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ORIGINAL ARTICLE

Climate change mitigation potential of community-based initiatives in Europe

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Abstract

There is a growing recognition that a transition to a sustainable low-carbon society is urgently needed. This transition takes place at multiple and complementary scales, including bottom-up approaches such as community-based initiatives (CBIs). However, empirical research on CBIs has focused until now on anecdotal evidence and little work has been done to quantitatively assess their impact in terms of greenhouse gas (GHG) emissions. In this paper, we analyze 38 European initiatives across the food, energy, transport, and waste sectors to address the following questions: How can the GHG reduction potential of CBIs be quantified and analyzed in a systematic manner across different sectors? What is the GHG mitigation potential of CBIs and how does the reduction potential differ across domains? Through the comparison of the emission intensity arising from the goods and services the CBIs provide in relation to a business-as-usual scenario, we present the potential they have across different activities. This constitutes the foundational step to upscaling and further understanding their potential contribution to achieving climate change mitigation targets. Our findings indicate that energy generation through renewable sources, changes in personal transportation, and dietary change present by far the highest GHG mitigation activities analyzed, since they reduce the carbon footprint of CBI beneficiaries by 24%, 11%, and 7%, respectively. In contrast, the potential for some activities, such as locally grown organic food, is limited. The service provided by these initiatives only reduces the carbon footprint by 0.1%. Overall, although the proliferation of CBIs is very desirable from a climate change mitigation perspective it is necessary to stress that bottom-up initiatives present other important positive dimensions besides GHG mitigation. These initiatives also hold the potential of improving community resilience by strengthening local economies and enhancing social cohesion.

Keywords Greenhouse gas emissions · Sustainability transitions · Grassroots initiatives · Carbon footprint · Sustainable lifestyles · Low carbon economy

Introduction

The impacts of human-induced climate change are growing with unprecedented rates of observed changes across continents and oceans in the last decades (IPCC 2014). Mitigating climate change and its associated risks is technically feasible with solutions that allow for continued economic and human development (World Bank 2012). However, limiting temperature to

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below 2 °C relative to preindustrial levels or even below 1.5 °C as agreed during the Paris negotiations (UNFCCC 2015) will require a transition to low-carbon societies that entails fundamental economic, social, and technological changes (IPCC 2014; Markard et al. 2012). This transition towards more sustainable modes of production and consumption (Markard et al. 2012) must take place at multiple and complementary scales (HM Government 2009) and has received increasing attention in the policy arena (OECD 2011; UNEP 2011). The role of civil society, through its citizens' individual behavior, is of great importance in this transition and is explicitly highlighted in the recent international Paris agreement (UNFCCC 2015).

Climate change mitigation through sustainable lifestyles in the form of behavior and consumption pattern changes are increasingly in focus across different sectors (UNEP 2016; Schanes et al. 2016; van Sluisveld et al. 2016). In parallel to the passing of almost 2 decades without an agreement on a binding and coherent top-down approach to mitigate GHG emissions, there has been an ever increasing awareness in regards to the role that bottom-up citizen action may play in mitigating GHG emissions (Leach et al. 2012). Although it is not always their primary objective, grassroots organizations, also known as community-based initiatives (CBIs), directly implement techniques and strategies that contribute to climate change mitigation. At the same time, they enhance public awareness and act as a bridge between climate science and the community in which they operate (Seyfang and Haxeltine 2012; Feola and Nunes 2014). CBIs are active in a wide variety of sectors and promote, among others, the promotion of alternative means of personal transportation, renewable energy implementation, waste reduction, organic food-purchasing groups, or the repair, reuse, upcycle, and recycle of products and materials. Innovations by CBIs are created by groups of citizens and organizations that generate bottom-up solutions for climate change mitigation, which respond to the specificities of local contexts and concerns and attitudes of the communities involved (Seyfang and Smith 2007; Feola and Nunes 2014). In contrast to a more conventional "business greening" approach, CBIs operate in civil society arenas and involve committed activists that use more sustainable technologies and experiment with social innovations that seek to promote social cohesion, strengthen local economies, and build more resilient communities (Seyfang and Smith 2007; Seyfang and Haxeltine 2012).

Among other environmental indicators (Čuček et al. 2012), GHG emissions reduction represents an important motivation for many CBIs (Forrest and Wiek 2015). Despite a growing interest from practitioners and policy and academic circles on the importance of community as a space for realizing pro-sustainability change towards low-carbon societies (Markard et al. 2012; Smith and Raven 2012; Leach et al. 2012), the treatment of the CBIs' role in creating such spaces has been reported to be in some cases unrigorous (Middlemiss and Parrish 2010). International comparisons are rare, conclusions rely on anecdotal evidence, and research tends to overlook discontinued responses in favor of successful ones (Feola and Nunes 2014). Moreover, existing evaluation schemes developed for sustainability transition experiments are too general to yield quantified information on their mitigation potential (Bai et al. 2010; Luederitz et al. 2017).

Although the local level is expected to serve as a "low-carbon lab" (Heiskanen et al. 2015), the environmental impact quantification of bottom-up engagement has focused mostly on specific sectors (Michalský and Hooda 2015) or on single communities (Barthelmie et al. 2008). Albeit calculators exist to quantify the carbon footprint on the individual level (Dawkins et al. 2011), non-theoretical, transparent and quantifiable approaches to understanding the potential of CBIs in contributing to a low-carbon transition are missing (Middlemiss and Parrish 2010; Padgett et al. 2008), perhaps as a consequence of the variety of activities they engage in (Hobson et al. 2016). However, the development of cross-sectoral quantification methodologies that address the GHG emissions reduction potential of CBIs is a necessary step in understanding their contribution to a low-carbon transition (UNFCCC 2015).

To fill this research gap, we analyzed 38 heterogeneous case studies of European initiatives across the food, energy, transport, and waste sectors located in Spain, Germany, the UK, Italy, Finland, and Romania. We define a CBI as an organization that is initiated and managed by a community. It may be for nonprofit as well as for profit, but their overall objectives should serve the transition of the community to sustainability. Based on this sample, we address the following questions: How can the GHG reduction potential of CBIs be quantified in a systematic manner across different sectors? What is the GHG mitigation potential of CBIs and how does the reduction potential differ across the variety of activities CBIs are engaged in? To answer these questions we identify the minimum data provisions that are required from CBIs and construct a methodological framework that provides indicators for the analysis and comparison of GHG mitigation achievements across eight different activities.

GHG accounting seeks to adhere to a set of basic principles, which are usually relevance, completeness, consistency, accuracy, and transparency (Greenhalgh et al. 2005). It is commonly differentiated at four different scales: national, project, organizational, and product scale (Stechemesser and Guenther 2012). CBIs, which reflect diverse forms of associations and are operated in many cases by volunteers, typically do not record the level of detail on their functioning that would be necessary to perform an exhaustive life-cycle assessment (LCA). Project scale accounting methods emerge as most appropriate for developing methodologies that attempt to analyze these organizations, since they examine their GHG emissions performance in relation to a business as usual scenario (i.e., baseline scenario) and can rely comparably on a lower amount of input data.

Methods and data

The CBIs represented in this analysis range from renewable energy and organic food cooperatives to organizations that promote through continuous events behavioral changes in recycling, personal transport, and dietary change. A full list of the CBI activities analyzed is presented in Table 1, and a description of each individual CBI and its location is given in Table S33.

The input data used for the calculations was provided by the CBIs through a survey carried out with more than 60 initiatives across six European regions: Finland, Germany, Italy, Romania, Spain, and the UK. The data acquisition was carried out within a larger EU project (TESS) in which the study regions were selected due to the proximity to the project partners for reasons of local expertise. Within each region, the landscape of CBIs was first identified by a snowball sampling technique, starting with a preliminary list of a few known initiatives. Through a following iterative, collaborative procedure CBIs were selected which (1) were running for at least a year; (2) operate within at least one of the food, transport, energy, or waste domains; and (3) were willing to share information on their activities. Further, a balanced representation of each of the food, transport, energy, and waste domains was considered within each study region. For further information on the case studies and the selection procedure see Tikkanen et al. (this issue).

In order to estimate the amount of GHG emissions avoided by the CBIs, the proposed method features a comparison of

Table 1 Summary of the activities engaged in by community-based initiatives (CBIs), baseline scenario definition, and input data used for the calculations of greenhouse gas emissions (GHG). Further details on the data used for the calculations are found in the Supplementary Material for each of the initiatives (Table S33)

Domain	Activity	Project activity	Baseline scenario	Input data used for calculations (provided by CBIs)
Transport	Personal transport	Promotion of changes towards less GHG-intensive means of personal transport for short distances, e.g., use of bicycle or public transport	Citizens travel according to the average national mode of personal transport for short distances (EC 2014)	km traveled per year by foot, bicycle, lift share, bus, and train
	Light weight goods transportation	Less GHG-intensive transport of light weight goods, e.g., small package bicycle delivery services	Delivery service is performed by an average size car (DEFRA 2015) (Section S2)	Delivery km traveled by bicycle, electric bicycle, electric scooter, and electric car
Food	Provision of organic food	Growing local food, e.g. urban gardening, allotments and small scale organic farming	Food is produced according to the national share of conventional and organic food production (FIBL 2015; Soil Association 2014) (Section S3; Table S4–5)	Kg of different food items produced and km traveled from the farm to the local market
	Food waste reduction	Saving food that is still edible from supermarkets and the promotion of food waste avoidance at the household level	In the absence of the activity, the baseline scenario considers both the waste emissions (Scherhaufer et al. 2015) and food production emissions (Tilman and Clark 2014; Weber and Matthews 2008, Lynch et al. 2011; Meier et al. 2015) that would have occurred (Section S4)	Kg of different food items saved
	Dietary change	Promotion of dietary change towards diets that include less animal-based products. Initiatives prepare vegetarian and vegan meals	Defined as the average conventional diets considered by Scarborough et al. (2014), Berners-Lee et al. (2012), Meier and Christen 2012) and van Dooren et al. (2014) (Section S5)	Type of meal—vegetarian or vegan—and number of meals
Energy	Electricity generation	Generation of electricity from renewable sources (solar, wind, hydro and biogas)	Electricity is produced according to the national electricity mix, which accounts for the different share of energy sources (EC 2015) (Section S6; Table S15)	kWh/year generated; source of renewable energy
	Heat supply	Provision of heat from renewable sources (biomass and geothermal sources)	The different share of energy sources used in national residential heating is accounted for in the absence of the initiative (ENTRANZE 2013) (Section S7; Table S20)	kWh/year generated or persons supplied; source of renewable energy
Waste	Recycling	Recycling of materials (paper, glass, plastic, and aluminum)	The baseline scenario considers the recycling rates for different materials (Eurostat 2013); Only the percentage of material that exceeds this rate is considered as emissions avoided (Section S8)	Kg of different materials collected

the emissions imputable to a specific CBIs' activity with the emissions of a baseline scenario. This is carried out by adopting the main principles of the GHG Protocol for Project Accounting (Greenhalgh et al. 2005) to the specificities of local initiatives. The baseline scenario is determined for each of the activities considered by measuring the GHG emissions of a standard counterfactual, defined as the expected behavior of the average citizen to obtain the same service in the absence of the implemented CBI's activity (Table 1).

The methodology is applied to 46-GHG emission-relevant activities carried out by 38 CBIs (i.e., some initiatives are involved in various domains simultaneously) with sufficient data for the analysis of their mitigation potential. The survey data used in our analysis may be found in Table S33. In the following section, the method adopted for the personal transport activity is presented; the rest of the activities, which follow a similar reasoning but respond to each of the domain-specific characteristics, may be found in the Supplementary Material (Sections S1–7). The calculations presented in this work have adhered to the accounting principles suggested by Greenhalgh et al. (2005), with a special consideration towards the principles of conservativeness and transparency.

Personal transportation

CBIs engaged in the personal transport activity promote changes towards less GHG-intensive modes of personal transportation for short distances, e.g., the use of bicycle and different types of public transportation. In the absence of the initiative, the baseline scenario is defined as the national average mode of transportation for short distances. This considers the four prevailing modes of passenger transport across European countries—car, tram and metro, buses, and coaches and rail (EC 2014) (Table S28). The different emission factors (EFs) used for the calculation, which indicate the GHG emissions emitted per unit of activity (kg CO_{2eq}/km), include the emissions that arise from the production of the vehicles and from the fuel combustion produced from their use (Table S27). The baseline EFs, applied for calculating the baseline emissions, are obtained as the weighted average of the different modes of personal transport present in each country, according to the following expression:

EFbase

$$EF_{base} = \sum_{i}^{n} \frac{dist_{base_i}}{dist_{base_t}} \times EF_i \tag{1}$$

$$E_{base} = EF_{base} \times dist_{\mathrm{act}} \tag{2}$$

where:

EF_{base}	is the emission factor of the baseline scenario (kg CO_{2eq}/km)
$\mathrm{dist}_{base}i$	is the annual per capita distance traveled by the individual mode of transport i (km)
$\mathrm{dist}_{base}t$	is the total annual per capita distance traveled (km)
EF_i	is the emission factor of the individual mode of transport i (kg CO_{2eq}/km)
E_{base}	are the baseline emissions (kg CO_{2eq})
dist_{act}	is the total distance traveled per person in the project activity (km)

The emissions of the CBIs' project activity are quantified as follows:

$$E_{act} = \sum_{i}^{n} EF_{act_i} \times \mathrm{dist}_{act_i} \tag{3}$$

where:

E_{act}	are the project activity emissions (kg CO_{2eq})
E_{act_i}	is the emission factor for the mode of transport i (kg CO_{2eq}/km)
dist_{act_i}	is the distance traveled for transport mode i for the project activity (km)

Finally, the total emissions avoided (kg CO_{2eq}) are calculated as the difference between the baseline and the project activity emissions:

$$E = E_{base} - E_{act} \tag{4}$$

The EFs used were derived from DEFRA (2015) and, when necessary, recalculated by considering the average occupation rate obtained by EC (2014). For some cases, the DEFRA dataset only provided the use stage EF; for such cases, the production EF was estimated through a ratio calculated through the PROBAS dataset (ProBas 2016), which differentiates emissions from the production and use stages. We prefered using the DEFRA dataset for consistency purposes, since it was also used as a source of EFs for some of the other activities. The emissions arising from the different types of transport are assumed to be the same across countries, with the exception of electric vehicles. Country-specific EFs are provided for this case, accounting for the different energy sources found in the national electricity mixes. The input data used for the equations above (distances of alternative modes of personal transport traveled in a year by the beneficiaries of CBIs) are obtained through the information recorded by the initiatives and refer to the year 2014.

Number of complete beneficiaries

We define complete beneficiaries (hereafter, beneficiaries) as the theoretical number of persons that satisfy 100% of their demand of a certain service through the initiative's functioning. Beneficiaries of the personal transport activity are estimated by relating the national per capita km of personal transportation for short distances (EC 2014; Eurostat 2014) to the total amount of alternative km promoted by the initiative. For instance, British

CBI SCO2 reported a total change of 321,256 km in personal transportation for the year 2014, including for example the use of bus, cycling, and walking. Since UK's per capita personal transport for short distances is of 11,948.9 km, we account for 26.9 beneficiaries. This approach is applied analogously for other activities (Table S31), which allows for the comparison of the CBIs' performance across different domains.

Performance indicators of community-based initiatives

The GHG mitigation performance of CBIs is presented by means of the following indicators:

(1) Absolute indicator: GHG emissions reduction per year in relation to the baseline scenario (kg CO_{2eq}/yr).
(2) Efficiency indicator: GHG emissions reduction per unit of product or service output (e.g. kg CO_{2eq} per km traveled for the transport domain).
(3) Carbon footprint indicator: GHG emissions reduction in relation to a beneficiary's carbon footprint (% of CF).

The absolute indicator presents the total GHG reductions achieved by a CBI for a certain activity in a given year, accounting for the efficacy of the mitigation achieved. The efficiency indicator is a valuable indicator for intra-activity CBI comparison, since it highlights the higher or lower reductions achieved per unit of the same service. Finally, the carbon footprint indicator (CF), intended for inter-activity CBI comparison, relates the emissions avoided by the initiative to the number of beneficiaries the CBI provides a service for. The emissions avoided are presented as a percentage of the average European carbon footprint—8.85 Mg CO_{2eq}/yr is used as benchmark for this analysis (EEA 2015). Indicators 1 and 3 are used in combination to discuss the results across different activities, while indicator 2 is recommended for highlighting the higher performing initiatives engaged within a given activity.

A summary of the methodology applied for the analysis of the GHG mitigation performance of CBIs is presented in Fig. 1. For confidentiality reasons, initiatives have been anonymized using a code that indicates their location, e.g., SCO2 refers to a CBI located in Scotland. However, the data used as input for the calculations may be found in Table S33.

Results

From the analysis of the inter-activity comparison indicators—absolute GHG emissions reduction and % of CF reduction—we can separate the activities' GHG mitigation performance into three major groups (Fig. 2). The generation of electricity is the best performing activity, since it presents a high-mitigation efficacy—an average reduction of 454,239 kg CO_{2eq} per year (454.2 t CO_{2eq})—and the greatest reduction of an average beneficiary's CF (24.4%). The second best performing group includes the activities of heat supply (612,312 kg CO_{2eq}/yr and 11.8% of CF), personal transport (25,134 kg CO_{2eq}/yr; 11.4% of CF), and dietary change (6,832 kg CO_{2eq}/yr; 6.9% of CF). Finally, the third group presents a much lower relevance in terms of CF performance, ranging from 0.1% for the provision of organic food activity (2,152 kg CO_{2eq}/yr) to 1.5% for recycling (21,010 kg CO_{2eq}/yr). For this group, we observe an especially high variation in terms of total emissions reduced, reflecting the very different size of operation found across these initiatives. CBIs engaged in the activities of transportation of lightweight goods and food waste reduction reduce on average emissions by 21,869 kg CO_{2eq}/yr (1.0% of CF) and 145,234 (1.78%), respectively. A summary of the average results obtained through the three proposed indicators is presented in Table 2.

Discussion

Transportation domain

CBIs engaged in the transportation sector, which accounts for 14% of the total anthropogenic GHG emissions (Sims et al. 2014), show a very high GHG–mitigation performance (Table 2; S29). This is especially the case for the personal transport activity: it offers the highest mitigation potential after the energy CBIs, with achieved average reductions of 1.01 t CO_{2eq} per beneficiary. Besides the total distances traveled by the CBIs' beneficiaries, the key factor that determines their performance is the type of alternative transport promoted by the CBI (Table S27). In contrast, when testing the influence of the country location on the CBI's performance, results indicate a very similar absolute emissions reduction across the six countries (Table S30), as a consequence of finding very similar shares of personal transport options (Table S28).

CBIs engaged in the transportation of lightweight goods (Section S1; Table S2) use different combinations of vehicles for their service and reduce on average emissions by 21,869 kg CO_{2eq}/yr (1.0% of CF). The main factor determining the results is the type of vehicle that substitutes the business as usual delivery service (Table S1). Interestingly, the use of electric vehicles currently produces an increase in the GHG emissions in relation to the baseline scenario in all the countries studied with the exception of Finland (Table S3). This is a consequence of the high share of GHG-intensive energy sources still found in the different national electricity mixes (DEFRA 2015) (Table S16). Germany presents the least favorable GHG emissions performance of the countries analyzed (Table S1); its electric car's EF is currently 46.4% higher than the EF of a diesel car, 0.211 kg CO_{2eq}/km (DEFRA 2015). This estimation takes into account the production of

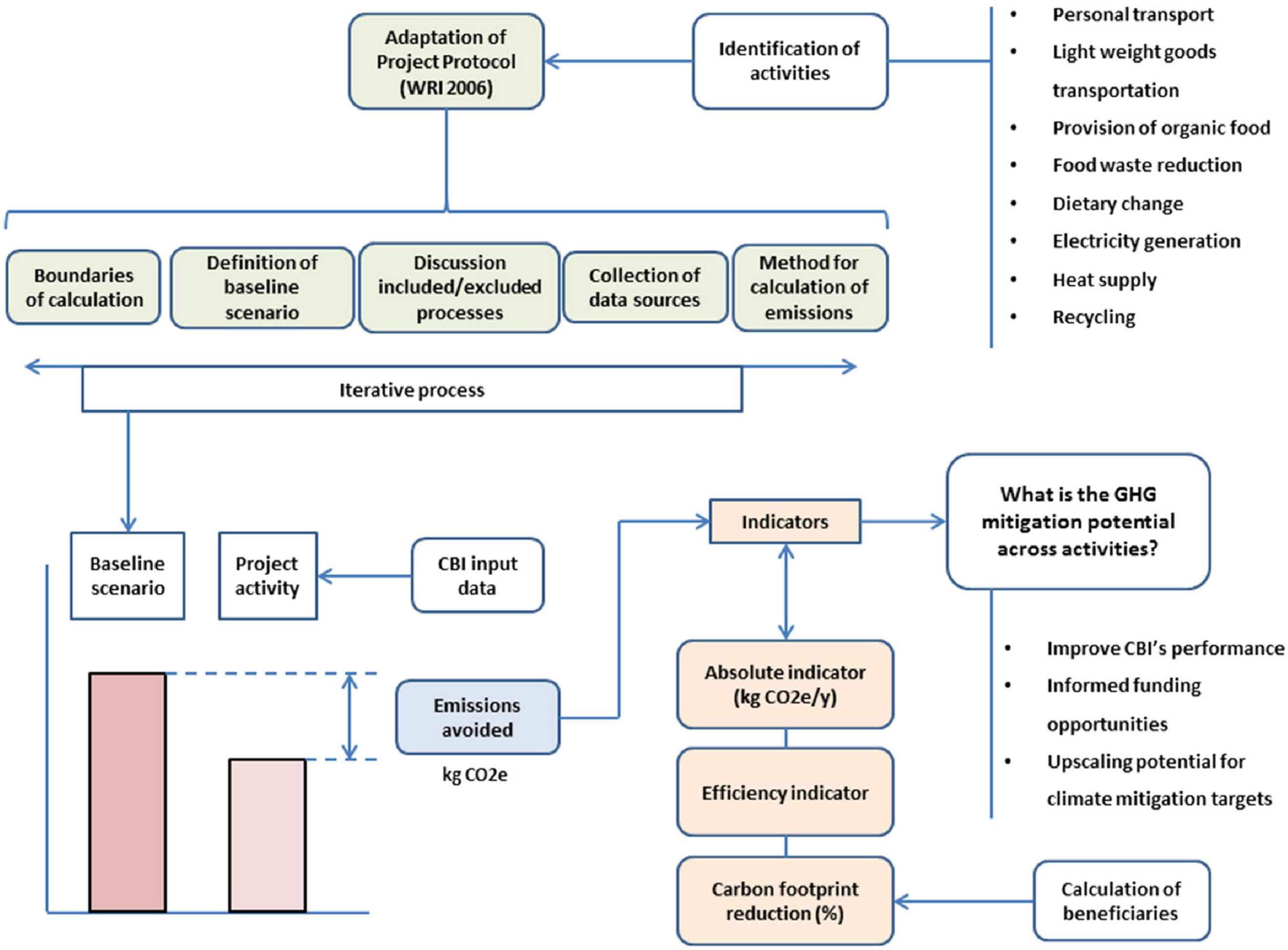

Fig. 1 Descriptive summary of the methodology followed for the calculation of avoided greenhouse gas emissions (GHG) by the community-based initiatives (CBIs) and analysis of results

the vehicle (Hawkins et al. 2013), the national electricity mix (Moomaw et al. 2011), and the estimation of electric energy consumed per kilometer from Granovskii et al. (2006). However, the GHG intensity of electric cars is expected to

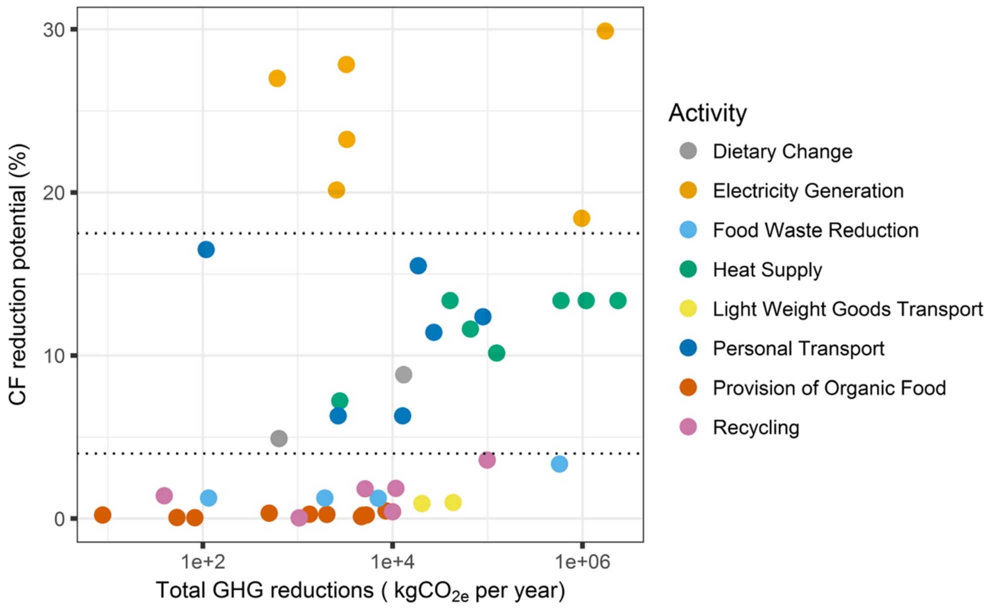

Fig. 2 Community-based initiative's (CBI) performance across different activities: absolute greenhouse gas (GHG)–emissions reductions and reductions as % of beneficiaries' carbon footprint (CF). Highlighted are the three identified groups by performance. Two CBIs from the organic food activity obtained negative emissions and are not represented

Table 2 Average results across activities of community-based initiatives (CBIs): Total emissions reduced (kg CO_{2e}/yr.—indicator 1), Total reduction per output unit (indicator 2) and % of carbon footprint (CF) reduction (indicator 3)

Domain	Activity (# of CBIs)	Baseline emissions (kg CO_{2e}/yr)	Project emissions (kg CO_{2e}/yr)	Total reduction (kg CO_{2e}/yr) (range)	Total reduction (kg CO_{2e}) per output unit	Output unit	Number of beneficiaries	Reductions as % of beneficiary's CF
Food	Provision of organic food (12)	6159.79	4007.98	2151.80 (−904.87; 8497.23)	0.15	kg	161.17	0.12
	Food waste reduction (4)	146,140.70	906.47	145,234.23 (114.95; 571,845.64)	0.53	kg	2161.51	1.78
	Dietary change (2)	17,572.31	10,740.34	6831.97 (635.36; 13,028.58)	0.56	meal	9.07	6.87
Energy	Heat supply (7)	671,579.54	59,267.22	612,312.32 (2769.43; 2,367,142.90)	0.15	kWh	523.62	11.78
	Electricity generation (6)	476,475.60	22,236.20	454,239.39 (609.04; 1,736,873.00)	0.35	kWh	210.33	24.42
Transport	Transport of goods (3)	23,740.18	1871.44	21,868.74 (1785.56; 43,464.34)	0.20	km	375.00	0.95
	Personal transport (6)	30,590.80	5456.41	25,134.38 (108.30; 89,468.60)	0.10	km	24.97	11.41
Waste	Recycling (6)	28,529.88	7520.14	21,009.74 (39.36; 99,087.87)	5.50	kg	191.36	1.52

decrease rapidly as the share of electricity from renewable sources in different countries' national mix increases in the future (Bruckner et al. 2014). In spite of this, the CBIs analyzed for this activity still achieve high-GHG reductions in relation to the baseline scenario because the use of bikes is more extended than the use of electric vehicles for their service.

Energy domain

Despite an ongoing energy transition, the energy supply sector is responsible for approximately 35% of the total anthropogenic CO_2 emissions (Bruckner et al. 2014). Since faster rates of decarbonization are needed to achieve the climate targets (UNFCCC 2015), the potential of bottom-up action by local energy initiatives is promising. CBIs engaged in renewable energies presented a very high absolute GHG–emissions reduction (Table 2; S19; S22). Electricity-generating initiatives achieved a larger emissions reduction per kilowatt hour than initiatives involved in the provision of heat (0.35 vs 0.15 kg CO2eq reduced per kilowatt hour), due to the different EFs that define their respective baseline scenarios (Tables S18; S21).

The reductions achieved by the energy CBIs are determined by several factors. Firstly, the amount of kWh generated by the CBIs—larger scale operations lead to higher absolute reductions. Secondly, the national share of energy sources in the electricity mix is important—the lower the share of renewable energies the higher the emissions reduction achieved can be. Finally, the EF of the implemented renewable energy technology has a high relevance (Moomaw et al. 2011): in the case of electricity generation (Table S17), the best EF is found for hydropower, followed by wind, biomass, and solar PV; for the case of heat supply, biomass presents the better performance and, to a lesser extent, natural gas (Table S21).

There are large differences existing between the CF indicator of the electricity and heat CBIs. It is important to note that, while the electricity generation of initiatives feeds into the grid, the heat supply activity considers exclusively household heating. Targeting this specific sector by heat CBIs has significant implications, since the kilowatt hour per person used for the calculation of beneficiaries for the heat activity will be lower (Section S9) and hence the percentage of CF indicator will be reduced. In other words, if the range of beneficiaries of heat CBIs were broader (e.g., included industry) the CF indicator for this activity would evidently increase. The approach is however consistent with the service that is currently provided by the CBIs.

Our analysis considered exclusively the kilowatt hour of energy generated by the CBIs; however, it is important to point out that these initiatives typically also engage in educational-related activities related to implementing behavioral changes in the energy consumption of their beneficiaries.

Obtaining energy from less GHG-intensive energy sources is important for reducing emissions, but reducing altogether its use when unnecessary is also highly impacting and was conservatively left out of this analysis.

Waste domain

Initiatives engaged in recycling activities reduce emissions on average by 5.5 kg of CO_{2eq} per kilogram of material collected, with values ranging from 0.75 to 12.12 kg CO_{2eq}/kg, depending on the material considered (Table S26). This variation is explained, firstly, by the absolute difference in EFs associated to the production of these materials from virgin or recycled material (Table S25). This difference is highest for batteries (meaning higher potential for the reduction of emissions per kilogram collected), followed by aluminium, plastic, and paper. Secondly, it is explained by the country-specific baseline recycling rates (Table S23), which determines how much of the collected material by the initiatives may be attributed to the emissions reduction. The consequence of this conservative methodological choice is that countries with already very high recycling rates (e.g., Finland) account for a lower GHG emissions reduction for a given quantity of collected material in relation to countries presenting low recycling rates, e.g., Romania (Table S23). However, this is in line with the desire of capturing the additional value that CBIs provide within the specific location they operate in. A third element that plays an important role is the per capita consumption of different materials. For example, although batteries present the largest absolute difference in EFs between production from virgin and recycled materials, they also present the lowest CF reduction indicator of all the materials considered. This is a consequence of a lower consumer demand in relation to other materials or products (Table S24). Considering the low recycling rates observed for some of the countries analyzed (e.g., Romania) or for some specific materials (e.g., plastic), CBIs could play an important role in closing the recycling gap in relation to some of its neighboring countries.

Food domain

The activities represented in the food domain present three very different approaches to reducing GHG emissions: focusing on how food is produced (providing organic food), focusing on avoiding food waste, and focusing on reducing the presence of animal-based products in diets (dietary change activity). The very different functionalities of this domain allows for a lengthier discussion for this sector.

Our results depict much higher GHG reductions for the activities of dietary change than for the provision of organic food, with reductions of beneficiaries' CF of 6.9% and 0.1%, respectively. This indicates that the type of food a beneficiary consumes is far more relevant from a GHG mitigation perspective than the manner in which it was produced. The reason behind this difference is the overall larger share of embedded GHG emissions present in animal-based products (Bryngelsson et al. 2014; Popp et al. 2010; Pradhan et al. 2015) (Table S13). The results are in line with the literature, which establishes three main elements for mitigation in a sector that accounts for 10–12% of global anthropogenic GHG emissions (Smith et al. 2014): yield-gap closure in lower income and developing countries (Pradhan et al. 2015), future technological mitigation options, and dietary change in higher-income countries (Bryngelsson et al. 2014; Popp et al. 2010; Hedenus et al. 2014). Despite some authors including the need for dietary changes as crucial for meeting the 2 °C target at the end of the century with a high probability (Hedenus et al. 2014), it is evident that cultural changes in relation to food consumption are not straightforward. Further research is still needed in regards to discerning the most effective way to deliver a dietary change message (Joyce et al. 2014), and should also address the effectiveness of bottom-up approaches such as CBIs in successfully communicating this message in their communities.

Initiatives engaged in growing organic food present a very modest mitigation potential (Table S9), offering the lowest emissions reduction of all the activities analyzed. These conclusions are strongly influenced by the EFs from conventional (Tilman and Clark 2014) and organic food production systems that were used (Lynch et al. 2011; Meier et al. 2015) (Table S8). The dataset is based on 120 LCA publications on agricultural products that consider all agriculture emissions occurring until farm gate, including transportation and excluding emissions from land use change. This exclusion is consistent with the nature of most of the initiatives—small scale urban gardening and allotment schemes that do not compete for land with conventional agriculture. Still, it should be noted that large uncertainties exist on the differences in emissions associated to the two different production systems (Meier et al. 2015) and is a debated topic in the organic/conventional agriculture literature (Kirchmann et al. 2016). In regards to our calculations, even when considering an optimistic approach for the organic food production activity (i.e., for most of the organic food types produced by the CBIs the EFs of organic production perform favorably in relation to conventional production), the CF mitigation performance is of a lower order of magnitude in relation to dietary change and food waste avoidance (Table 2). Local post-farm gate transportation is identified as playing a key role in the results—the already low GHG-emissions reduction that is achieved by producing organic food in relation to the baseline scenario is rapidly neutralized as transportation distances to local markets increase. For example, CBI SCO5 produced 378 kg of vegetables and achieved during its production stage a reduction in GHG emissions equivalent to 105 kg CO_{2eq}/yr. Considering the EF of the diesel car that was used for the post-farm gate transportation of this small scale operation, it means that the emissions reduction achieved until here would be neutralized if the total monthly transportation to the local market was higher than 48 km. This initiative exemplifies how the transport efficiency of small initiatives is crucial in order to have any GHG mitigation impact in the provision of organic food activity.

Food loss and food waste currently account for a third of the total food production (Gustavsson et al. 2011; Scherhaufer et al. 2015), and global emissions related to food surplus are expected to increase in the future (Hiç et al. 2016). The performance of food waste avoidance lies between the two activities previously discussed (Table 2; Table S11). Our results show, firstly, that the emissions saved through the avoided food production are larger than the avoided landfilling waste emissions, which is a consequence of the difference in EFs (Table S6). Secondly, since the initiatives' transportation of redistributed food takes place on foot or by bicycle, the main factor that determines the efficiency of the CBIs' reduced emissions in this activity is the share of different food types that are redistributed. A larger emissions reduction per kilogram of food is observed for some food types (e.g., animal-based products or cereals) than for others (e.g. fruits, legumes, or vegetables) (Table S6). Finally, refrigerating energy requirements for storing the redistributed food are found to not play a significant role for this activity (Section S3.5; Table S10). The CBIs engaged in food waste–reduction activities that were studied target food waste at the household and retail levels, with a greater focus on the latter. These sectors account for 53% and 5% of the total food waste, respectively (Scherhaufer et al. 2015). In light of the enormous contribution of the household level to the total food waste budget, the potential of CBIs for influencing a reduction in food waste at this level through educational-related activities is very large: 16% of household food is currently wasted and 75% of it is considered to be avoidable (Vanham et al. 2015). Reducing food waste at the household and retail levels are two important pieces of a larger food waste picture, i.e., food waste occurring at the agricultural production, post-harvest, or processing stages are also important and not targeted by local initiatives.

Limitations of methodology

Several limitations have been identified through the application of the chosen methodology (Table S32). Firstly, some uncertainty arises through the definition of the different baseline scenarios, where subjective choices are necessarily made to define how society currently produces the same goods and services provided by the CBIs. The assumptions surrounding this definition are unavoidable, but are based on a transparent discussion of included and excluded processes for each activity (Sections S1-8). Additionally, citizens currently engaged in the services provided by the CBIs might not represent in some cases an average citizen behavior. They may have already been interested in reducing their animal product consumption or in reducing their car use before participating in the products and services offered by the initiatives. However, presenting the methodology in this way will allow in a further step to estimate the country-scale mitigation potential of CBIs. Nonetheless, further research opportunities could focus on the interesting "demand-side" of CBIs, i.e., what context and factors ultimately drive citizens to engage with the products and services offered by sustainability initiatives. Secondly, in regards to the data used for the calculation, country-specific EFs are not always available, as was the case for the production of many different food types (Tilman and Clark 2014), for food-specific waste EFs (Scherhaufer et al. 2015) or for the GHG characterization of country-specific diets, which are available only for a handful of countries (Scarborough et al. 2014; van Dooren et al. 2014; Berners-Lee et al. 2012; Meier and Christen 2013). Finally, CBIs are often involved in educational-related activities for which the application of a baseline versus project scenario methodology would introduce too many subjective assumptions. In some cases, the indirect educational effects could be much larger than the direct effects calculated here. For instance, the GHG emissions reduction for the dietary change activity was calculated through the number of vegan and vegetarian meals provided in a year by the CBI. However, the indirect effect of permanently changing a certain percentage of the beneficiaries' diets is certainly larger, and was not accounted for in the absolute emissions reduction results presented here. This was also identified for most of the other activities, such as for the recycling and food waste reduction CBIs, where the educational impact may be larger than the direct emissions reduced by the material recovered and by the household food waste avoided, respectively. The exclusion of CBIs' indirect effects adds to the conservativeness of the absolute GHG mitigation results presented here, though further research should focus on this important effect of bottom-up action.

Conclusions

Until now, empirical research has focused on anecdotal evidence and little work has been done to quantitatively assess community-based initiatives' (CBIs) environmental impacts in terms of GHG emissions using comparative and quantitative methodologies. In this paper, we have bridged this research gap by providing a seminal methodological framework that enables the first systematic quantification of the GHG mitigation potential of local initiatives. We apply the methodology to 38 CBIs in six different European countries and find that the mitigation potential of these organizations is very relevant for most of the activities considered and that the proliferation of these organizations is therefore very desirable from a climate change mitigation perspective. Through the comparison of the emission intensity arising from the goods and services the CBIs provide in relation to a business as usual scenario, we quantified this potential for eight different activities across the transport, food, energy, and waste domains. Electricity generation and heat provision through renewable sources, changes in personal transportation, and dietary change present by large the highest climate change mitigation potential of the activities analyzed. In contrast, the provision of organic food was the activity with the lowest emissions reduction and our results indicate that CBIs promoting dietary change towards a reduction of animal-based products in diets is a far more efficient GHG mitigation strategy. Further, interesting research gaps have been identified, namely the need for addressing the important education-related, indirect GHG mitigation CBIs achieve through their activities by stimulating sustainable lifestyle changes of their beneficiaries; the analysis of potential GHG rebound effects arising from CBIs' beneficiaries in certain sectors; and finally, the development of a more detailed, country-specific EFs in certain activities for increasing the accuracy of calculations in certain countries. Moreover, it is important to emphasize that CBIs should keep detailed records on the activities they engage in, not only of the energy, materials, and transport used to provide their goods and services, but also of the working hours invested in their activities and the number of beneficiaries that use these services. Although this work has focused on GHG mitigation, it is necessary to stress that CBIs present other important positive dimensions, which hold the potential of improving the resilience of local communities by strengthening local economies and by enhancing social inclusion and cohesion. The work presented here is a first step in understanding the potential role that local sustainability initiatives may play in the future in regards to meeting the current European climate change mitigation targets. Furthermore, it opens the door to the development of further methodologies that address GHG mitigation through bottom-up action and may guide the development of informed public policies regarding climate change mitigation aiming at regulating and supporting CBIs' activities.

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