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Sub-National Scale Initiatives for Climate Change Mitigation: Refining the Approach to Increase the Effectiveness of the Covenant of Mayors

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Abstract: Climate change mitigation strategies include sub-national initiatives proposed and operated by municipalities. An example of such initiatives is the Covenant of Mayors, the signatories of which are requested to compile territorial greenhouse gas emission inventories to identify entry points for mitigating policies and to be able to monitor their effectiveness over time. However, the current accounting approach presents some limitations, providing an incomplete picture of the territorial emissive status, thus hampering the mitigation potential of the set of measures. The present study shows that the current approach required by the Sustainable Energy and Climate Action Plan (SECAP) guidelines for compiling the Baseline Emission Inventory (BEI) can be complemented with the accounting guidelines proposed by the Intergovernmental Panel on Climate Change (IPCC) in order to fill existing gaps and provide a comprehensive picture from a different point of view. The proposed refinement demonstrates that local administrative bodies can count on a tool able to provide detailed and accurate information, stimulate knowledge and awareness, and optimize local mitigation efforts sometimes limited by the application of large scale (national) top-down initiatives.

Keywords: climate policy; Covenant of Mayors; GHG emission accounting; sub-national scale climate action; Sustainable Energy and Climate Action Plan (SECAP)

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1. Introduction

The fight against climate change includes mitigation and adaptation strategies [1]. The first ones are aimed at preventing or reducing the emission of greenhouse gases (GHG) [2], which are the main cause of climate change [3]. The second ones aim at preserving both human and natural environments from the unavoidable impacts of climate change [2].

International agreements defined country-specific GHG emission reduction targets [4]. At the same time, countries themselves must identify and define the best mitigation and adaptation strategies to apply [5,6]. Various initiatives at international, national and sub-national scale have been launched in the past decades [7–9]. Among these, several bottom-up initiatives have been developed at a municipality-scale across the globe, such as 100 Resilient Cities, C40 cities, the International Council for Local Environmental Initiatives (ICLEI), and the Covenant of Mayors.

The Covenant of Mayors (CoM) initiative was launched in 2008 by the European Commission after the adoption of the 2020 European Union Climate and Energy Package, with the aim of engaging and supporting mayors to achieve the EU climate and energy targets through a 20% reduction of the GHG emission of the involved municipalities by 2020 [10]. As such, the CoM was designed as a mitigation action that included the implementation of a Sustainable Energy Action Plan (SEAP). However, in 2014 the European Commission launched the Mayors Adapt, a CoM's sister initiative set up to inspire cities to take action to adapt to climate change as part of the EU adaptation strategy [11]. The following year the two initiatives merged in a new standalone initiative, the Covenant of Mayors for Climate & Energy, that focuses on both mitigation and adaptation strategies and aims at actively supporting the implementation of the EU 40% GHG-reduction target by 2030 compared to the baseline year [12]. Finally, in 2016, the EU-based Covenant of Mayors for Climate & Energy merged with the Compact of Mayors, an initiative launched in 2014 by the United Nations aimed at reducing GHG emissions by 454 megatons by 2020 [13]. This resulted in the Global Covenant of Mayors for Climate and Energy (GCoM), the largest city-led movement committed to fighting climate change with mitigation and adaptation actions. Fully in line with the UN Sustainable Development Goals and climate justice principles, the GCoM involves more than 7100 cities, 119 countries, and 600 million people [14]. Since then, it expanded by including new signatories. The initiative aims to tackle three pillars that are regionally tailored: climate change mitigation; adaptation to the adverse effects of climate change; and universal access to secure, clean, and affordable energy.

Accordingly, the scope of the GCoM focuses on the energy sector [15]. This choice is linked to the relevance of the energy sector in terms of GHG emission (about 70% of the global total emission [16]).

By joining the GCoM, the local authorities commit to create a Sustainable Energy and Climate Action Plan (SECAP). The SECAP is based on a Baseline Emission Inventory (BEI) and a Climate Risk & Vulnerability Assessment, which provide a picture of the current situation. These documents allow them to identify a set of actions to reach the climate mitigation and adaptation goals that have been set [17]. Mitigation results are monitored by continuously updating the BEI through the periodical compilation of Monitoring Emission Inventories, such as the stage to assess the progresses toward the mitigation target established in SECAP [15].

The BEI and the Monitoring Emission Inventories follow the original objective of the first initiative, namely climate change mitigation through actions mostly addressing the energy sector. Indeed, the compilation of the BEI mandates the estimation of the GHG emission of some sectors that are considered significant and are strictly related to energy production and consumption, whereas it considers the inclusion of other sectors, such as industrial processes and agricultural direct emission, as optional [15].

This work aims to compare the BEI compiled according to the respective SECAP methodology and the emission inventory elaborated according to the Intergovernmental Panel on Climate Change (IPCC) guidelines (the latter being one of the most complete GHG accounting frameworks currently adopted worldwide) and investigate possible integrations. Through the analysis of a case study, we unveil the critical differences existing among the two methodologies and highlight their relevance in terms of overall significance. Accordingly, we explore the mitigation potential deriving from a refinement of the BEI that may be obtained by an integration between SECAP and IPCC guidelines. Such refinement could support decision-makers in designing more effective and comprehensive mitigation policies at the municipal level, but also at the higher administrative level.

In terms of methodology, both the IPCC guidelines and the Global Protocol for Community-Scale Greenhouse Gas Emissions Inventories (GPC) are considered valid options for compiling the BEI. However, the limited data availability or quality and the complexity of the latter hamper the possibility for local governments to design accurate policies [18]. The BEI compilation guidelines provided within the SECAP support and guide the compiler during the collection of data at sub-national scale with a specific focus on the activities pertaining to the energy sector. This allows to overcome the challenges that can be encountered while dealing with sub-national accounts.

The energy sector plays a major role in terms of global GHG emission [16]. However, passing from a global level to a municipal one, the relevance of each sector can vary significantly, due to the extreme heterogeneity that characterizes different municipalities and, in general, small areas and communities across the globe. In fact, there are areas where the agricultural sector covers a large percentage of the overall GHG emission [19,20]. While at a global scale an overall reduction of the emission linked to the energy sector could have on average a high significance, local actions on the agricultural sector and industrial processes and product use (IPPU) might be as relevant as the energy sectors, since the related GHG emission covers a significant share, too (around 24% [16]). According to the 6th IPCC Assessment Report [21], Agriculture, Forestry and Other Land Use (AFOLU) sector covers 23% of the net global anthropogenic GHG emission.

Emission Trading Schemes (ETS) are agreements that regulate GHG emission from certain energy-intensive industrial plants (e.g., heat or electricity production) or industrial plants with direct process emission of GHG (e.g., concrete, ceramics, and glass production) depending on the emission quantity or production volume. Various examples of ETS are currently running at both national and international level [22]. The exclusion from a BEI of all the GHG emission due to ETS activities originating from both energy production or consumption and industrial non-energy processes [23] would result in incomplete Energy and IPPU sectors' GHG accounts. This, in turn, would result in the provision of an incomplete picture of the municipality status in terms of GHG emission, and it would even limit the possibility to jointly engage the private and public sectors in an effective collaboration aimed at reducing the GHG emission through fine-tuned mitigation strategies. The latter could focus on both the industrial energy production or consumption or the industrial processes per se.

The agricultural sector can play a significant role in rural contexts in terms of emission. CH_4 and N_2O emission from livestock, rice cultivation, and fertilizers use (GHG with remarkably high Global Warming Potential—GWP) can represent the largest contributor to the GHG emission of an entire area [19]. On the other hand, mitigating actions could be highly effective in that sector, focusing on several emission hot spots and simultaneously gaining productivity [24–28]. Therefore, an a priori exclusion of some sectors from monitoring activities and mitigation strategies could prevent potential emission reduction and neglect possible contribution to the achievement of national and international reduction targets.

The paper is structured as follows. First, we briefly summarize the limitations and critical points of the current approach. Second, we show the methodological proposal. Third, we present and discuss the results obtained by applying the proposal to a case study in the Municipality of Grosseto (Italy), highlighting the currently unexplored potential. The paper concludes with remarks on the contributions of the study and its limitations.

2. Materials and Methods

2.1. Data Collection and Emission Estimation

The estimation of the GHG emissions for both approaches—the current SECAP methodology for the BEI compilation and the IPCC guidelines—is based on an equation that links activity data and related environmental efficiency through specific emission factors, as follows in Equation (1):

$$Emissions = \sum_i Activity\ Data_i \times Emission\ Factor_i \quad (1)$$

Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emissions, the main GHG regulated by the Kyoto Protocol, were estimated applying Equation (1). All GHG emissions other than CO_2 were transformed into CO_2eq, using 100-year Global Warming Potentials (GWPs) published in the IPCC 6th Assessment Report (IPCC, 2021) (see Table S1 in Supplementary Material).

For the application at the sub-national level, activity data should be collected directly through a bottom-up approach whenever possible. The bottom-up approach consists of the collection of activity data referring directly to the considered context. Such data does not require any type of refinement or correction by virtue of comprehensiveness and coherence with the boundaries of the study. In the case study presented here, more than 60% of data was collected in this way, ensuring high estimation accuracy. When bottom-up information is not available, a top-down approach can be adopted by disaggregating and scaling down activity data referred to a larger scale (e.g., national, or regional), by means of proxies. In our analysis, we adopted this solution in the case of fuel and lubricant consumption (i.e., mobility, heating, and energy production for industrial activities, with the exception of natural gas use) as well as emission from soil (i.e., application of chemical fertilizers and crop residues) (see Table S2 in Supplementary Material). The emissions factors were mainly extrapolated from the 2006 and 2019 IPCC Guidelines and the Handbook of National Emissions Factors (see Table S2 for details). Emissions can be classified as direct and indirect. The former are an immediate consequence of an activity and happen when and where the activity occurs. For example, fuel combustion for heating generates direct emissions. The latter refer to any activity that does not generate emissions as the activity takes place, but emissions have been generated elsewhere and/or previously. For instance, the consumption of electricity imported form the national grid does not generate any emissions on site. However, that electricity flow might have been produced in a power plant fed by fuel combustion, therefore creating emission far away in space and time from the place where electricity is consumed. In our case, indirect emissions include: (i) electricity consumption imported from the national grid, (ii) methane emission from landfills located outside the municipal boundaries but receiving waste generated from within, and (iii) emissions from waste-to-energy plants incinerating waste generated within the municipal boundaries.

2.2. The Two Existing Approaches: BEI and IPCC Accounting Frameworks

The first version of the guidelines for BEI compilation was almost exclusively focused on the energy sector since it was meant to represent the basis upon which policy makers were called to design the Sustainable Energy Action Plan (SEAP), namely the document of key policy actions to be delivered according to the CoM [29] (Table 1). Accordingly, the guidelines focused on CO_2 emission—as the main GHG derived from energy production—overlooking other GHGs. The latest version of the guidelines, proposed in 2019 and used to design the SECAP, expanded the scope of the inventory in order to include energy activities previously excluded as well as activities from other sectors, also including N_2O and CH_4 [15]. However, many activities are still neglected or optional (Table 1).

Table 1. Activities to be included (I), excluded (E), or Optional (O) for the BEI compilation, according to the two versions of the guidelines. * Only transport entirely occurring within city boundaries, ** included in "Municipal buildings, equipment/facilities", *** Depending on the output power or input fuel.

Sectors and Sub-Sectors	Inclusion	
	Bertoldi et al. (2010) [29], following SEAP Guidelines	**Global Covenant of Mayors (2019) [15], following SECAP Guidelines**
Stationary energy		
Residential buildings	I	I
Commercial building and facilities	I	I
Institutional buildings and facilities	I	I
Industrial buildings and facilities (Non-ETS)	O	I
Industrial buildings and facilities (ETS)	E	I
Agriculture	I	I
Fugitive emissions	E	I
Transportation		

Table 1. *Cont.*

Sectors and Sub-Sectors	**Inclusion**	
	Bertoldi et al. (2010) [29], following SEAP Guidelines	**Global Covenant of Mayors (2019) [15], following SECAP Guidelines**
On-road	I *	I *
Rail	I *	I *
Highway transport	O	I *
Shipping/fluvial transport	E	I *
Local ferries	O	I *
High speed rail	O	I *
Aviation	E	I *
Off-road	O	I *
Waste		
Solid waste disposal	O	I
Biological treatment	Not Available	I
Incineration and open burning	**	I
Wastewater treatment and discharge	O	I
Industrial Process and Product Use (IPPU)		
Industrial Process (whether ETS or not)	E	O
Product Use	E	O
Agriculture, Forestry and Other Land Use (AFOLU)		
Livestock	E	O
Land use	E	O
Other AFOLU	E	O
Energy Generation		
Electricity-only generation (Non-ETS)	O	I
Electricity-only generation (ETS)	E	I
Cogeneration Heat and Power (CHP) generation	***	I
Heat/cold generation	I	I
Local renewable generation	***	O

The IPCC guidelines for national greenhouse gas inventories [23,30] stem from an all-encompassing approach including any kind of source of GHG emission and subdividing the sources according to the kind of physical or chemical reaction that causes each emission, regardless of the user [23] (Table 2). Accordingly, the guidelines impose the mandatory inclusion of all GHG emission besides CO_2.

Table 2. Summary of activities to be included into the inventory according to the IPCC guidelines.

Sectors and Sub-Sectors	
Energy	Agriculture, Forestry and Other Land Use (AFOLU)
Stationary combustion	Forest land
Mobile combustion	Cropland
Fugitive emissions	Grassland
Carbon dioxide transport, injection, and geological storage	Wetlands
Industrial Processes and Product Use (IPPU)	Settlements

Table 2. *Cont.*

Sectors and Sub-Sectors	
Mineral industry emissions	Other land
Chemical industry emissions	Emissions from livestock and manure management
Metal industry emissions	N_2O emissions from managed soils, and CO_2 emissions from lime and urea application
Non-energy products from fuels and solvent use	Harvested wood products
Electronics industry emissions	Waste
Emissions of fluorinated substitutes for ozone depleting substances	Solid waste disposal
Other manufacture and use	Biological treatment
	Incineration and open burning
	Wastewater treatment and discharge

2.3. The Case Study

The ductility of the GHG accounting method, also applicable to the sub-national level, is not always coupled with the institutionalization of this procedure. Our first aim is to operationalize the connection, operating the necessary adjustments and refinements in order to make the two approaches consistent with each other. The case study presented here focuses on the Municipality of Grosseto, located along the coast of the Tyrrhenian Sea in Tuscany, in central Italy for the year 2019. We chose 2019 since it is the most recent year for which all data is available and not affected by the COVID-19 pandemic effect. The Municipality of Grosseto has a population of 81,440 residents [31]. It is the largest municipality in Tuscany, whose territory covers 473,684,439 m^2, 57.4% of which is agricultural land, 19.8% is covered by forest, and 7.8% is covered by woody crops (fruit, olives, and vineyards). Urban settlement accounts for just 9.5% of the territory [32]. The municipality's economy is based on the service industry (e.g., retailers, tourism, and hospitality sector operators, especially along the coast) and on traditional agriculture. Besides cereals, sunflowers, vegetables, olives, and grapes, the territory is characterized by the Maremmana beef production and specific rice varieties. The industrial sector plays a minor role in this area [32].

The Municipality of Grosseto presents a variety of economic activities, including manufacturing enterprises, though without the presence of heavy industries, the latter being linked to GHG emission from industrial processes [23,30]. This does not limit the applicability of the proposed methodology, which is capable of fully capturing all the emission sectors as described in the IPCC guidelines [30]. We believe that in general it is unlikely that a municipality is characterized by the simultaneous presence of all the industrial activities with GHG emission from industrial processes (e.g., mineral, metallurgical, electronics, and chemical industries) and by agricultural activities due to the physical limits imposed by the administrative boundaries. Ultimately, this work stems from a partnership with the municipal administration, which provided comprehensive data, useful for the bottom-up representation of all the relevant activities in the territory. For the sake of brevity, we provide the complete description of the data sources utilized for both inventories without providing details about the underpinning theoretical framework since the guidelines are standardized. The sources include activity data and emission factors—namely, the two primary datasets necessary for the estimation of the emission in most categories, unless directly measured. The Supplementary material also provides details about any assumption made for the calculation (see Tables S1 and S2 in Supplementary Material).

3. Results

In 2019, the gross emission of the Municipality of Grosseto reached 395,125 t of CO_{2eq}; the forest area absorbed 67,551 t of CO_2, corresponding to 17% of the gross emission. The total net emission is therefore 327,574 t of CO_{2eq} (Tables 3 and 4). The results of the IPCC inventory are shown in Table 3, which includes all sources of emissions based on the underlying chemical, physical, and biological processes, as well as all the GHG emissions occurring in the territorial context under study. The energy sector alone covers 88% of the territorial GHG emission, with transport, heating, and imported electricity consumption activities accounting for the largest share within the sector, but also within the whole inventory. The emissions from the IPPU sector are absent. The waste sector reached 4% of the total gross emission (15,332 t of CO_{2eq}), with landfilling activities covering the largest part of such sector, and 3% over the whole inventory. The AFOLU sector accounted for 8% of the gross emission of the territory, equal to 32,060 t of CO_{2eq}, with enteric fermentation covering a remarkable part of the whole sector (and 5% of the total).

Table 3. Emission of the Municipality of Grosseto in 2019 partitioned according to the IPCC method. Totals might not match the sums due to rounding. In Table 3 the bule color indicates the total GHG emissions by sector, the green the CO2 uptake by local ecosystems and the orange the percentage abatement of gross emissions. The bold items highlight the main outputs.

Activity	CO_2 t CO_{2eq}	CH_4 t CO_{2eq}	N_2O t CO_{2eq}	Total t CO_{2eq}	Share %
Energy	**334,078**	**9861**	**3794**	**347,733**	**88%**
Transport	211,603	977	3583	216,163	55%
Heating	58,580	161	38	58,779	15%
Combustion for manufacturing and construction	8278	8	173	8459	2%
Waste-to-energy power generation	10,608			10,608	3%
Imported electricity consumption	45,005			45,005	11%
Biogas power plant		2485		2485	<1%
Fugitive emission	4	6230		6235	2%
Industrial processes and product use	**-**	**-**	**-**	**-**	**0%**
Waste		**13,467**	**1865**	**15,332**	**4%**
Solid waste disposal		12,955		12,955	3%
Composting		8	488	496	<1%
Biological treatment of solid waste		18	1065	1083	<1%
Wastewater treatment and discharge		487	311	798	<1%
AFOLU	**4730**	**22,449**	**4881**	**32,060**	**8%**
Loss of Carbon (wood withdrawals and fires)	4561			4561	1%
Urea application	168			168	<1%
Enteric fermentation		18,436		18,436	5%
Manure management		2.,50	240	2991	<1%
Agricultural soils			4561	4561	1%
Wetlands		417		417	<1%
Rice cultivation		846		846	<1%
Aquaculture			80	80	<1%
Total gross emission	**338,808**	**45,777**	**10,540**	**395,125**	**100%**
Absorption	**−67,551**			**−67,551**	
Total net emission				**327,574**	
% GHG on total emission	**83%**	**14%**	**3%**	**100%**	
Absorption share				**17%**	

Table 4. Emission of the Municipality of Grosseto in 2019 partitioned according to the BEI guideline. Totals might not match the sums due to rounding. In Table 4 the green color indicates the mandatory emissions sources to be accounted and the blue color indicates the optional ones. The bold items highlight the main outputs.

Sectors and Sub-Sectors	Direct Emissions			Indirect Emissions			Total	% on Total
	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O		
	t CO_{2eq}	t CO_{2eq}	t CO_{2eq}	t CO_{2eq}	t CO_{2eq}	t CO_{2eq}	t CO_{2eq}	%
Stationary energy	**66,862**	**6399**	**211**	**45,004**	**0**	**0**	**118,476**	**30%**
Residential buildings	27,265	75	18	17,832			45,189	11%
Commercial building and facilities	9046	25	6	15,091			24,168	6%
Institutional buildings and facilities	15,080	41	10	3705			18,835	5%
Industrial buildings and facilities	14,561	25	177	5486			20,250	5%
Agriculture	907	2	1	2890			3800	1%
Fugitive emissions	4	6230					6235	2%
Transportation	**211,603**	**977**	**3583**	**1**	**0**	**0**	**216,163**	**55%**
On-road	181,474	928	675	1			183,078	46%
Rail								0%
Waterborne navigation	972	3	7				982	<1%
Aviation	1760	0	13				1774	<1%
Off-road	27,397	46	2887				30,329	8%
Waste		**512**	**1865**		**12,955**		**15,332**	**4%**
Solid waste disposal					12,955		12,955	3%
Biological treatment		26	1554				1579	<1%
Incineration and open burning								0%
Wastewater treatment and discharge		487	311				798	<1%
Industrial Process and Product Use (IPPU)								**0%**
Industrial Process								0%
Product Use								0%
Agriculture, Forestry and Other Land Use (AFOLU)	**−62,821**	**22,449**	**4881**				**−35,491**	
Livestock		21,186	320				21,506	5%
Land use	168	1263	4561				5993	2%
Other AFOLU	−62,989						−62,989	
Energy Generation		**2485**		**10,608**			**13,093**	**3%**
Electricity-only generation				10,608			10,608	3%
Cogeneration Heat and Power (CHP) generation								0%
Heat/cold generation								0%
Local renewable generation		2485					2485	1%
Total net emission	**215,644**	**32,822**	**10,540**	**55,613**	**12,955**	**0**	**327,574**	
Absorption	**−67,551**						**−67,551**	
Total gross emission							**395,125**	
Absorption share							**−17%**	
Total mandatory				**91%**				
Total optional				**9%**				

The GHG emission inventory for the Municipality of Grosseto was then elaborated according to the BEI compilation guidelines, including both mandatory and optional categories [15] (Table 1). We sourced user-side information (e.g., municipal fleet consumption or institutional building heating fuel consumption) to satisfy the data requirement of the BEI. The emission estimated through the IPCC guidelines were redistributed to match the sub-division required by the BEI according to SECAP guidelines and implementing an integrated approach of both accounting methodologies (Figure 1). Moreover, all GHG generated in the territorial context have been included in the inventory. Accordingly, not only CO_2, but also N_2O and CH_4 emission were accounted for (Table 4). We considered the difference between direct emissions deriving from on-site activities, such as fuel burning for heating in buildings, and indirect ones deriving from the consumption in buildings of the electricity imported form the national grid, and the impacts of solid waste generated within the municipality but disposed in a landfill outside its boundaries.

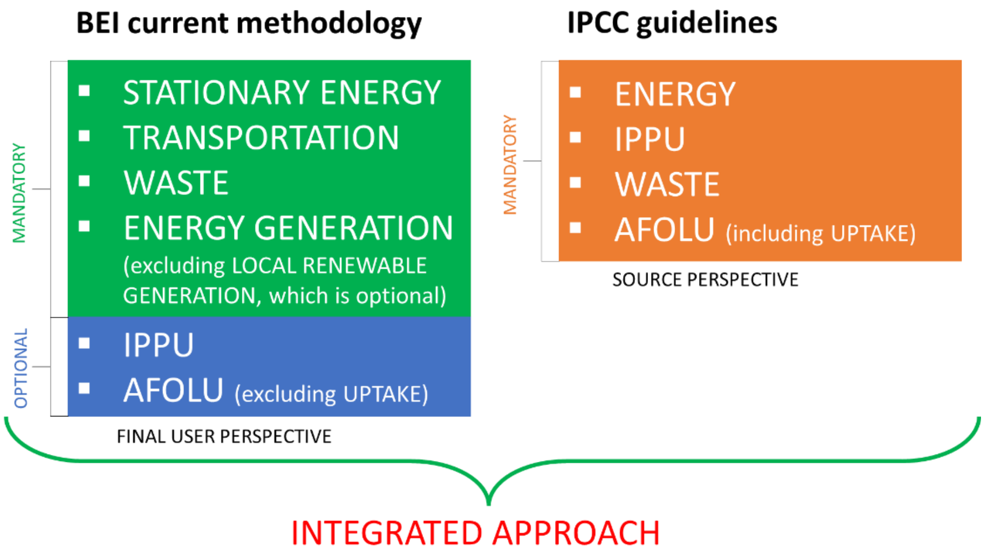

Figure 1. Integrated approach of BEI compilation guidelines and IPCC methodology.

Transport covered most of the GHG emission (216,163 t of CO_{2eq}), with on-road transport accounting for the largest part (46%). Stationary energy was the second largest GHG emission sector, covering 30% of the total gross emission, with residential buildings accounting for the largest part (11%, 45,189 t of CO_{2eq}). Energy generation covered 3% of the overall gross emission with electricity-only and local renewables covering ≈3% and ≈1% of the total inventory (Table 4).

By merely comparing the classification differences between the two methods (Tables 1 and 2) it is immediately possible to observe that the BEI follows an approach that aims at highlighting the final user's responsibility for the emission whereas the IPCC's one tends to highlight the physical sources of the emission. This limits the possibility to directly compare the two results. At the same time, the comparison between emissions from mandatory and optional activities enables to notice that the exclusion of the latter would lead to an underestimation of up to 9% of the total gross emission (~36 kt CO_{2eq}) (Tables 3 and 4).

Moreover, the compensation potential of the territorial context would be overlooked if the AFOLU sector is not included. This leads to the provision of an incomplete picture of the emissive status of the territory and, specifically in the case of CO_2 fixation, it would lead to missed opportunities in terms of a nature-based solution. In the case of the Municipality of Grosseto, the CO_2 fixation provided by the areas covered by vegetation grants the reduction of the gross emission of about ~17%, which is a remarkable amount.

Despite the most recent update of the scope of the BEI found in the compilation guidelines includes GHGs other than just the CO_2 and sectors other than just energy, the implementation of such guidelines will only affect inventories compiled after 2019. Indeed, most municipalities, which became GCoM signatories before 2019, have compiled a BEI with reduced scopes, meaning that a large amount of emission was not accounted for, and, in turn, the corresponding large potential for mitigation strategies is not exploited. For example, only 15 out of 5576 signatories of the GCoM reported IPPU emission [33]. While clearly not all municipalities are characterized by the presence of production plants with direct process emission, it is out of question that more than 15 are. At the same time, a large amount of municipalities' efforts—despite compliant with the guidelines in force at the time of signature of the covenant—are limited since they overlook GHGs other than CO_2.

4. Discussion

This work demonstrates the feasibility and potential of implementing an integrated approach of both accounting methodologies where the comprehensiveness of the IPCC guidelines is fully kept, though adjusted to the criteria of the BEI, to provide richer information (Table 4). A sub-national inventory compiled following the IPCC guidelines captures, per se, a broader amount of emission sources, including all the commonly optional or excluded activities in a BEI. This represents the first improvement of the current state of the art regarding BEI compilation practices. However, such kind of inventory cannot be used—directly—as BEI since the IPCC categorization of the emissions significantly differs from the one required by the BEI guidelines. Therefore, an intermediate passage is required to fully exploit the potential of such integration. This passage is necessary but feasible: in fact, as we showed (Tables 3 and 4) no further calculation is required. Rather, a different way of allocating, synthesizing, and presenting the results of the calculations previously performed is required, including the ones for the activities that are commonly excluded or optional.

The local-scale GHG accounting practice presents a significant fragmentation. Such a situation derives from a lack of a general (or global) agreement on the reporting framework, the related approach, rules, methodology, and, finally, scope. This is also due to lack of temporal consistency among the various versions of the guidelines.

Whilst the assumptions to be made might be strongly driven by the data quality and availability, we believe that a common standard for the methodology and the scope should be identified, agreed on, and applied. We acknowledge that the original objective of the former CoM initiative, and related SEAP, was to focus on the energy sector and, thus, the methodology and scope were designed as energy sector-centered. However, a shift from a single-sector inventory approach to a complete inventory would provide multiple advantages.

In particular, we believe that the more recent GCoM initiative could lead a world-wide comprehensive bottom-up monitoring and mitigation action, although its framework still needs to be improved to ensure an enhanced effectiveness of the initiative. The possible improvement pathway follows two main directions: (i) the expansion of the scope of the activities included in the BEI to ensure that all the sources and sinks of emission are captured and liable to mitigation action and (ii) the expansion of the set of GHGs to be included in the BEI. Indeed, currently, most of the signatories compiled the BEI—and designed related policies—following the outdated guidelines [34]. This means that the emissive situation depicted by such BEIs might overlook a large part of the emissions and, therefore, municipalities might miss the opportunity of mitigating emissions because of such still unexplored potential.

The improvement of the framework would ensure the provision of a comprehensive picture of the emissive status of the municipality studied. The inclusion of the AFOLU and IPPU sectors would expand the possible actions to be implemented and, therefore, the possible attainable reduction. For the AFOLU sector, this would mean the inclusion of some of the most important sources of N_2O and CH_4. In particular, agriculture alone covers more than half global non-CO_2 GHG emissions, and therefore, it can stimulate strategical mitigation measures [35–41], especially in areas in which this sector is prevalent. Mitigating actions focusing on CH_4 are extremely relevant now since the emissions are raising faster than ever [42], driving climate change [43] and, in turn, representing a hot spot for actions [44]. In addition, acting on soil, through carbon sequestration, represents another powerful and effective mitigation effort [45].

As such, agriculture should cover a role of primary importance in the context of local mitigation initiatives like the GCoM. Moreover, the inclusion of the IPPU sector would ensure that the related GHG emission reduction derives not only from interventions on the energetic efficiency of the processes, but also on the technological development, able to either avoid direct emission, reduce, or recover them [46]. Accordingly, excluding ETS activities from the BEI (and, in turn, from the GCoM) would not only lead to an underestimation of the GHG emission status of the municipality considered, but it would exclude the associated energy-related GHG emission from possible municipality-led mitigation actions through the mere GCoM, even if the latter currently accounts only for energy-related emission. Furthermore, by including the IPPU sector, the direct industrial processes' non-energy GHG emission (e.g., due to chemical reactions) would be captured and could be subject to municipality efforts towards emission mitigation. This refers not only to the production plants that fall under ETS regulations, but also to all production plants that have process emission (e.g., small size installations [47]). Mitigation efforts of this kind could stem from different types of actions promoted by the local administrations. Among them are awareness campaigns, the creation (and following promotion, support, and development) of consortia or alliances among individual private companies who engage in a mitigating effort. Such effort could then be acknowledged and used for marketing purposes.

In the case of the EU, this improvement could also enhance Member States' capacity to identify mitigating actions for the agricultural sector, enabling them to match the national target attributed by the Effort Sharing Regulation [48]. Nevertheless, comprehensive carbon accounting is essential to ensure the design of effective actions [49]. Finally, municipality-scale footprints are powerful tools to assess their sustainability in terms of Sustainable Development Goals (SDGs) [50].

The IPCC methodology can be applied with success on the sub-national scale, as it has been demonstrated in many studies developed [51–55]. Specifically, this study demonstrated that it is possible to compile a complete GHG inventory by following the IPCC guidelines at the municipal scale also. We showed that it is feasible for a local administrative body to take care of this kind of environmental accounting. This accounting procedure is repeatable in a systematic fashion to be performed possibly even through the creation of an ad hoc office. It would represent an operation remarkably helpful, especially in terms of mitigating actions. Indeed, administrative bodies endowed with this kind of tool would be able to enhance their capacity to design local policies on one hand by relying on detailed and accurate estimates and, on the other hand, by relying on knowledge of the territory typical of people who experience it and impossible to obtain by national governments, utilizing national aggregate data. The joint vision provided by the proposed approach generates a comprehensive knowledge of the emissive status of the analyzed territory and allows the development of more punctual policies that can act on multiple emitting sectors.

As a final remark, for territories with a developed touristic sector, it would be significant to distinguish between the impacts (direct or indirect) attributable to such a sector and the impacts not related to tourisms. While this is not possible at the moment, a time series analysis performed through a systematic periodical compilation of a municipality-scale GHG inventory—facilitated by the institutionalization of the method here proposed—together with the collection of specific data on touristic activities (either already available or to be specifically produced) could allow us to investigate existing relationships between emissions and tourism, designing mitigation actions accordingly. This could be generalized for any key-sector identified through the application of the proposed method.

5. Conclusions

This study proposes a modification of the current mainstream approach for the GHG accounts at a municipality-level. By juxtaposing a BEI with a complete municipality-scale GHG inventory compiled according to the IPCC guidelines, it is possible to provide additional information to policy-makers through the point of view of the sources of emission. Together with the user's perspective provided by the inventories compiled according to the GCoM guidelines, this advancement would ensure higher informative potential and support for the municipalities' SECAP. Furthermore, the inclusion of the currently excluded GHG or activities would make it possible to derive more effective mitigation policies, fostering the collaboration between the public and private sector. This should be the aim of municipalities that joined the covenant before the release of the latest, more comprehensive, guidelines. In addition, it would make it possible to obtain more information not only at a small-scale but also at the regional scale through the aggregation of various BEIs. This would, in turn, enable possible policy actions at higher territorial levels, maintaining high data resolution. Ultimately, a systematic application of the proposed method could provide insights for key-sectors that cannot easily be studied and managed as elements isolated from the others.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su15010125/s1, Table S1: The Global Warming Potential (GWP) used to convert GHG into CO_2eq—values retrieved from the IPCC Sixth Assessment Report.; Table S2: Activity data and emission factors sources for the Municipality of Grosseto.

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References

1. Pasimeni, M.R.; Valente, D.; Zurlini, G.; Petrosillo, I. The Interplay between Urban Mitigation and Adaptation Strategies to Face Climate Change in Two European Countries. *Environ. Sci. Policy* **2019**, *95*, 20–27. [CrossRef]
2. IPCC. *AR5 Synthesis Report: Climate Change 2014*; IPCC: Geneva, Switzerland, 2014.
3. IPCC. *Climate Change 2021—The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report 2021*; IPCC: Geneva, Switzerland, 2021.
4. Robiou du Pont, Y.; Meinshausen, M. Warming Assessment of the Bottom-up Paris Agreement Emissions Pledges. *Nat. Commun.* **2018**, *9*, 4810. [CrossRef] [PubMed]
5. EU Parliament. *Council of the European Union Regulation (EU) 2018/842 of the European Parliament and of the Council of 30 May 2018 on Binding Annual Greenhouse Gas Emission Reductions by Member States from 2021 to 2030 Contributing to Climate Action to Meet Commitments under the Paris Agreement and Amending Regulation (EU) No 525/2013*; EU Parliament: Strasbourg, France, 2018.
6. UNFCCC. *Nationally Determined Contributions under the Paris Agreement—Synthesis Report by the Secretariat 2021*; UNFCCC: Bonn, Germany, 2021.
7. FAO. *FAO Strategy on Climate Change 2017*; FAO: Rome, Italy, 2017.
8. GEF. *Reflecting on 30 Years of the GEF*; GEF Secretariat: Washington, DC, USA, 2021; ISBN 978-1-948690-89-8.
9. Earth-Mates Dialogue Center (EMDC). *The Muslim 7-Year Action Plan (M7YAP) to Deal with Global Climate Change 2009*; Earth-Mates Dialogue Center (EMDC): London, UK, 2009.
10. European Commission. *Sustainable Energy Cities Take the Lead on Climate Change: The European Commission Launches the Covenant of Mayors*; IP/08/103; European Commission: Brussels, Belgium, 2008.
11. European Commission. *Commission Joins Forces with European Cities to Promote Urban Adaptation to Climate Change*; MEMO/14/200; European Commission: Brussels, Belgium, 2014.

12. European Commission. *Cities Unite for Energy and Climate Action: New Integrated Covenant of Mayors Launch*; European Commission: Brussels, Belgium, 2015.
13. United Nations. *Mayors at UN Climate Summit Announce Pledges towards Major Carbon Cuts in Cities*; UN: New York, NY, USA, 2014.
14. European Commission. *EU Covenant of Mayors and Compact of Mayors Launch Largest Global Coalition of Cities Committed to Fighting Climate Change*; IP/16/2247; European Commission: Brussels, Belgium, 2016.
15. Global Covenant of Mayors Explanatory Note Accompanying the Global Covenant of Mayors Common Reporting Framework . 2019. Available online: https://www.globalcovenantofmayors.org/wp-content/uploads/2019/04/Data-TWG_Reporting-Framework_GUIDANCE-NOTE.pdf (accessed on 9 September 2022).
16. Ritchie, H.; Roser, M. *CO_2 and Greenhouse Gas Emissions*; Our World in Data: Oxford, UK, 2020.
17. Neves, A.; Blondel, L.; Brand, K.; Hendel Blackford, S.; Rivas Calvete, S.; Iancu, A.; Melica, G.; Koffi Lefeivre, B.; Zancanella, P.; Kona, A. *The Covenant of Mayors for Climate and Energy Reporting Guidelines*; Climate-ADAPT: Luxembourg, 2016.
18. Arioli, M.S.; de Almeida D'Agosto, M.; Amaral, F.G.; Cybis, H.B.B. The Evolution of City-Scale GHG Emissions Inventory Methods: A Systematic Review. *Environ. Impact Assess. Rev.* **2020**, *80*, 106316. [CrossRef]
19. Landholm, D.M.; Pradhan, P.; Wegmann, P.; Sánchez, M.A.R.; Salazar, J.C.S.; Kropp, J.P. Reducing Deforestation and Improving Livestock Productivity: Greenhouse Gas Mitigation Potential of Silvopastoral Systems in Caquetá. *Environ. Res. Lett.* **2019**, *14*, 114007. [CrossRef]
20. Kistowski, M.; Wiśniewski, P. Regionalisation of Needs to Reduce GHG Emission from Agriculture in Poland. *Geogr. Pol.* **2020**, *93*, 361–376. [CrossRef]
21. IPCC. *Climate Change and Land. An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems*; IPCC: Geneva, Switzerland, 2020.
22. ICAP. *Emission Trading Worldwide—Report 2021*; ICAP: Berlin, Germany, 2021.
23. IPCC. *IPCC 2006 Guidelines for National Greenhouse Gas Inventories*; Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T., Tanabe, K., Eds.; IGES: Kanagawa, Japan, 2006; ISBN 4-88788-032-4.
24. Mottet, A.; Henderson, B.; Opio, C.; Falcucci, A.; Tempio, G.; Silvestri, S.; Chesterman, S.; Gerber, P.J. Climate Change Mitigation and Productivity Gains in Livestock Supply Chains: Insights from Regional Case Studies. *Reg. Environ. Chang.* **2017**, *17*, 129–141. [CrossRef]
25. Henderson, B.B.; Gerber, P.J.; Hilinski, T.E.; Falcucci, A.; Ojima, D.S.; Salvatore, M.; Conant, R.T. Greenhouse Gas Mitigation Potential of the World's Grazing Lands: Modeling Soil Carbon and Nitrogen Fluxes of Mitigation Practices. *Agric. Ecosyst. Environ.* **2015**, *207*, 91–100. [CrossRef]
26. Herrero, M.; Henderson, B.; Havlík, P.; Thornton, P.K.; Conant, R.T.; Smith, P.; Wirsenius, S.; Hristov, A.N.; Gerber, P.; Gill, M.; et al. Greenhouse Gas Mitigation Potentials in the Livestock Sector. *Nat. Clim. Chang.* **2016**, *6*, 452–461. [CrossRef]
27. Havlík, P.; Valin, H.; Herrero, M.; Obersteiner, M.; Schmid, E.; Rufino, M.C.; Mosnier, A.; Thornton, P.K.; Böttcher, H.; Conant, R.T.; et al. Climate Change Mitigation through Livestock System Transitions. *Proc. Natl. Acad. Sci. USA* **2014**, *111*, 3709–3714. [CrossRef]
28. Schleussner, C.-F.; Lissner, T.K.; Fischer, E.M.; Wohland, J.; Perrette, M.; Golly, A.; Rogelj, J.; Childers, K.; Schewe, J.; Frieler, K. Differential Climate Impacts for Policy-Relevant Limits to Global Warming: The Case of 1.5 C and 2 C. *Earth Syst. Dyn.* **2016**, *7*, 327–351. [CrossRef]
29. Bertoldi, P.; Bornás Cayuela, D.; Monni, S.; Ronald, P.d.R. *Guidebook "How to Develop a Sustainable Energy Action Plan (Seap)"*; European Commission: Luxembourg, 2010.
30. IPCC. *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*; IPCC: Geneva, Switzerland, 2019.
31. ISTAT. Resident Population on 1st January. 2022. Available online: http://dati.istat.it (accessed on 13 September 2022).
32. *Comune di Grosseto Monitoraggio Delle Emissioni di Gas Serra del Comune di Grosseto*; University of Siena, Ecodynamics Group: Siena, Italy, 2017.
33. GCoM Our Cities. 2022. Available online: https://Www.Globalcovenantofmayors.Org/Our-Cities/ (accessed on 9 September 2022).
34. CoM Plans & Actions. 2022. Available online: https://Www.Covenantofmayors.Eu/Plans-and-Actions/Action-Plans.Html (accessed on 9 September 2022).
35. Beach, R.H.; Creason, J.; Ohrel, S.B.; Ragnauth, S.; Ogle, S.; Li, C.; Ingraham, P.; Salas, W. Global Mitigation Potential and Costs of Reducing Agricultural Non-CO_2 Greenhouse Gas Emissions through 2030. *J. Integr. Environ. Sci.* **2015**, *12*, 87–105. [CrossRef]
36. Gerber, J.S.; Carlson, K.M.; Makowski, D.; Mueller, N.D.; Garcia de Cortazar-Atauri, I.; Havlík, P.; Herrero, M.; Launay, M.; O'Connell, C.S.; Smith, P.; et al. Spatially Explicit Estimates of N2O Emissions from Croplands Suggest Climate Mitigation Opportunities from Improved Fertilizer Management. *Glob. Chang. Biol.* **2016**, *22*, 3383–3394. [CrossRef] [PubMed]
37. Johnson, J.M.-F.; Franzluebbers, A.J.; Weyers, S.L.; Reicosky, D.C. Agricultural Opportunities to Mitigate Greenhouse Gas Emissions. *Environ. Pollut.* **2007**, *150*, 107–124. [CrossRef] [PubMed]
38. Smith, P.; Martino, D.; Cai, Z.; Gwary, D.; Janzen, H.; Kumar, P.; McCarl, B.; Ogle, S.; O'Mara, F.; Rice, C.; et al. Greenhouse Gas Mitigation in Agriculture. *Phil. Trans. R. Soc.* **2008**, *363*, 789. [CrossRef]

39. Charkovska, N.; Horabik-Pyzel, J.; Bun, R.; Danylo, O.; Nahorski, Z.; Jonas, M.; Xiangyang, X. High-Resolution Spatial Distribution and Associated Uncertainties of Greenhouse Gas Emissions from the Agricultural Sector. *Mitig. Adapt. Strateg. Glob. Chang.* **2019**, *24*, 881–905. [CrossRef]
40. Tesfaye, K.; Takele, R.; Sapkota, T.B.; Khatri-Chhetri, A.; Solomon, D.; Stirling, C.; Albanito, F. Model Comparison and Quantification of Nitrous Oxide Emission and Mitigation Potential from Maize and Wheat Fields at a Global Scale. *Sci. Total Environ.* **2021**, *782*, 146696. [CrossRef]
41. Gurung, R.B.; Ogle, S.M.; Breidt, F.J.; Parton, W.J.; Del Grosso, S.J.; Zhang, Y.; Hartman, M.D.; Williams, S.A.; Venterea, R.T. Modeling Nitrous Oxide Mitigation Potential of Enhanced Efficiency Nitrogen Fertilizers from Agricultural Systems. *Sci. Total Environ.* **2021**, *801*, 149342. [CrossRef]
42. Tollefson, J. Scientists Raise Alarm over'dangerously Fast'growth in Atmospheric Methane. *Nature* **2022**. [CrossRef]
43. UNEP. *Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions*; UNEP: Kenya, Nairobi, 2021.
44. Nature Control Methane to Slow Global Warming—Fast. *Nature* **2021**, *596*, 461. [CrossRef]
45. Amelung, W.; Bossio, D.; de Vries, W.; Kögel-Knabner, I.; Lehmann, J.; Amundson, R.; Bol, R.; Collins, C.; Lal, R.; Leifeld, J.; et al. Towards a Global-Scale Soil Climate Mitigation Strategy. *Nat. Commun.* **2020**, *11*, 5427. [CrossRef]
46. Miller, S.A.; Habert, G.; Myers, R.J.; Harvey, J.T. Achieving Net Zero Greenhouse Gas Emissions in the Cement Industry via Value Chain Mitigation Strategies. *One Earth* **2021**, *4*, 1398–1411. [CrossRef]
47. European Commission. EU Emissions Trading System (EU ETS). 2022. Available online: https://ec.europa.eu/clima/eu-action/eu-emissions-trading-system-eu-ets_en (accessed on 7 November 2022).
48. European Commission. *Questions and Answers—The Effort Sharing Regulation and Land, Forestry and Agriculture Regulation—QANDA/21/3543*; European Commission: Brussels, Belgium, 2021.
49. Keith, H.; Vardon, M.; Obst, C.; Young, V.; Houghton, R.A.; Mackey, B. Evaluating Nature-Based Solutions for Climate Mitigation and Conservation Requires Comprehensive Carbon Accounting. *Sci. Total Environ.* **2021**, *769*, 144341. [CrossRef] [PubMed]
50. Wiedmann, T.; Allen, C. City Footprints and SDGs Provide Untapped Potential for Assessing City Sustainability. *Nat. Commun.* **2021**, *12*, 3758. [CrossRef] [PubMed]
51. Marchi, M.; Jørgensen, S.E.; Pulselli, F.M.; Marchettini, N.; Bastianoni, S. Modelling the Carbon Cycle of Siena Province (Tuscany, Central Italy). *Ecol. Modell.* **2012**, *225*, 40–60. [CrossRef]
52. Marchi, M.; Niccolucci, V.; Pulselli, R.M.; Marchettini, N. Environmental Policies for GHG Emissions Reduction and Energy Transition in the Medieval Historic Centre of Siena (Italy): The Role of Solar Energy. *J. Clean. Prod.* **2018**, *185*, 829–840. [CrossRef]
53. Bastianoni, S.; Marchi, M.; Caro, D.; Casprini, P.; Pulselli, F.M. The Connection between 2006 IPCC GHG Inventory Methodology and ISO 14064-1 Certification Standard—A Reference Point for the Environmental Policies at Sub-National Scale. *Environ. Sci. Policy* **2014**, *44*, 97–107. [CrossRef]
54. Arora, R.U. Inequality in Carbon Emissions at Sub-National Level in India. *J. Dev. Areas* **2014**, *48*, 383–397. [CrossRef]
55. Clarke-Sather, A.; Qu, J.; Wang, Q.; Zeng, J.; Li, Y. Carbon Inequality at the Sub-National Scale: A Case Study of Provincial-Level Inequality in CO_2 Emissions in China 1997–2007. *Energy Policy* **2011**, *39*, 5420–5428. [CrossRef]