far, have been the failed search for co-benefits and a lack of motivation for cooperation. The obligation of municipal heat planning in the course of an amendment of the Climate Protection Act (KlimaSchutzG) could mean improved data availability, e.g., on the integration of energy sources in the existing LUBW Energy Atlas (LUBW 2020). In regards to scale, the municipal level appears to be the most promising in terms of data availability and query. From this and other examples, the following conclusions were drawn: The transdisciplinary approach and methodology exhibit suitability and compelling necessity within this project.

Situation 3 deals with data generation via proxies and thus indirect data generation. This individual data generation took place via freely available data (e.g., via public real estate portals) using modelling and methods of geoinformatics. Using a crawling script, for example, publicly accessible information on living space, coordinates, energy efficiency class, and energy source or heating type was retrieved via a real estate portal and stored for the Heidelberg area and the Rhine-Neckar district. In the process, information on 1185 apartments and 127 houses (properties for rent or purchase) in Heidelberg and 1055 houses (also properties for rent or purchase) in the Rhine-Neckar district was recorded for the period from April 9, 2020 (for the houses in Heidelberg from February 26, 2020) to July 20, 2020. The required information on emission data based on the type of heating was available in heterogeneous form. Information on energy sources used or the type of heating was available in 84% (apartments) and 91% (houses) of the cases in this period. With regard to data generation, the following conclusion was drawn from the process: Methods of geoinformatics are an important component in the project work for greenhouse gas inventory and visualization; suitable tools and methods are known and used; the processing of new data with relevance for the project is possible e.g., via proxy data and the necessary visualization methods are already available.
In terms of the sector structure, the energy sector alone accounted for about 86% of emissions (1% is equivalent to 895 megatons). This is due to the fact that the energy industry as well as the transport sector are combined in this sector alone. Since national inventory reports are designed for states, no further subdivision by actor can be found in this system. In our case, only private households and small businesses (industry/commerce, trade and services) were considered from the energy sector. For the transport sector, the "Road Transportation" segment was considered. Other sub-sectors such as "Civil Aviation" are only applicable in the case of a responsibility-based inventory.
For the sector "Fugitive Emissions from Fuels", which includes, for example, emissions from coal mines and the transport of fuels, one would have to evaluate for the Heidelberg area whether a significant proportion of fuels are transported through the area and whether a calculation based on the distance travelled within the administrative unit under consideration would make sense. Alternatively, these emissions can be included in the emission factor for energy consumption.
The category "Carbon Dioxide Transport and Storage" was not included in the analysis as it is not applicable to the district level.

The sector "Industrial Processes and Product Use" represented approximately 7% of total emissions. Depending on the inventory principle, categories such as "Mineral Industry" can be applied to consumers or the location of the company headquarters. However, there is a fundamental problem that, for example, cement consumption cannot be determined according to the consumer/responsibility principle.

The sector "Agriculture, Forestry, and other Land Use" accounted for about 6% of emissions. Other sectors such as "Waste" contributed a much smaller amount to total emissions (approx. 1%). Here, the applicability to the district level must also be examined.

4.2 TRANSFER OF DATA INTO DECISION-RELEVANT INFORMATION

The conversion of data into relevant climate information for decision-makers was based on the question what kind of data is required by policy makers?
Data resolution levels must match the resolution level of the actors. For the sake of clarity, we also differentiated in the development process between a so called “production layer” (measurable data) and a “consumer layer” (considering personal decisions, action, CO_2-footprint, and consumption).
This showed that in most cases not complex and exact data or figures are required for municipal decision-makers, but rather action-relevant data like maps and recommendations on potential CO_2 reductions or development trends.

4.3 EXAMPLE: EMISSION MAPS FOR PSYCHOLOGICAL EXPERIMENTS

One goal and product of our research group was to visualize greenhouse gas emissions on maps to make them available for psychological experiments. These experiments tested whether and how the information presented influences attitudes towards climate protection and the consultancy on climate action. The objectives in the production of these maps were to present comparable greenhouse gas emissions on two scale levels, to produce control maps with alternative information on two scale levels, and to make them as comprehensible and comparable as possible. The challenges were diverse and included data availability (no information at district level and missing information for individual federal states and municipalities), comparability (aggregated information at federal state level should be comparable to municipal level), and comprehensibility or accountability (energy-based emissions in tonnes of CO_2; principle of primary energy consumption versus territorial principle based on final energy consumption called the polluter-pays principle; dealing with or characterising the private household sector and including upstream chains in the balancing process).
The emissions of the municipalities were divided by the absolute number of inhabitants, resulting in “per capita” emissions (Fig. 3). The focus regarding the maps was to use it in psychological testing to address and possibly influence climate actors. Information transfer had priority over scientific accuracy in this case. Further information including interactive maps can be found on the website Climate Action Science.

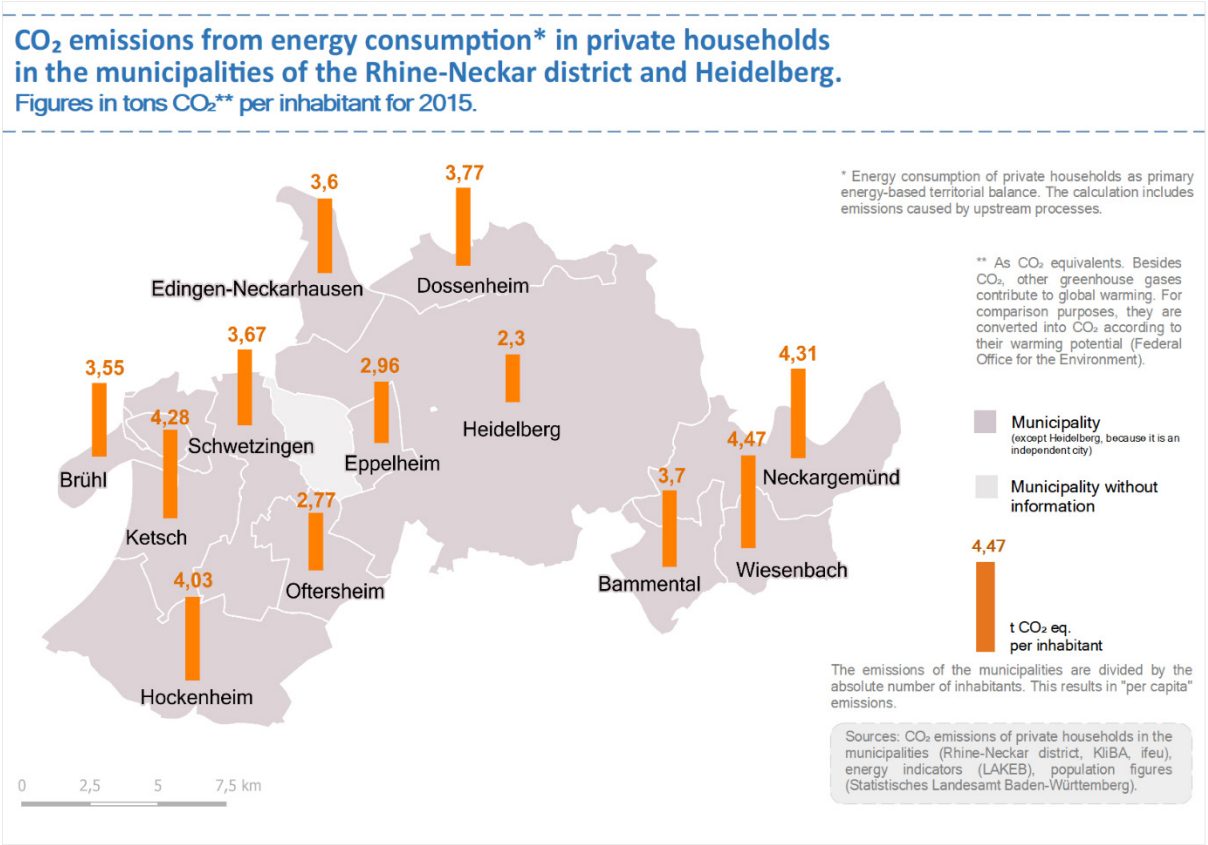

Fig. 3: Generated map based on KLiBA Heidelberg emission data for use in psychological experiments. Shown are CO_2 emissions from the energy consumption of private households as primary energy-based territorial balance in the municipalities of the Rhine-Neckar district and the city of Heidelberg (data in tons of CO_2 per inhabitant for 2015 as CO_2 equivalents). The calculation includes emission caused by upstream processes (Map based on KLiBA data (Kliba Heidelberg 2020)).

5 CONCLUSION AND OUTLOOK

While establishing the inventory, general process knowledge could be generated: First insights and findings on accounting approaches, various challenges, actors, and feasibility were identified to build a complete, incorporated emissions inventory. Here, it has been shown that there are also similar requirements for a standardized, centralized data storage on the side of the different stakeholders involved in GHG accounting processes. The different inventories, methodologies (IPCC, BISKO, etc.), and lack of uniformity in data collection and strategy make standardized accounting challenging.

Furthermore, three basic situations regarding data availability could be identified, which in turn entail different activities of data acquisition or generation: measurements, transdisciplinary approach, and data generation via proxies. The different approaches can also complement each other. Through this exploratory approach, several products have been developed within the pilot project: Maps and visualizations directed at climate actors (for psychological experiments), content and interactive maps for the project website, and several more.

For further work, the approach to downscaling data in particular would be worth pursuing. Here a greater value could be created if it becomes possible to minimize errors and inaccuracies in the downscaling process. In addition, further and broader experiments with stakeholders could

be useful. Information dissemination could be expanded through additional interactive media and web materials to reach a wider range of target users. Furthermore, the development of a central data platform with uniform standards regarding data, methodology, and accounting is necessary. In this way, all actors involved, such as municipalities, public utilities, climate agencies, chimney sweeps, etc., could follow the same approach.
With regard to sub-national actors and the alliance via the Under2 Coalition, generally applicable toolkits need to be developed that allow data and inventories to be determined on large and micro scales to provide insight into what information enables climate action and makes CO_2 reduction measures actionable.

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