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THE PADANIAN LIMES

SPATIAL INTERPRETATION OF LOCAL GHG EMISSION DATA

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ABSTRACT

The relevant role of spatial planning in the enforcement of climate change mitigation, managing the development of new low-carbon infrastructures and increasing system-wide efficiencies across sectors, has been addressed at global level (IPCC, 2014 WGIII). In this context, local GHG inventories appear a relevant tool toward the definition of a coherent, inter-sectorial background for local planning, mitigation, and adaptation policies.
Taking advantage of consistent GHG emissions data availability in the Lombard context, local maps of direct GHG emissions have been linked with geographic data – produced and organized within the research PRIN 2007 *From metropolitan city to metropolitan corridor: the case of the Po Valley Corridor* – including municipal boundaries, population data, and land-use information.
The results of this mapping exercise have been evaluated on the background of consolidated knowledge about northern Italy urban patterns, including the Linear Metropolitan System – LiMeS – and preliminary observations about characteristics, potential, and limits of the tool are proposed.

KEYWORDS:
local carbon emissions inventories, GHG accounting, climate change mitigation.

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帕达尼亚 LIMES

对当地温室气体排放数据的空间解读

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摘要

空间规划在执行气候变化缓解政策、管理新低碳础设施的发展以及提高全系统效率中的相关作用已获得了全球层面的阐述 (IPCC, 2014 WGIII). 在这个背景下, 当地温室气体清单变成为当地的规划, 缓解和适应政策确定连贯, 跨部门背景的相关工具. 通过利用伦巴第环境中统一温室气体排放数据的可用性, 直接温室气体排放的本地示意图已与名为 从大都市到都市走廊:波河流域走廊案例分析 的 PRIN 2007 研究所产生和整理的地理数据相联系, 其中包括城市边界, 人口数据和土地利用信息. 本次图上演示的结果已在意大利南部城市形态的巩固知识的背景下进行了评, 其中包括线性都市系统“LiMeS”, 并提出了对这个工具的特征,潜力和限制的初步观察.

关键词
当地碳排放清单, 温室气体核算, 气候变化缓解

1 INTRODUCTION

The present effort in climate modelling, including global greenhouse gases (GHG) monitoring and accounting, is unprecedented in human history. The establishment of a global carbon budget, aimed at keeping the increase of global temperature within 2-Celsius degrees above pre-industrial levels, has deep economical, social and political implications. Therefore, carbon accounting methodologies are catalysing a growing attention from the most diverse disciplinary sectors.

The atmospheric carbon balance is only one of the key components of the global dynamic equilibrium: biodiversity, stratospheric ozone, nitrogen and phosphorous cycles represent other domains in which human action must be contained within global limits. However, what makes the concentration of GHG peculiar among global limiting factors is its pervasive influence on almost all natural and anthropogenic systems.

Rising the concentration of carbon dioxide and other greenhouse gases in the atmosphere we do not only increase the global temperature and its burden of perilous consequences, but we are notably reducing the dispersion of *entropy* toward the cold sink of outer space through thermal infrared irradiation, thus affecting the efficiency of almost every process occurring within the biosphere. Furthermore, anthropogenic climate change stands apart from all the environmental issues we have faced so far because we are challenging a global, pervasive limit that involves significant changes in all aspects of human activity, at least as long as our energy system is mainly supported by the use of fossil fuels.

The analysis and interpretation of GHG emissions values poses unique challenges since emissions are produced by a very large number of processes and the hyper-connected structure of our economy, as well as the role of technological evolution, should always be carefully considered.

At urban scale the multi-dimensional nature of the energy issue, which is deeply connected with carbon emissions, has been underlined and the limits of sectorial approaches have been described, in contrast with the need of quantitative, holistic studies (Papa, Gargiulo, Zucaro, 2014b). In this perspective, local carbon emissions inventories can represent a pertinent analytical instrument. However, cities and regions are open systems and, since the relative weight of the energy and material flows exchanged by local systems through their boundaries tends to increase as the scale of the system decreases, preparation and interpretation of local inventories pose several challenges that have to be properly addressed (Pezzagno, Rosini, 2014).

Under these premises, the present contribution is mainly aimed at summarizing the methodologies adopted for developing carbon inventories at local scale and at revising the main approaches adopted for addressing the 'responsibility problem'. A mapping exercise on the LiMeS urban system in Northern Italy, based on existing GHG emissions datasets, is then presented in order to discuss the relevance, the possible applications, and the limits of the tool.

Recent experiences have shown how the preparation and certification of local GHG inventories, together with the co-operation between academic, legislative and administrative organizations, are important points for a sustainable management of an administrative jurisdiction, providing positive environmental effects (Bastianoni, Marchi, Caro, Casprini, Pulselli, 2014).

In this context, the spatial mapping of coherent time series of carbon emissions data, including the analysis of sectorial emissions in relationship with land-use classes, can provide further insights and could be positively adopted as a significant reference for spatial planning and local decision-making.

2 CARBON ACCOUNTING AT LOCAL SCALE: GENERAL REMARKS

Anthropogenic greenhouse gases represent a peculiar category of pollutants: they affect the global ecosystem independently from their point of emission[1], while their direct effect on local ecosystems can often be considered negligible, like in the case of carbon dioxide. Furthermore, their generation is commonly

[1] This is not true for some categories of climate-influencing pollutants like black carbon (IPCC, 2014a).

connected with the production of electric power or goods that can be exported and consumed far away from the site of production. A local reduction of emissions – achieved, for example, by relocating an industrial facility in another region – can paradoxically represent an *increase* in global emissions, determined by the added relocation and transport costs (i.e. the emissions generated for building the new infrastructure and transporting the goods back to the original market).

For this reason, the theme of GHG emissions *responsibility* in open economies represents a complex and relevant topic that has been already discussed since in the earlier stages of development of carbon accounting methodologies (Munksgaard, Pedersen, 2001), when it soon became clear that the problem of properly assigning the liability for carbon emissions represents a primary issue at sub-national and local scales (Bastianoni, Pulselli, Tiezzi, 2004).

Producers and consumers, importers and exporters can be always considered co-responsible, and two main approaches have been proposed in order to solve the liability dilemma: the geographical (or producer-responsibility) and the consumer-responsibility approach, which will be summarized and commented in the next paragraph. Another major difficulty, when dealing with local inventories of greenhouse gases, is then represented by the fact that the relationship between the reduction of emissions and the overall performance, the health, and the resilience of local systems is not necessarily linear. With regard to the significance of local carbon emissions inventories at local scale for spatial planning, it is worth noting that GHG emissions can be, in the first place, considered as an *entropy-proxy*: a general representation of local processes energy-intensity. In this perspective, local carbon emission inventories can be used as a tool to discuss the efficiency and the evolutionary trajectories of cities and local systems with reference to their production of entropy, in the perspective proposed by Fistola and La Rocca (2014).

Furthermore, GHG emissions are strongly related with the dense idea of urban *resilience*.

The complex concept of resilience has been proposed as logic and semantic pivot for addressing climate change at local and urban level (Galderisi, Ferrara, 2012), including both mitigation and adaptation strategies. Indeed, although a differentiation between mitigation measures, aimed at reducing GHG emissions, and adaptation measures, aimed at adjusting natural or human systems in response to actual or expected climatic stimuli or their effects is widely adopted, it is worth noting that these concepts are deeply interconnected and should never be considered as independent. This observation is only apparently basic, and has relevant consequences when considering the role of spatial planning at regional and local scale for tackling anthropogenic climate change and its consequences.

While the importance of spatial planning is evident when dealing with *adaptation* policies for enhancing the resilience of infrastructures, ecosystems, and economies (IPCC, 2014, WGII), the role of urban and regional planning has been clearly addressed as pivotal[2] in the enforcement of Climate Change Mitigation (i.e. reduction of local GHG emissions, development of low-carbon infrastructures) only recently.

The relevance of cities as *loci* of energy consumption and GHG emission has been clearly underlined, since urban areas account for between 71 % and 76 % of CO2 emissions from global final energy use (IPCC, 2014, WGIII), but satisfactory models and practices for tackling mitigation at urban level still appear in their early stages of development (Papa, Gargiulo, Zucaro, 2014a).

This is hardly surprising: it's difficult to separate, to clearly distinguish the city from the evolving background of the entire human activity. In particular, as we recognize the fundamental importance of technological evolution (in power generation, industrial processes, transport, etc.), it appears quite natural to expect that cities could just follow the stream of technological innovation, progressively adopting better solutions as in the case of mitigation policies based on buildings energy-efficiency.

2 As pointed out in IPCC AR5 - WGIII, Chapter 12, the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC, 2007) did not have a chapter on human settlements or urban areas. Urban areas were addressed through the lens of individual sector chapters. Since the publication of AR4, there has been a growing recognition of the significant contribution of urban areas to GHG emissions, their potential role in mitigating them, and a multi-fold increase in the corresponding scientific literature.

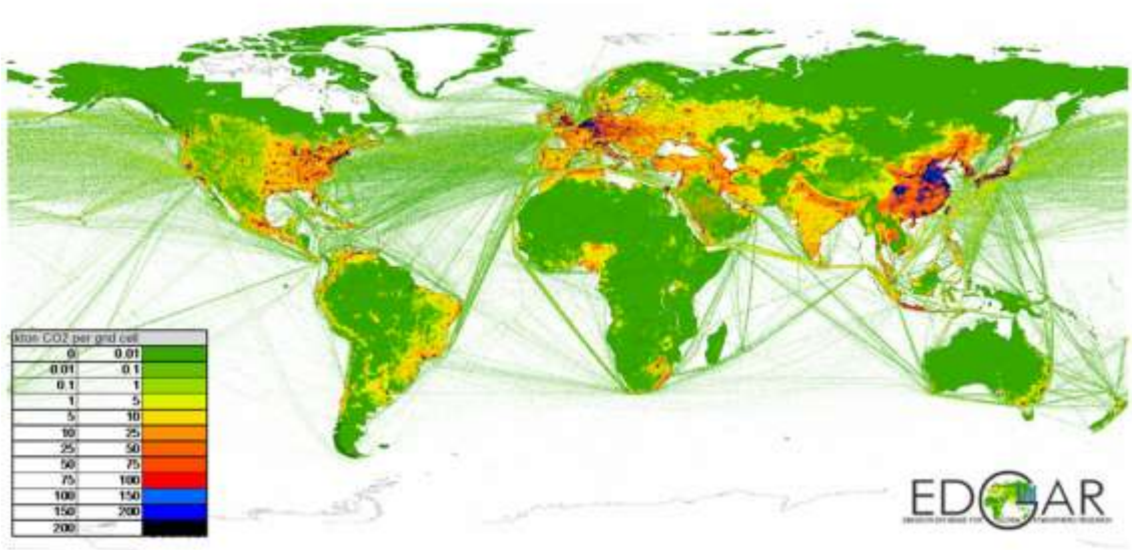

Fig. 1 Global gridded carbon dioxide emissions from fossil fuel and other anthropogenic direct emissions (excluding aviation and organic carbon emissions) expressed in kton of CO2 per 0.1x0.1 deg cell (2005 values). EDGAR inventory 4.0.

This assumption can appear fairly reasonable, but it is radically insufficient if we consider the countless opportunities of systemic, cross-sectorial efficiencies, industrial symbioses, and smart urban settings that can be properly addressed only through an appropriate spatial analysis and with effective planning tools.

3 GEOGRAPHIC AND CONSUMER-RESPONSIBILITY CRITERIA IN CARBON EMISSIONS ACCOUNTING

The Kyoto Protocol, adopted in December 1997 and finally entered into force in 2005, has established emission reduction objectives for Annex B[3] Parties, which are committed to develop, publish and regularly update national emission inventories of greenhouse gases as well as formulate and implement programmes to reduce these emissions.

In order to establish compliance with national and international commitments, national GHG emission inventories are compiled according to the guidelines provided by the United Nations Framework Convention on Climate Change (IPCC, 2006). Emission estimates comprise six direct greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6), which contribute directly to climate change due to their positive radiative forcing effect, and four indirect greenhouse gases (NOx, CO, non-methane volatile organic compounds, and SO_2).

The IPCC guidelines for GHG accounting, developed from a revision of a precedent 1996 version, have been designed in order to ensure the transparency, consistency, comparability, accuracy and completeness of the inventory provided by the national authorities, and consider 4 emission sectors: (1) Energy, (2) Industrial Processes and Product Use, (3) Waste, and (4) Agriculture, Forestry and Other Land Use (AFOLU). It's worth noting that national inventories are updated annually in order to reflect revisions and improvements in the methodology and adjustments are applied retrospectively to earlier years, which accounts for any difference in previously published data.

The IPCC methodology adopts a polluter-responsibility approach, also indicated as territorial or *geographic approach*, since countries are held responsible for all GHG emitted from their domestic territory.

3 Annex B parties are industrialized countries and countries with economy in transition (Annex I Parties) with first- or second-round Kyoto greenhouse gas emissions targets.

The main problem determined by the adoption of a geographical approach as a reference for emissions reduction policies in a limited number of countries is represented by the risk of inducing *carbon-leaking* phenomena, i.e. the re-localization of energy intensive industries and technologies from nations with strict climate policies. Furthermore, adopting the geographic principle, a territory can be considered 'virtuous' even if imports energy and carbon-intensive goods, because it does not *directly* emit greenhouse gases.

The problem of *indirect emissions* is considered by other organization-based GHG accounting systems, like proposed in the EU LIFE LAKS project, or in the recently launched[4] GHG protocol for Cities (ICLEI, 2012), including the *consumer responsibility* (or just responsibility) *principle*.

In these frameworks the accounting of direct emissions, namely the emissions rising from within the city boundaries (see fig. 2, Global Protocol for Community-Scale Greenhouse Gas Emission Inventories, Scope 1), is followed by the accounting of indirect emissions generated for producing the imported energy (grid supplied power, Scope 2) and other indirect emissions (wastes, power transmission and distribution, out of boundary transportation, Scope 3).

The main advantage of adopting a geographical approach within a local context is represented by the consistency and coherence of results between different territories and different scales. A province or a municipality can be considered as a subsystem of the national inventory, its inventory can be compiled following the same methodologies, and consistently updated over the same time series.

Actually, the IPCC guidelines include the possibility of adopting bottom-up approaches for the compilation of higher-precision esteems. Local inventories can thus represent a contribution to national accounting efforts, just like national inventories compose the global esteem that can, and must, be verified in atmospheric concentrations.

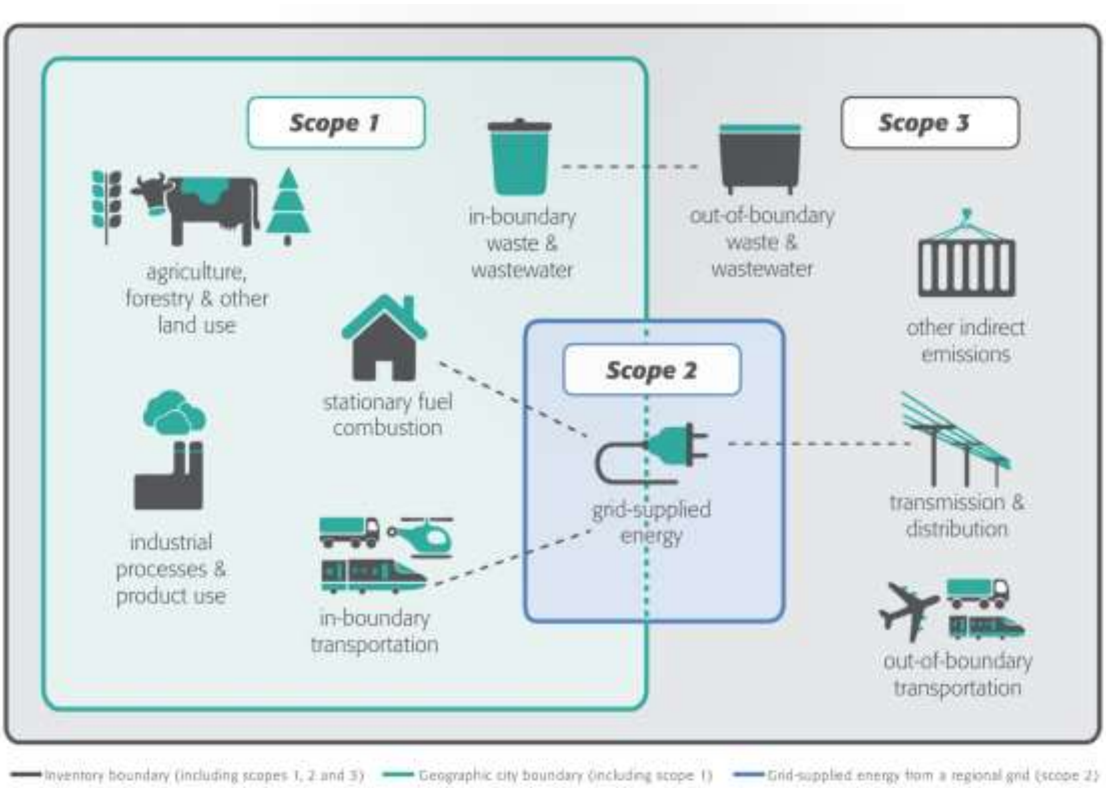

Fig. 2 Following the "responsibility principle": sources and boundaries of city GHG emissions in the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC).

[4] The GPC has been adopted, among other initiatives, by the Compact of Majors and has been launched on December, 8 - 2014 in Lima by the lead authors World Resources Institute, C40 Cities Climate Leadership Group, and ICLEI - Local Governments for Sustainability.

Direct measurements and remote sensing techniques can be used for comparison with direct emissions inventories, like in the case of the Megacities Carbon Project (Duren, Miller, 2012), or the CO2 MegaParis Project (Bréon, et al, 2015).
On the other side, the main advantage of adopting approaches developed including the 'responsibility principle' is that the results give a more complete, sound picture of the local context. Including indirect emissions, the interpretation of a result or of a trend is more univocal, since a low value of emissions can almost always be interpreted as *good*, and *lower* means almost always *better*.
These characteristics make protocols enforcing the responsibility principle particularly appropriate for informing and monitoring initiatives aimed at reducing emissions that are focused on local communities and are managed by local institutions, like in the Covenant of Majors initiative.
Unfortunately, since such approaches are conceived as autonomous accounting systems, overlapping and double counting issues between different areas are generally not considered, and therefore they are less suitable for spatial analysis purposes.

4 CARBON DENSITY MAPS OF THE LINEAR METROPOLITAN SYSTEM – LIMES – IN LOMBARDY: DATA AND METHODS

The availability GHG emissions data at municipality level, provided by the INEMAR project (ARPA Lombardia, 2014), has been exploited to create GHG emission density maps. The INEMAR atmospheric emission inventory, currently in its version 7.0, is a database developed in order to estimate emissions of pollutants for different activities (power production, heating, road transport, agriculture, industry, etc.). The system has been applied in the years between 2001 an 2012, and includes information from several administrative Regions in northern Italy. For the elaborations presented in this paper we have taken advantage of the final emission data for the year 2010, provided by the INEMAR database with distinct values for each of the 1546 municipalities of Lombardy.
Emissions are grouped by CORINAIR activity (group, sub-group, activity) and by fuel typology, and are available at different aggregation levels[5]. The value of greenhouse gas emissions is presented as tCO2e/y, taking into account the IPCC methodologies[6], and represents the sum of emissions weighted by the respective Global Warming Potentials (GWP).
A mapping exercise has been produced linking the INEMAR dataset with geographic data, including municipal boundaries, population data, and land-use information, produced and organized within the research PRIN 2007 *From metropolitan city to metropolitan corridor: the case of the Po Valley Corridor*.
The study, funded by the Italian Ministry of University and Scientific Research in 2007, has highlighted the urban and territorial phenomena in Northern Italy and proposed the concept of LiMeS (Linear Metropolitan System) to define the mega linear metropolitan area structured prevalently in East-West direction in the Po valley and mainly organized along the principal traffic corridor (Busi, Pezzagno, Eds. 2011). The research has identified transport, historic, traditional and new types of housing, communications, cultural tourism and leisure as major elements of the LiMeS and introduced the concept of *sprawling metropolis* as a structuring element, especially in the eastern area that is characterized by low-density expansions, determining a polycentric metropolitan area.

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5 With reference to the categories introduced in the previous paragraph, the database considers direct emissions only: indirect (also named *shadow*) emissions, related to final energy consumption, are not estimated by INEMAR.

6 The CORINAIR - SNAP 97 subdivision/nomenclature is not the same adopted by IPCC guidelines, but this is not deemed relevant for the spatial elaborations presented in this paper.

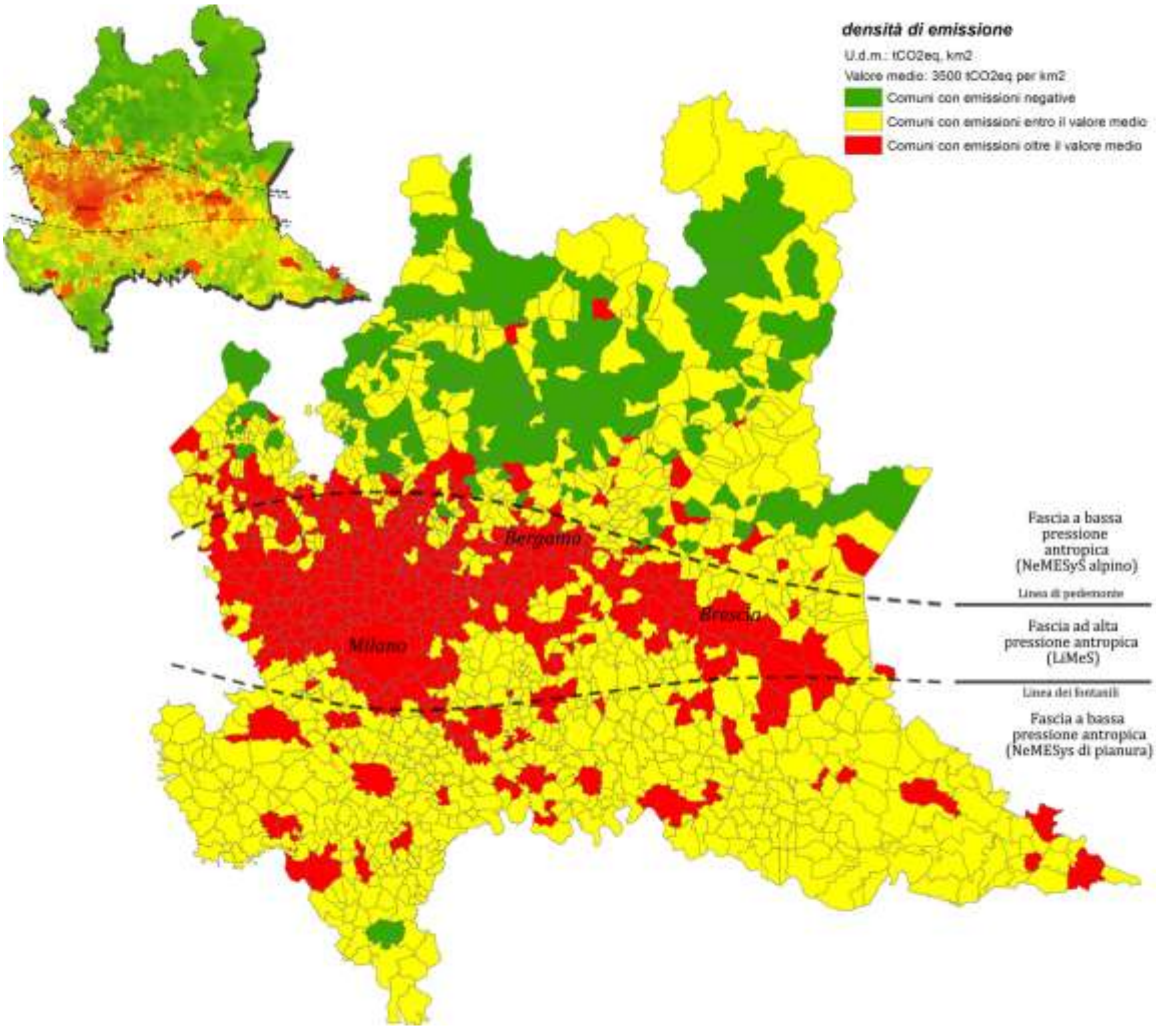

Fig. 3 Density of GHG emissions for municipality, expressed as tCO2e/km2, in the Lombardy region (2010). The gradient representation (top-left) has been forced in three classes: negative emissions, emissions up to 3,5 ktCO2e, and above

The spatial analysis of GHG emissions in Lombardy has been conducted on the relevant background of the LiMeS research: the basic structure of urban phenomena has been confirmed, and relevant information has been produced identifying specific anomalies.

The analysis has firstly considered total GHG emissions per municipality. However, the representation of absolute data within administrative boundaries can be poorly significant, if not misleading, due to the very different extension of municipalities. In order to produce a first significant picture of the metabolism of the territory at stake it is necessary to consider emissions densities, obtained dividing local GHG emissions by municipality areas.

In Figure 3 a representation of aggregate GHG emissions density for the Lombard regional area is presented. A rough classification between high, medium and negative emissions has been adopted, in order to highlight the basic distinction between high and low-anthropic pressure areas examined in depth by the PRIN research. The northern part of the region, named as the Alpine NeMESyS (Neighbouring Mega Ecological Systems) in the research cited above, is characterized by negative or low emissions, the intermediate urban LiMeS area contains the highest values, while medium values with some significant exception appear in the Plain NeMESyS.

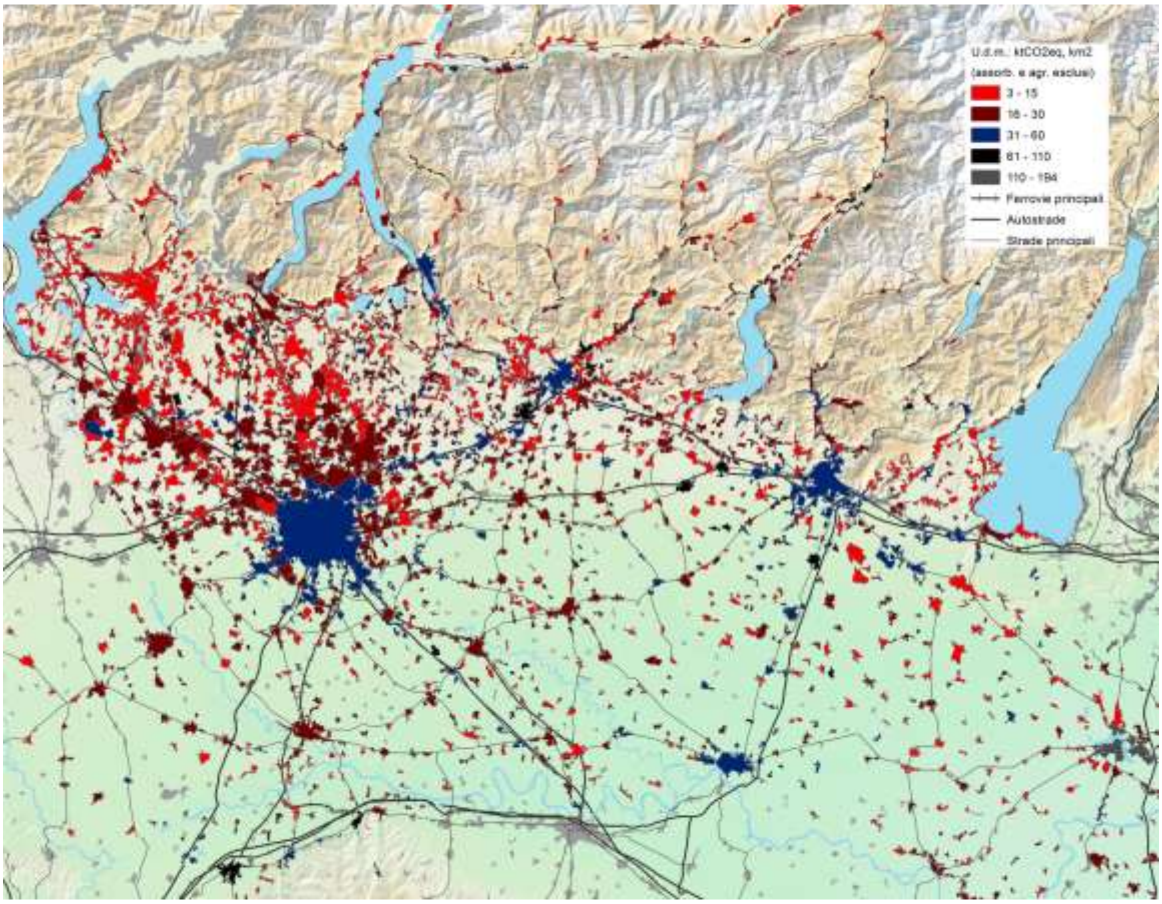

Fig. 4 GHG Emissions densities, excluding absorptions and emissions from the agricultural sector, relative to urbanized areas

The availability of disaggregated data within the INEMAR inventory (as in all IPPC-compliant emissions datasets) permits to analyse specific sectors, or to exclude them from the analysis. Taking advantage of this flexibility, the EU standard CORINE Land Cover classification has been adopted to give a first, but replicable sample of the potential insight achievable by studying the spatial correlations between sector-specific emissions and related land use classes.

In the case proposed in Figure 4, for example, the attention has been focussed on urban areas. Carbon absorptions and emissions from agriculture have been excluded (i.e. macro-sectors 10-11 of the CORINAIR classification[7]), and the resulting emissions have been mapped solely on the urbanized areas (as defined within the CORINE Land Cover classification).

The density of emissions per urbanized area significantly reflects the intensity of urban phenomena, and the resulting patterns confirm the structure of the central sector of the LiMeS. The Milan Universe characterizes the western part of the Region, with its radial propagations along the main transport infrastructures (e.g. toward the node of Bergamo), while at East the western portion of the Cenomane Dipole (Brescia-Verona) is incomplete due to the lack of data regarding the Veneto Region, but appears already intelligible. Within this general picture some significant anomalies can be identified, characterized by the highest values of emissions density (above 100 ktCO2e/km2) like in the case of Mantua, strongly characterized by the presence of a large chemical center, showing the highest values of emissions per square kilometer of the region.

In order to further enhance the perception and the understanding of exceptional values, urban emissions densities have been further elaborated, and subdivided by the number of inhabitants.

[7] One of the most significant anomalies emerged in this study has been the relative weight of agricultural emissions in the southern belt of Brescia, determined by the high concentration of intensive livestock farming plants.

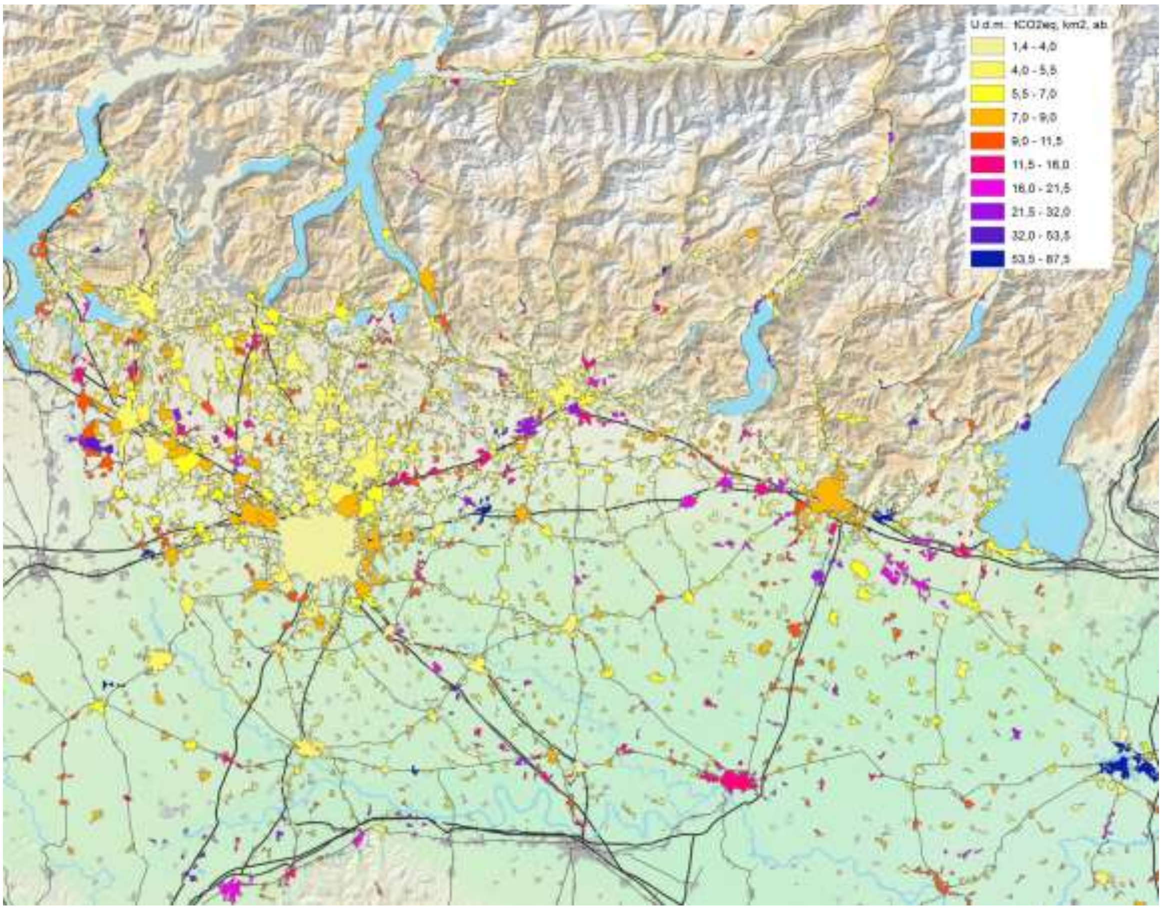

Fig. 5 Urban GHG emission densities per inhabitant: high density anomalies are represented by power plants or energy intensive industrial facilities

The resulting map, presented in Figure 5, clearly identifies an increase of emissions per inhabitant in peri-urban areas, and several, high-density anomalies that correspond to thermoelectric power plants or energy intensive industrial plants. (e.g. chemical plants, cement and paper industries).

The correlation between low-density urbanization patterns and higher per-capita emissions observed in peri-urban areas within the LiMeS is mainly driven by transport emissions[8], and confirms patterns that have been observed, applying a similar methodology, in suburbanized areas in the US (Jones, Kammen, 2013).

Considering household carbon footprints (HCF) Jones and Kammen (2013) have summed up and expressed with the common unit of GHG emissions (tCO2e/household) intensity values coming from electricity, natural gas, fuels, food, services, etc. The combined result has shown distinct carbon footprint rings surrounding urban cores, with suburbs exhibiting noticeably higher HCF, as shown in the maps reported here in Figure 6.

5 DISCUSSION: GHG EMSSION MAPS IN PERSPECTIVE

The brief GHG emissions mapping exercise proposed in Lombardy has so far confirmed behaviors and characteristics of urban systems already identified by precedent research, showing specific anomalies in correspondence with critical processes or phenomena related with large scale, energy-intense activities.

The intensity of GHG emissions per area is a viable representation of anthropic pressure on the environment that can be further detailed linking sectorial carbon emissions with land use classes.

[8] This correspondence was already observed analyzing transport costs in the cited PRIN research (Busi, Pezzagno, Eds. 2011, pag. 51).

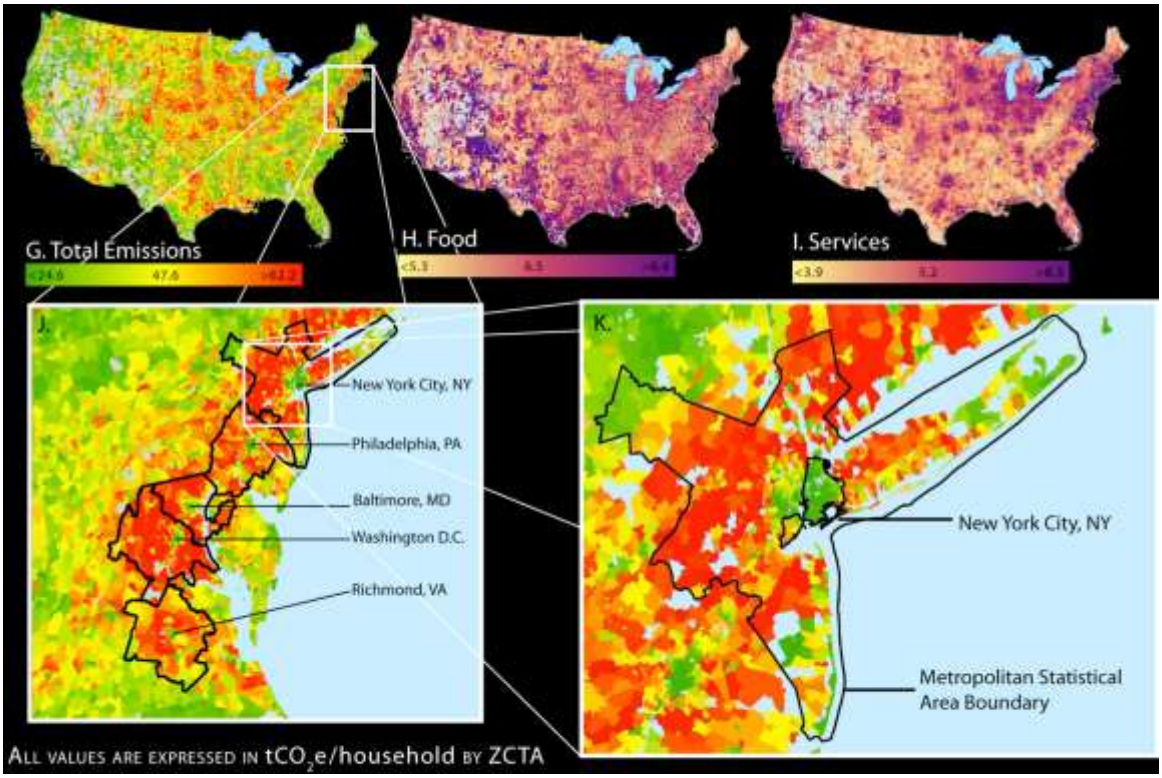

Fig. 6 Average Household Carbon Footprint - Eastern United States (Jones, Kammen, 2013)

The exclusion of emissions from the agriculture sector and the attribution of the resulting values to urbanized areas allowed a better description of urban phenomena. Within urbanized areas, the relationship between GHG emissions and population density has indicated higher carbon intensity values in correspondence with low-density settlements.

These preliminary results allow foreseeing a reasonable potential for further research, with specific regard to the development of the tool for the analysis of the metabolism of regional and local systems. With regard to smaller scales, however, it must be stressed that the higher granularity implies a level of accuracy in GHG inventories that generally cannot be provided following a top-down approach (as in the INEMAR project), in which local breakdown factors are applied starting from data harvested at the large scale.

The case of higher per-person emissions observed in lower density areas, or the case of high intensity centers identified within the LiMeS, are useful to underline the nature of the tool represented by direct emissions inventories and their spatial analysis, which require a fairly different attitude with respect – for example – to local inventories including indirect emissions.

Planners and decision makers should always approach emission density results as a signal of intensity, of consumption of resources, but also of a relevant *potential* for a transformation that always involves complex relationships between different spatial scales, infrastructures, hierarchies, and technological variables.

For example, low-density suburbs are a specific form of the city that can be considered poor regarding urban quality: i.e. mono-functional residential areas lack of socio-cultural attraction, and are difficult to target with innovative high quality public transport systems due to the low demand. However, should the ongoing advancements in distributed power generation (PV, micro wind), energy storage solutions, and electric transportation respect their promises, these settlements can be probably converted in a zero-emissions profile easier than the denser central districts. Similar considerations can be done with regard to other existing infrastructures, like the ones evidenced in emission hotspots determined by thermal power plants: should power-to-gas technologies[9] become the main strategy for long-term energy storage in the European

[9] Production of methane from peak renewable power production through water-splitting + methanation or Sabatier reactions and its storage, including relatively high percentages of hydrogen, in the gas grid.

context, and/or should fossil methane be substituted by biogas generated from agricultural waste, suddenly the entire Italian natural gas infrastructure could completely change its "meaning"[10].

Cities are complex systems that cannot be understood or defined through single-issue perspectives. Even taking into account the pervasive importance of climate change we need to improve our understanding of how GHG emissions may be managed, given the other dimensions, constraints, values and complexities of the urban system (Chester et al., 2014).

In this perspective, the integration between GHG emission inventories and land-use mapping represents a useful tool to better understand the complexity of phenomena and improve knowledge in relation to:

- achievable targets on specific topics (i.e. an emissions reduction form a specific plant or sector);
- complex policies needed in overlapping phenomena (i.e. when on the same area relevant emissions are rising from different activities / sectors without a clear profile or dominance);

toward a better use of funding and public resources and a better oriented urban regeneration.

5 CONCLUSIONS

There are unique challenges and opportunities ahead for reducing GHG emissions acting on the metabolism and on the built environment within regional and local systems. In this context the establishment of reliable representations of direct emissions at local scale can provide a common and consistent background for linking local change to the global targets defined by international goals and treaties.

We must recognize that the economy de-carbonization path ahead of us is far from being a linear or a homogeneous one. For example reducing GHG emission from urban systems in developed regions, where infrastructure is established and the capital stock turnover limited to incremental change will require solutions to different challenges than in developing regions.[11]

In this extremely complex and evolving context, local carbon emissions mapping can be represent a useful analytical tool to support the knowledge of local systems and contribute to define mitigation and adaptation policies. However, spatial mapping of direct GHG emissions should not be ingenuously interpreted and the difference with local inventories including indirect emissions should be properly addressed.

We have stressed the importance of considering GHG spatial mapping as a *tool* for producing a very general knowledge: a thermodynamic *proxy*, meaning an indicator of the intensity of the processes occurring in a local system, without implicit goal functions, which represents a starting point for further research and for pursuing appropriate mitigation strategies.

In this perspective, and taking into account the dimensional limits of top-down inventories at the smaller scales, the tool can be profitably used as a low-level reference, the much-needed common and consistent background for linking local change to global de-carbonization pathways.

In conclusion, spatial mapping should cautiously be considered a discipline in its early stages of development, with an interesting potential for supporting spatial planning and mitigation policies at regional and local scale.

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10 Fast modulating thermal power plants, together with pumped hydro plants, can play a vital role in grid short and long-term stability in a power generation scenario with high content of intermittent renewable sources.

11 The greatest opportunity for configuring cities for low GHG emissions may be in developing regions. The majority of urbanization in the next 50–100 years will be occurring in medium-sized towns in Asia and Africa. As half of urban land in existence in 2030 is yet to be developed the next decades offer a critical window of opportunity to influence how cities are built. The way that these cities urbanize and the type of infrastructure developed will have large impacts on GHG emissions in the future (Chester et al., 2014).

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IMAGE SOURCES

Cover image: free composition with the INEMAR inventory basic formula, considering emissions from activities for relative emission factors. Background image, eclipse from NASA Solar Dynamics Observatory (SDO); Front, nocturnal image of northern Italy – with the LiMeS urban system highlighted – from the ISS. Credits ESA/NASA.

Fig. 1: EDGAR inventory 4.0 - http://edgar.jrc.ec.europa.eu/part_CO2.php

Fig. 2: ICLEI. (2014)

Fig. 3, 4, 5: Berni, A. (2013)

Fig. 6: Jones, Kammen. (2013)

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