Assessing environmental impacts of individual households: A large-scale bottom-up LCA-model for Switzerland

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1. Introduction

Households are the main drivers of the economy by triggering a multitude of activities along the supply chain of products and services they consume. Therefore, household consumption can be regarded as ultimately responsible for any environmental impacts that occur over the life cycle of products and services. However, most household consumption studies apply top-down approaches and provide estimates of the impacts of the average national household. This is not an appropriate method to support local policymakers in their quest for specific strategies to reduce environmental impacts in their particular regions. The deduction and prioritization of targeted measures requires an understanding and a quantification of the variability in behavior of individual households within a certain area. A few approaches for such bottom-up models exist, but most are either limited in scope or do not capture the context of total household consumption. The goal of this study is to develop a comprehensive regionalized bottom-up household consumption model which is able to derive a realistic environmental profile for each household in a region. The presented approach was applied to the whole of Switzerland.

2. Methodology

Three existing bottom-up models were merged in the new regionalized household consumption model: a building stock energy model, an agent-based transport simulation and a data-driven consumption model. The physically-based building energy model [1] estimates space heating, hot water and electricity demand for each residential building in Switzerland based on simplified energy balances as a function of time, site, climate data, building characteristics, surrounding topography and 3D-geometries derived from laser-scanning data. Since the Swiss national census [2] indicates in which building a household lives, these housing energy estimates can be directly allocated to individual households. The mobility sub-model builds upon the simulation results of MATSim [3], an agent-based traffic simulation framework. The application of MATSim to Switzerland [4] reproduced the mobility behavior of the Swiss population and provides spatio-temporal information on chosen traffic modes and driven routes for each agent. Building upon spatial information and a number of personal characteristics, the simulated agents and their associated mobility demands were assigned to household members by means of a partially randomized optimization approach. The third sub-model [5] identified consumption patterns based on the Swiss household budget survey [6] and derived 28 different consumption-based archetypes through extensive data mining techniques. These archetypes quantify the consumption behavior for food, consumables, and other goods and services for different clusters of households. To assign these archetypes to the households and thus to cover the remaining parts of consumption, a Random-Forest-Classifier was trained based on geographic information and household characteristics, as well as on housing energy and mobility demand, for merging the consumption model with the building energy model and the mobility sub-model. Because the national census [2] does not provide all information that is necessary to classify precisely a specific household as a certain archetype, we used the calibrated classifier to compute the probabilities with which the different archetypes can be assigned to a census household and then randomly sampled among these archetypes in question. This probabilistic assignment shall ensure the reproduction of a realistic variability of household behavior within a certain area. In a final step, the estimated housing, mobility and consumption demands were coupled with detailed life cycle background data in order to assess the resource uses and emissions along the whole supply chain. Pursuing a hybrid life cycle assessment approach, we included data from ecoinvent v3.3, Agribalyse v1.2 as well as EXIOBASE v2.2 to compute the environmental footprints of individual Swiss households.

3. Results and discussion

The interlinked model assesses the current environmental footprints for all 4 million Swiss households as a realistic estimate taking into account the given circumstances of a particular household (Figure 1b shows the distribution of all household carbon footprints). The results of bottom-up models can be aggregated on any desired regional scale and thus, for instance, provide benchmarking maps of municipalities as shown in Figure 1a. In addition, different spatial structures can be compared. In Figure 1c, it becomes obvious that different degrees of urbanization exhibit similar total emissions per capita. However, the compositions of the footprints reveal that rural areas tend to cause larger mobility GHG emissions per person than urban regions. This is due to larger mobility demands and higher shares of car-driven kilometers. But even more detailed analyses of compositions are possible: more than 200 different consumption areas can be investigated in the model's highest resolution. Moreover, our model is able to apply all life cycle impact assessment methods supported by the background databases. However, we only show carbon footprints in Figure 1 to enable for comparison with existing top-down studies. For instance, the composition of the estimated Swiss average carbon footprint shown in Figure 1d is comparable with [7] while the absolute amount deviates by less than 15%. Housing, mobility and food are identified as the most important consumption areas in both studies.

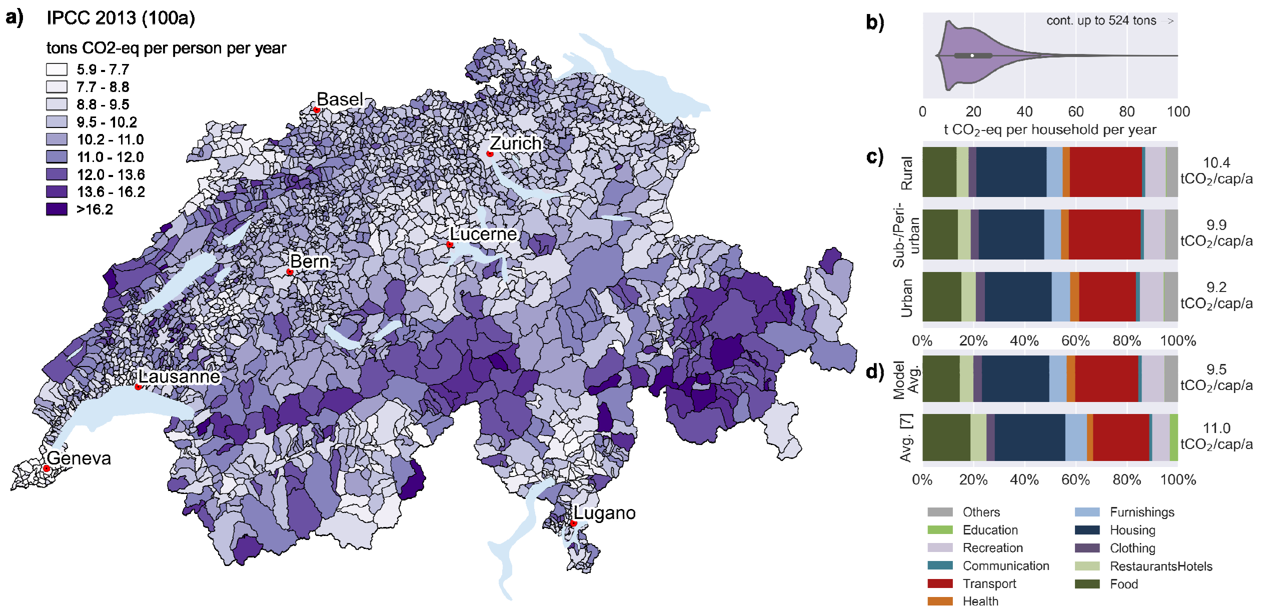

Figure 1: Results for GHG: a) Average per capita emissions per municipality, b) Violinplot of the carbon footprints of all Swiss households, c) Comparison of different spatial structures on a per capita basis, d) Comparison of Swiss average with [7].

4. Conclusions and outlook

This highly resolved model enables for the comparison of households, regions, and different consumption areas. It provides insights into the specific problems of a region and allows for the analysis of consumption patterns within this area. The model may not only be used to derive targeted incentives for more sustainable consumption, but also to investigate in detail future scenarios and thus effects of planned measures. For instance, the component-based approach of the building model facilitates the analysis of detailed refurbishment scenarios, while the link to MATSim allows for including future mobility scenarios such as electric car penetration, increased home office activities or even autonomous vehicle systems. The model might thus be regarded as a virtual platform to evaluate policy scenarios aimed at lowering environmental impacts from household consumption. In the future, it could also serve as a basis for a complete agent-based model for Switzerland in which agents can manage their expenditures as well as interact with buildings and the mobility system. This improved model can then be used for analyzing dynamic scenarios such as diffuse penetrations of new technologies and might even capture associated rebound effects.

5. References

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