

NEW GREENHOUSE GAS SIMULATION AND MAPPING TOOLS TO SUPPORT LOCAL CARBON NEUTRALITY AGENDAS: A CASE STUDY OF THE CITY OF ALMADA, PORTUGAL

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ABSTRACT

The aim of this work is to develop three innovative decision support tools: (1) a scenario tool that enables users to interactively design scenarios of activity variables that support decarbonisation trajectories on a local scale; (2) a mitigation tool that translates scenarios into greenhouse gas (GHG) emissions, taking into account the identification and prioritisation of the most innovative, cost-effective mitigation options (technological and behavioural) for Portuguese municipalities; and (3) a mapping tool to identify GHG emissions 'hot spots' on a local scale. In the first phase, these tools are applied and tested for the case study of the city of Almada in support of the 'Agenda for a Carbon Neutral Almada by 2050'. These tools will also contribute to the training and involvement of local stakeholders, to improve the design of local GHG emissions mitigation strategies and roadmap. In the second phase, these tools will be further developed so they can be used in other Portuguese municipalities.

Keywords: GHG modelling tools, climate mitigation, cities planning.

1 INTRODUCTION

The main motive for this work is the pressing need for cities to become carbon neutral. For these cities require specialised and qualified assistance, particularly, small and medium sized cities. National roadmaps have been developed in the most recent past years, Portugal being one of the precursor countries developing such type of roadmaps [1]. Going from national to regional and local scales besides setting their own targets, there is need to address implementation challenges that range from cities adoption of digitalisation practices in most services and clean and sustainable technology adoption across their economies. While investment and financing are key aspects to be dealt with to accelerate the transition at all scales, knowledge and sharing of cities best practices is seen as an essential mean to drive local actors in their pathways to decarbonisation. Appropriate modelling tools along with capacity building in city actors and coordination and cooperation among them are a requirement for cities that aim to reach carbon neutrality.

1.1 Context

In the last years the European Union (EU) has been making advances to meet the goals established in the National Energy and Climate Plans concerning climate change mitigation and sustainable energy consumption. The funding program EU Missions is an example of the European Commission (EC) addressing the importance of climate-neutral and smart cities through a response to these topics, specifically directed to the urban and energy challenges, to promote innovative solutions and strategies and to deliver tangible results in the 2030–2050 period. Responding to these challenges the EU also has been funding several projects for smart cities that develop distinct approaches and contributions to meet the energy and



climate goals of the different Member States. Also, the cities themselves, all over the world, have been establishing strategies and policy guidelines at regional and local levels as well as best practices recommendations for the development of cities paving their way towards climate neutrality in 2050 [2].

The EU fully recognises the significance of sustainable development and aims to reduce its carbon footprint and make Europe a global role model in energy transition. In 2019, all EU Member States encoded this ambition into their National Energy and Climate Plans 2030 [3].

The EU Council has set targets on greenhouse gas reduction, renewable energy production and energy efficiency for 2020 and 2030, which paves the way to the long-term goal of a climate neutral economy by 2050 [4]. Subsequent to the energy union and climate action rules entering into force in December 2018, EU countries are required to develop integrated National Energy and Climate Plans (NECPs) that will cover the five dimensions of the energy union, i.e., (i) security, solidarity and trust, (ii) a fully integrated internal energy market, (iii) energy efficiency, (iv) climate actions – decarbonising the economy, and (v) research, innovation and competitiveness for the period 2021 to 2030. These plans are updated every 5-year period. In the Portuguese case the timelines are being followed: the draft NECP update has been submitted by June 2023 and the final version submitted in July 2024.

For Europe to be climate neutral by 2050, the EC proposed several approaches to stimulate energy transition and climate neutrality in urban environment, addressing different scales from city level to districts and neighbourhoods. In this context, modelling tools are essential.

The authors of this study intend to share the first results of the work developed by LNEG within the 14 months project ‘Agenda for a Carbon Neutral Almada by 2050’, currently underway, started in May 2023 and to be completed by October 2024. The aim of the project is to contribute to scientific innovation by developing practical approaches and tools that support the development of deep local decarbonisation agendas in medium sized cities, which represent the majority of European cities [5]. The simulation and mapping greenhouse gas (GHG) tools are applied and tested for the case study of the city of Almada aiming at the development of an ‘Agenda for a Carbon Neutral Almada by 2050’ and will also integrate the Municipal Climate Action Plan 2030 currently being prepared. The GHG modelling tools for cities are intended to facilitate and simplify the reassessment of municipal strategic options in line with city decarbonisation pathways, without compromising scientific robustness.

The currently existing tools are not adapted to the Portuguese context, having been developed mainly in other European countries and the United States and having been implemented in large cities in northern Europe, Africa or Asia. Therefore, existing tools are not designed to consider the type and format of information available in Portugal at a municipal scale, the specific national costs of the various mitigation options, the typology of buildings and automobile fleet, and/or the current reference situation of Portuguese municipalities, neither consider explicitly the spatial component of the territory. Furthermore, most GHG existing tools generally are not publicly available.

The paper first describes the main aspects of the methodology developed which was inspired on the Portuguese National Carbon Neutral Roadmap 2050 overall approach by envisioning, through participatory events with local stakeholders, three scenarios for the city in 2050, that also account for the regional, national and global expected evolutions to 2050.



2 METHODOLOGY

2.1 Data and scope

The GHG modelling tools are being developed to comply with the most prominent European cities contracts frameworks (Covenant of Mayors (CoM) Carbon Disclosure Project (CDP), EU Cities mission, NZEB cities, others) particularly regarding sectors of activity, which characterise both demand and supply of energy in the Almada municipal system. These include: municipal buildings, other service buildings (non-municipal), residential buildings, industry (non-ETS), municipal transport fleet, other transport, public lighting, energy production and conversion, agriculture, forestry and fisheries, solid waste management, water and wastewater management, and other non-energy sources (e.g., fluorinated gases). The modelling tools also consider the specificities and opportunities for medium and small sized Portuguese cities. The work addresses all the GHG, as included in the Paris Agreement, and refers to direct and indirect emissions for which the city is responsible for, relying as much as possible in the existing publicly available data sources (Section 2.1) and considering explicitly the sectors/subsectors of activity associated to their sources' location, in the 11 different zones corresponding to the old parishes (NUTs4). This spatial scale is possible to map and is seen most adequate meso-local scale which are easily recognisable by city stakeholders and also by the city planning bodies. The tools have been co-developed with local city agents (Section 2.2) and are oriented towards their comprehensive understanding of GHG emissions current situation and the potential for most effective mitigation actions in order to accelerate decarbonisation. The tools development therefore started with a comprehensive characterisation of a base year of 2019 given that this was the reference year with 'complete' available data and was not affected by covid pandemic situation. The future scenarios consider years 2025, 2030, 2035, 2040 and 2050 and their respective level of activity and energy consumption as well as GHG emissions.

To estimate GHG emissions, the methodological approaches and emission factors contained in the NIR (Portuguese National Emission Inventory Report) submitted to the United Nations Framework (UNFCCC) will be primarily used.

The three decision support tools will support the development of three decarbonisation trajectories at a local scale (Fig. 1): the scenarisation tool to design socioeconomic scenarios and evolution of other activity variables relevant to local decarbonisation roadmaps (Section 2.3); the mitigation tool to estimate GHG emissions and tests the impact of different combinations of mitigation options at the local scale (Section 2.4); and the GHG emissions mapping tool illustrates both the reference situation and different future scenarios (Section 2.5). These tools are linked to each other and are sequential and complementary.

2.1.1 Data sources

The main sources of information for the development of the tools, i.e., characterising the current reference energy system of the municipality of Almada and allowing a more detailed knowledge of how to reach different visions of the future, have been preferably institutional sources also available for other cities, from which we highlight the following: the energy balances from General Directorate of Energy and Geology (DGEG); statistics from the National Statistics Institute (on population and buildings included in Population Census; on mobility included in the Lisbon Metropolitan Area (AML) Imob2017; others; PORDATA data; ADENE Database of Energy Certified Buildings; APA Portuguese Environment Agency; COS2018 – Land Occupation and Use Letter from DGT (General Directorate of



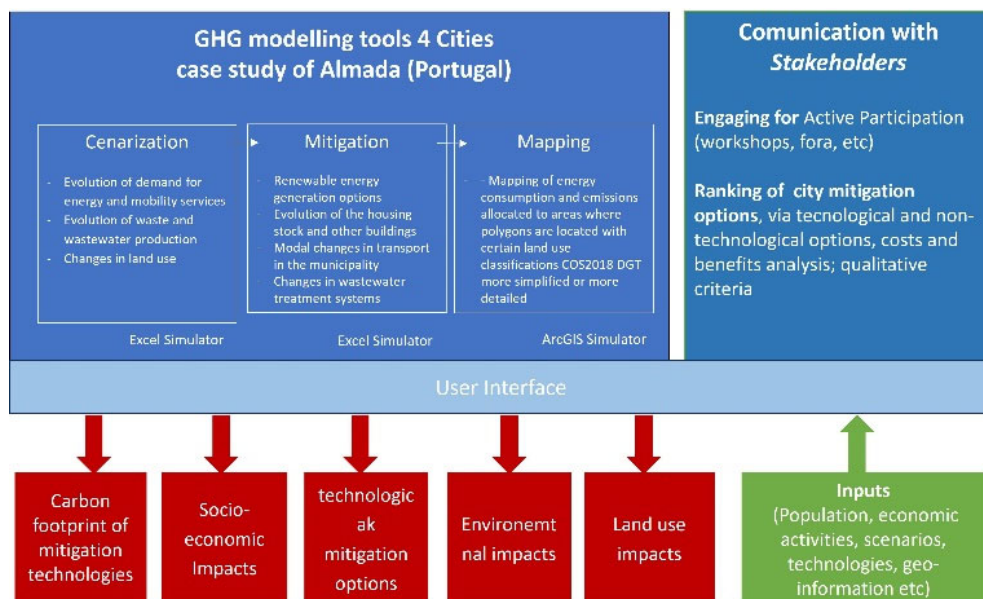


Figure 1: Methodology for developing tools for decarbonisation trajectories in Almada.

Territory). Specific and extremely relevant data sources, in the case of Almada, have also been the SureCity project reports for the Almada case study and the base year files for the TIMES Almada model developed and implemented in the SureCity project (1); the city council experts' information and administrative data gathered (e.g., AVACs operation in municipal buildings); the inventory of GHG emissions produced by the city council from previous years; project under development with implementation set up to 2025; Circular Strategy for Almada 2030. Finally, all this has been complemented with scientific and technical information and data from both national and international publications, complemented by consultation with experts on specific topics.

2.2 Co-developments with municipality technicians and stakeholders

The methodological approach to be used is based on a perspective of co-development with the city council teams and other stakeholders, external and internal to the city council, such as: municipal technicians, council executive, parish councils, energy communities, large energy consumers in the municipality (e.g., Faculty of Science and Technology of NOVA University of Lisbon, Almada Shopping, Garcia da Orta Hospital, Alfeite Arsenal, etc.), transport operators (e.g., MST, Carris Metropolitan, TST, etc.), trade associations, school groups, recreational associations, etc. Therefore, technical participatory workshops and events open to the population of Almada have been held to: (i) develop a common vision for the city in 2050; (ii) discuss plausible and effective decarbonisation scenarios, as well as the mitigation options to be included in the modelling tools; and (iii) discuss the results of the tools and their application to the Neutrality Roadmap 2050. The bidirectional straightforward communication also included online inquiries gathering opinions and insights that are quantifiable and translated into the scenario narratives over which the mitigation options are

Table 1: Synthesis of key socioeconomic variables and assumptions for each sector/subsector of activity up to 2030 and up to 2050.

Sector/subsector	Socioeconomic variable driver for the projection	Assumptions
Residential buildings	No. of main dwellings and total of m ²	2030 According to Municipal Master Plan (PDM) 2050 SureCity Project [6]; Population projections [7]
Municipal – Educational buildings	No. of students registered in schools/year and used m ²	2030 According to PDM 2050 Population from (1),(2)
Municipal – Cultural buildings	No. of cultural facilities managed by municipality and avg. and total area (m ²)	2030 According to PDM 2050 Constant
Municipal – Sports facilities	Avg. and total area (m ²) and no. of users/year	2030 According to PDM 2050 Constant
Municipal – Social housing	Avg. and total area (m ²) and no. of dwellings	2030 Constant 2050 Constant
Municipal – Other type of buildings and facilities	Avg. and total area (m ²) and no. of buildings managed by the municipality	2030 According to PDM 2050 Constant
Non-municipal – Educational buildings	Avg. and total area (m ²) and no. of educational private establishments	2030 Constant 2050 Constant
Non-municipal – Cultural buildings	Avg. and total area (m ²) and no. of cultural private establishments	2030 Constant 2050 Constant
Non-municipal – Sports facilities	Avg. and total area (m ²) and no. of establishments	2030 According to PDM 2050 GDP
Non-municipal – Health facilities	Avg. and total area (m ²) and no. of establishments	2030 Population evolution 2050 Population evolution
Non-municipal – Tourism	Avg. and total area (m ²) and no. of establishments	2030 According to PDM 2050 GDP growth
Non-municipal – Retail	Avg. and total area (m ²) and no. of establishments	2030 According to PDM 2050 GDP growth



Table 1: Continued.

Sector/subsector	Socioeconomic variable driver for the projection	Assumptions
Non-municipal – Offices	Avg. and total area (m ²) and no. of establishments	2030 According to PDM 2050 GDP growth
Non-municipal – Other services buildings	Avg. and total area (m ²) and no. of establishments	2030 According to PDM 2050 GDP growth
Public lighting	No. of inhabitants per zone	2030 According to PDM 2050 Population
Industry (non ETS)	Assumed constant	2030 Constant 2050 Constant
Agriculture and fishery	Assumed constant	2030 Constant 2050 Constant
Waste	Production of waste per capita per type of waste considering no. of inhabitants	2030 Population evolution 2050 Population evolution
Water and wastewater	Production and consumption of water and wastewater per capita considering no. inhabitants	2030 Population evolution 2050 Population evolution
Private passenger transport – all except railway	No. inhabitants combined with mean of transport in pkm	2030 Population evolution 2050 Population evolution
Private passenger transport – railway	pkm travelled by railway	2030 GDP growth 2050 GDP growth
Transport municipal fleet – all except waste collection	pkm estimated from city council data	2030 Constant 2050 Constant
Municipal fleet of waste collection	tkm estimated from city council data	2030 Waste production per capita (RU/capita) evolution 2050 RU/per capita evolution
Freight transport (private and from municipal fleet)	Tons of transported freight and stock data, combined with a mean of transport, in tkm	2030 GDP growth 2050 GDP growth

applied; as well as quizzes developed including some of the findings of the project, such as the current characterisation of GHG emissions in Almada or the choice of the most relevant mitigation options voted by participants.

2.3 Developing visions to 2050: Scenario tool

The scenario tool will allow designing scenarios of socioeconomic evolution and other activity variables and will enable stakeholders to test, in an interactive way, the impact of various assumptions on the evolution of these driver variables on: (i) demand for energy services; (ii) production of waste and wastewater; and (iii) changes in land use, which in turn will have impacts on energy consumption and GHG emissions.

2.3.1 Key socioeconomic variables

Key socioeconomic variables influence GHG emissions, and their evolutions determine and are used to explain the evolution of business-as-usual (BAU) scenarios (Table 1).

2.3.2 Business as usual scenarios

BAU scenarios enable the assessment of mitigation measures. Each BAU scenario is associated with a narrative of the city and means that only the key drivers evolve, all the rest being considered equal (Table 2).

Table 2: Assumptions for each BAU scenario.

Scenario BAU_A	Scenario BAU_B	Scenario BAU_C
<ul style="list-style-type: none"> • High population growth until 2050 (INE) • No. of accommodations grows significantly in all zones • Services and tourism as foreseen in the PDM until 2030 and until 2050 annual • Evolution indexed to GDP (according to PNEC review) • pkm according to population • tkm indexed to GDP 	<ul style="list-style-type: none"> • Moderate population growth until 2050 (INE) • No. of accommodations grows moderately in almost all areas and especially Charneca, Caparica and Sobreda • Services and tourism 75% of what is foreseen in the PDM by 2030 and until 2050 75% of GDP evolution (rev. PNEC) • pkm according to population • tkm 75% GDP growth 	<ul style="list-style-type: none"> • Population growth only in Caparica, Costa, Charneca and maintenance in the rest • No. of accommodations follows population trend (without demolition) • Services and tourism 50% of what is foreseen in the PDM by 2030 and until 2050 50% of GDP growth (rev. PNEC) • pkm according to population growth • tkm 50% GDP growth

2.4 Setting the pathways: Mitigation options tools

The mitigation tool interactively allows the selection and testing of different combinations of GHG mitigation options for the city. The starting point for the database of mitigation options was developed for Almada within the scope of the SureCity project (1) and was developed based on the participatory processes already described in Section 2.2. The database with the various options considered in the tool are characterised with efficiencies, investment and O&M costs. and with the respective maximum threshold of potential application in the



various locations of the city. Examples of mitigation options are: replacing electric heating equipment with heat pumps in an urbanisation, restrictions on circulation around automobile in certain areas of the city, among others. The emphasis is given primarily to technological mitigation options, related to energy production and consumption, without neglecting options related to changes in infrastructure and/or energy use.

2.5 Mapping tools

The mapping tool of the main location sources of GHG emissions in the municipal territory, will combine the emissions obtained for each decarbonisation scenario/trajectory with the georeferenced information for the city. Current information on land use and occupation will be used, such as that contained in COS2018 – Land Use and Occupation Letter (COS) published by the General Directorate of Territory (DGT) for mainland Portugal and can be used at municipal level. COS2018 divides the territory of mainland Portugal into 83 land occupation classes. The nomenclature of these classes follows a hierarchy with four levels that represent land occupation/use at different levels of thematic detail (e.g., predominantly vertical continuous buildings, predominantly horizontal continuous buildings, industry, commercial, agricultural facilities, sports facilities, leisure equipment, others). The tool employs simplified mapping using average coefficients for the different sectors of activity combined with the location area of polygons within the 83 categories of COS2018 classifications.

3 RESULTS

The GHG simulation tools enabled a thorough characterisation and visualisation of emissions' current situation in the city including distribution per activity sector, type of energy as well as per area of the city. Fig. 2 shows the overall city picture, while Fig. 3 shows the case of municipal buildings. This type of output is produced per type of emitting source. Fig. 4 illustrates the evolution of socioeconomic variable in Almada in each BAU scenario

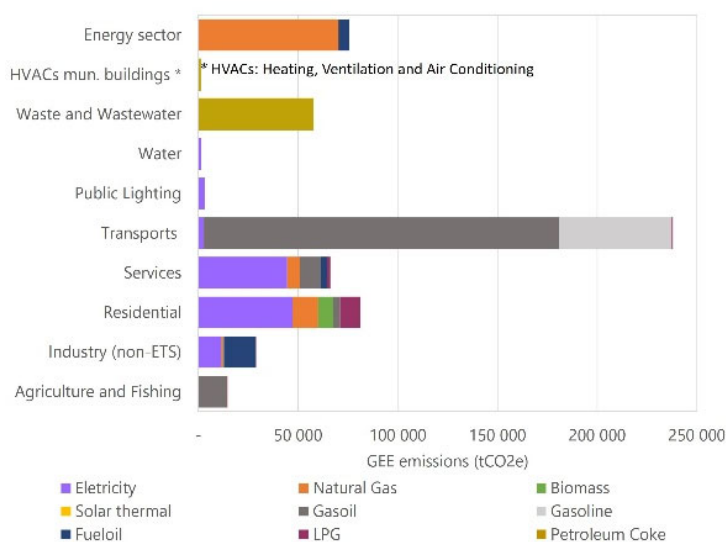


Figure 2: GHG emissions per activity sector and type of energy in Almada in 2019.

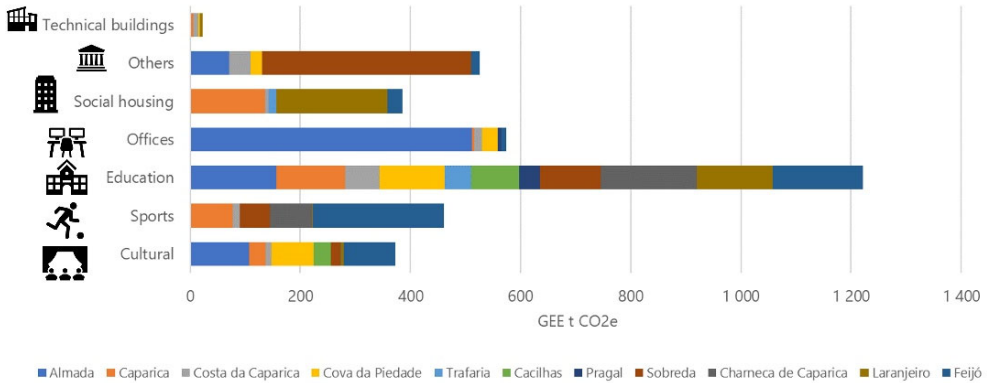


Figure 3: GHG emissions in municipal buildings per zone in the city of Almada in 2019.

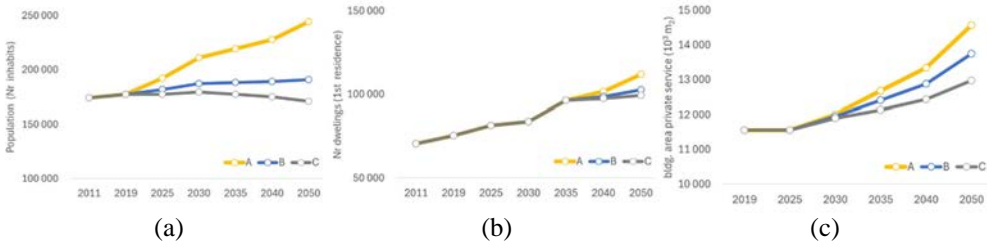


Figure 4: Evolution of socioeconomic variables in Almada. (a) Population; (b) Dwellings; and (c) Area of buildings/equipment dedicated to services.

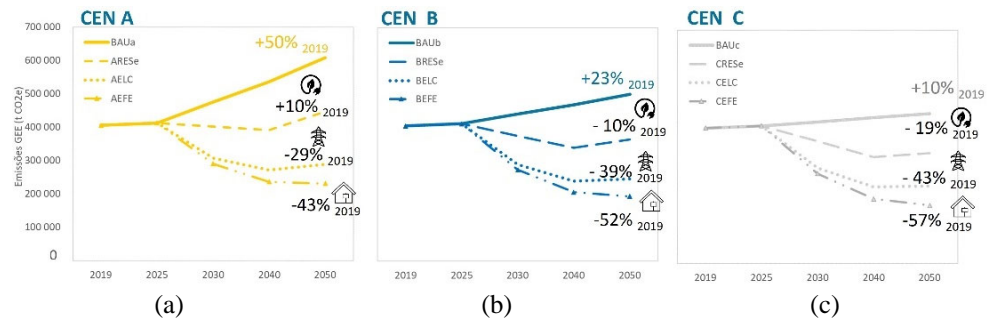


Figure 5: Preliminary mitigation options: electrification, renewable power network, energy efficiency in (a) Scenario A; (b) Scenario B; and (c) Scenario C.

for three of the key variables. Fig. 5 shows preliminary mitigation options in each BAU scenario.

3.1 Mapping of GHG emissions hotspots

GHG emissions hotspots results are illustrated in maps as shown in Fig. 6 for the indicator of overall level of emissions per capita and in Fig. 7 for the indicators of emissions per area concerning the residential sector, in particular, detached and semi-detached houses. In this figure it becomes visible that most such houses in Almada city have relatively lower emissions and that in older parts of the city, these houses have higher associated emissions per square metre.

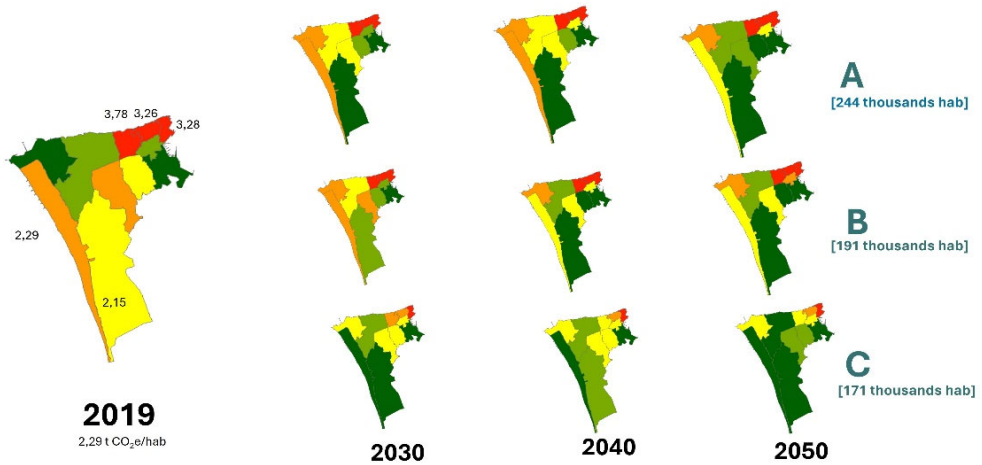


Figure 6: GHG emissions hotspots (tCO₂e/capita) in Almada per zone in 2019, 2030, 2040 and 2050 under (a) Scenario BAU_A; (b) Scenario BAU_B; and (c) Scenario BAU_C.

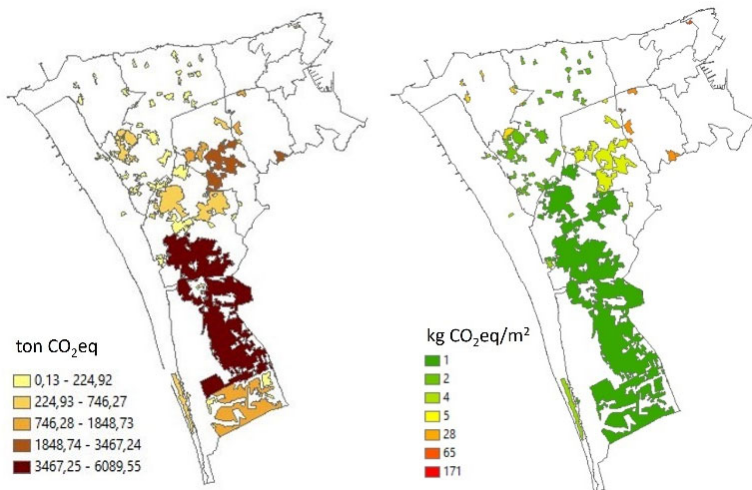


Figure 7: GHG emissions hotspots of detached and semi-detached houses in Almada per zone in 2019 (tCO₂e and kgCO₂e/m²).

4 CONCLUSIONS

Meeting carbon neutrality goals will be very challenging for Almada municipality (as for other municipalities in the capital vicinity) partly because this is a municipality where the population is growing. Being in the Lisbon Metropolitan area, Almada is (and will continue to be) a coveted destination for persons moving from rural inland Portugal and for foreigners that relocate to the country to study or work. Whereas the national carbon neutrality roadmap relies on reducing or stable population scenarios, for the Almada case study two of the scenarios consider that the population is increasing.

This highlights the importance of considering the specificities of regional and local contexts and brings forward the relevance of improving the interaction between national and local carbon neutrality agendas. Currently the two are developed in separated spheres. Therefore, it would be relevant checking the consistency between national and local strategies. Maybe national strategies are not coherent *viz-à-viz* the combination of local ones. On the other hand, local strategies rely on socio-economic assumptions that are context-specific, but that need to be coherent with national socio-economic scenarios as a whole. This is an area of study that merits further research.

Another important, and well-known aspect supporting local carbon neutrality agendas is the adoption of a co-development process engaging the municipality and other local stakeholders. This was considered in the newly developed GHG simulation and mapping tools as follows: (i) by adopting a disaggregated geographic resolution in city zones that allow all those involved to associate estimated energy and emission with actual buildings, transport routes and other major emission sources. It also allowed for easier error checking and data validation; (ii) by disaggregating emissions in activities aligned with the municipality organisational structure, facilitating allocation of data, results and mitigation measures more easily across departments and divisions (e.g., education, sports, tourism, etc.); (iii) by developing a simplified user interface that allows users to alter socio-economic assumptions and see how GHG emissions change in the future across city zones/sectors; and (iv) by mapping emissions per capita evolution in city zones, as well as for different buildings. The co-development process also included a series of workshops and meetings with municipality staff, external stakeholders and the public from different age groups. An online survey was carried out with circa 200 replies. All of these were considered, as much as possible into the developed tools. The whole process was found to be very useful for developing the tools, for obtaining more reliable information and for creating a sense of ownership of results. A communication channel was established within and outside the municipality and bidirectional capacity building was made (on carbon neutrality and GHG emission estimates on one way and on barriers and municipal operation on the other). However, it is important to acknowledge that such co-development is a time-consuming process that substantially adds time to the standard process of 'making a GHG emission inventory'. The tools developed here could have been achieved in a 'stand-alone mode' in a 6-month period but would have been more 'hermetic' and less useful. Because more time was available to develop the tools (circa 14 months) it was possible to make them more reliable and its results more appealing to users.

Having said that, and despite the best efforts, it is possible that the developed tools maybe still too complex to be used in stand-alone mode by the municipality. Medium sized municipalities (and sometimes even rather large ones) frequently lack human resources to be allocated to untangling and operating strategic complex tools, even if made in relatively straightforward excel software. Although a long way has been journeyed since organisations as the CoM have been implemented, the fact is that municipalities are frequently understaffed and underbudgeted and carbon neutrality is one of many pressing concerns which frequently



is outsourced for short-term contracts that do not allow for co-development or in-house carbon neutrality agendas' development. It is of uttermost importance to research on how to transfer these to municipalities with small external support.

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