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How can cities effectively contribute towards decarbonisation targets? A downscaling method to assess the alignment of local energy plans with national strategies

Iñigo Muñoz [a,b,*], Patxi Hernández [a], Estibaliz Pérez-Iribarren [c], Diego García-Gusano [a], Eneko Arrizabalaga [a]

[a] *TECNALIA, Basque Research and Technology Alliance (BRTA), Astondo Bidea, Edificio 700, Derio, 48160, Spain*
[b] *University of the Basque Country UPV-EHU, Bilbao, Spain*
[c] *ENEDI Research Group, Department of Thermal Engineering, Faculty of Engineering of Bilbao, University of the Basque Country UPV/EHU, Plaza Ingeniero Torres Quevedo 1, Bilbao, 48013, Spain*

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ABSTRACT

Following the example of national pledges and strategies to tackle climate change, cities are mobilising themselves towards decarbonisation, playing a key role in the achievement of those commitments due to their relevance within national energy systems. However, despite cities ambitions, there is a need for coordinating the efforts from national and local scales in order to ensure the effective fulfilment of energy and climate goals at both levels. In this paper a method for the transposition of national energy planning to the local level is proposed based on the downscaling, adaptation, and allocation of specific targets and energy measures from the national plan to the city scale. The further modelling of downscaled national energy measures allows to quantify the reach of their impacts, thus supporting the establishment of realistic goals aligned with national ones and achieving the effective contribution of urban areas towards higher climate targets. The methodology is demonstrated through the downscaling and comparison of the measures from the Spanish national energy strategy with the ones included in the energy plan of the Spanish city of Valencia. A mismatch between the two is evidenced with some local measures outperforming the national plan, while others proving themselves insufficient. These results show that urban energy planners should consider the real capacities and competences of the city when setting energy measures and goals in accordance with national ones. A correct downscaling and modelling of the former are key in this work.

1. Introduction

The Paris Agreement set the path to mitigate climate change and adapt to its effects. Through their Nationally Determined Contributions (NDCs), the signatory countries pledged to reduce their greenhouse gas (GHG) emissions striving for world carbon neutrality by mid-century. Together with this global commitment, the European Union (EU) launched in 2019 its Green Deal [1] seeking to decouple the European economy from energy and resource use and aiming to become carbon neutral by 2050. Under this framework, the EU has launched a set of climate actions to achieve these goals (cf. European Climate Law [2] and European Climate Pact [3]). In line with these, the Member States had to submit their National Energy and Climate Plans (NECP) for the period 2021–2030 [4], where, similarly to the NDCs regarding the Paris Agreement goals, each country must define its transition roadmap in accordance with the EU targets.

At lower scale, cities have also committed their efforts towards sustainable development. At EU level, the Covenant of Mayors for Climate and Energy (CoM) [5] has been gathering since 2008 those local governments which voluntarily have committed to achieve and even exceed the EU climate and energy targets, reducing their GHG emissions and ensuring access to secure, sustainable and affordable energy for all. In a similar way as for the countries and their NECPs, cities commit themselves to submit a Sustainable Energy and Climate Action Plan (SECAP)

* Corresponding author. TECNALIA, Basque Research and Technology Alliance (BRTA), Astondo Bidea, Edificio 700, Derio, 48160, Spain.
E-mail addresses: inigo.munoz@tecnalia.com (I. Muñoz), patxi.hernandez@tecnalia.com (P. Hernández), estibaliz.perezi@ehu.eus (E. Pérez-Iribarren), diego.garcia@tecnalia.com (D. García-Gusano), eneko.arrizabalaga@tecnalia.com (E. Arrizabalaga).

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which must serve as a roadmap to achieve the pledged goals. Since urban areas in the EU embody 75% of the total population of the region [6], this initiative addresses a field which represents a large share of the region's final energy consumption. Globally, similar initiatives have also risen, gathering municipalities and other non-state actors which have pledged themselves to reduce their environmental impact [7–13].

However, despite these ambitious commitments and initiatives, efforts to effectively bring them to fruition are far from being a reality, hindered, in part, by the lack of coordination amongst the different agents of the energy system. The decarbonisation of the world energy system is indeed a challenge that involves actors across multiple levels [14]. In order to be effective, carried out actions should be coordinated among the several scales which integrate the whole system. Actors ranging from global to local levels should harmonise their planning frameworks and actions to align their roadmaps [15]. Low-level strategies should be built in accordance with the upper ones to achieve major objectives. On this concern, the balanced coordination of local and national strategies has not been carried out efficiently yet, while the absence of methodologies consistently quantifying the part played by cities in the achievement of upper energy and climate targets makes this harmonisation an even more challenging task.

This paper evaluates the alignment of urban and national energy plans. The objective is to determine the part that cities should play in the implementation of national energy and climate strategies and to assess how and to what extent energy efficiency and mitigation actions planned at urban level support the fulfilment of national goals. To this purpose, a method to downscale, adapt and allocate specific targets and energy measures from the national to the local scale is proposed. The transposition of specific energy measures from the national to the local level and their subsequent modelling at the city scale, allows to assess and quantify the reach of their impacts, while supporting the establishment of realistic goals which should drive cities long-term energy plans. In short, this study aims to provide insights on the alignment of urban and national energy and climate strategies looking for their correct coordination and for the effective contribution of cities towards the fulfilment of upper climate goals. The downscaling of national policies into local strategies and plans is of utmost relevance due to the important role of cities in decarbonising societies.

This paper is structured as follows. Section 2 reviews the impact and contributions of energy and climate actions carried out at local level, identifying the challenges faced in the planning and setting of climate goals at urban level. Section 3 presents the approach proposed for the transposition of national measures to the local level and the quantification of the contribution of urban energy plans towards the fulfilment of national energy targets. The suitability of the methodology is further demonstrated in section 4 for the Spanish city of Valencia. Results are then discussed in section 5, while conclusions of the whole analysis are summarised in section 6.

2. Literature review

Concentrating 64% of the world primary energy consumption and being responsible of about 70% of the CO_2 energy-related emissions [16], cities have become increasingly relevant in the fight against climate change. This significance has been reflected in the increase of initiatives and strategies focusing on actions at urban level. Cities have set themselves climate objectives and developed local action plans including mitigation and adaptation measures to reduce their impact on the environment. Considering that urban areas are embedded in a national and global context, actions carried out by local authorities should be aligned and coordinated with upper instances to be effective.

2.1. Urban energy plans and climate objectives

In the last years, urban energy plans have been developed [17,18], a part of them being fostered by city networks initiatives. City networks gather municipalities around climate-related objectives and engage local authorities in meeting them through the development of roadmaps and deployment of mitigation (and in some cases adaptation) measures. These initiatives have revealed themselves as an efficient tool to support the fulfilment of climate objectives in absence of national legislation on this concern by boosting voluntary commitments [19,20], influencing the governance, policies and measures of cities which address climate change [21], advancing knowledge and methods for climate change mitigation at local scale [22], achieving energy consumption reductions [23], and supporting urban adaptation [24]. Moreover, city networks are especially influential over small municipalities, usually with less experience and resources to tackle climate change. Whereas larger cities may develop their plans independently or in response to national legislation without requiring any support due to a higher level of climate awareness, broader knowledge in energy planning, and greater institutional capacity [25].

It should be noted that the development of city energy plans and fulfilment of urban climate goals is not an exclusive task of local authorities. Other municipal actors like individual citizens, private companies, neighbourhood communities, NGOs, and other local stakeholders should be considered as they have an important role to play in urban energy planning [26–28]. Indeed, these municipal stakeholders can support the elaboration of urban energy strategies like the cities networks initiatives, by providing different types of knowledge and perspectives, increasing the participation in the decision-making, and reaching agreements regarding common goals [29,30].

Regarding the set-up of energy and climate-related objectives at urban level, these should take into account the current situation of the city and its background. Kennedy et al. [31] stated that city characteristics had an impact on the strategies developed to reduce emissions. The International Panel on Climate Change (IPCC) remarked that the longer the time horizon and greater the wealth of cities, the higher abatement goals [32]. Although ultimately, baseline emissions usually drove the level of emission reductions to be achieved, i.e. higher emissions in the base year imply higher intended reductions [33–35]. Moreover, urban climate targets should not be outlined as "political statements or aspirational goals" away from the real capabilities of cities as this could lead to their non-compliance [34]. That is, targets should not be set arbitrarily and should reflect true mitigation potentials. Per capita metrics are more meaningful than absolute ones to track urban abatement goals [32]. Also, urban goals should not be directly translated from upper objectives but adapted to the local context. Pasimeni et al. [14] advocated for the downscaling of upper policies to the local level so that these could be tailored to the urban conditions in order that municipalities could effectively contribute to higher objectives from a bottom-up approach. Furthermore, Maya-Drysdale et al. [15] verified a lack of long-term visions in the planning frameworks of cities. These rather focused on medium-term goals which were revisited when the time came, thus leading to a discontinuity in the long-term planning. Moreover, cities had not their objectives connected to the national ones, which caused problems when establishing long-term and integrated strategies. Leal and Azevedo [36] remarked the lack of alignment and continuity between local short/medium-term goals and global long-term targets and referred to the unsuitability of setting the same objectives, in relative terms, for cities with different starting point situations. Altogether, as concluded by Lemon et al. [37], there is still a need of methodologies which clearly adjust upper climate objectives to lower scales.

2.2. Accounting and allocation issues at city level

Due to the complexity of urban systems, the quantification of urban emissions and energy use reveals itself as a difficult task, hindering the development of energy plans and the setting of targets at city level. Indeed, based on the boundary definition (administrative, functional, or morphological [32]) and on the accounting approach (production-based or consumption-based [32,38–44]) different results may be obtained, The scope and accounting approach selection has also a pivotal impact on the allocation of competences and responsibilities, crucial aspects in the build-up of harmonised multi-level strategies.

Regarding urban energy accounting, the IPCC [32] highlighted the impact of choosing a consumption-based or production-based approach on the accounting of energy and emissions. As urban areas are transitioning from industrial to tertiary centres (especially in developed countries), most of the emissions currently occur outside the boundaries of cities. Thus, the impact of embodied energy in urban areas is higher and hidden in production offshoring and import of finished goods. If not accounted, this may give a false impression of decarbonisation and decoupling. To quantify the impact of this embodied energy at local level, Input-Output models have been developed allowing to correctly assess the carbon footprint of urban areas [45–50].

Another interesting remark regarding the differences in the emissions inventories depending on the chosen approach was highlighted by Dodman [51] and Kennedy et al. [52]. The authors noticed that emissions per capita in cities were lower than their national counterparts as the formers usually included emissions from agriculture, industry and intra-national mobility that are not accounted in urban inventories. However, when embodied emissions (from food, services, and produced goods) were allocated to the cities, emissions per capita resulted to be similar at both national and local level. Using the accounting framework and nomenclature defined by the GHG protocol [53], Tong et al. [54] estimated the share of carbon emissions from Chinese cities while Wang et al. [55] assessed the emissions from 39 worldwide cities from the C40 network. The authors concluded that local authorities could act directly on emissions from scope 1 (accounting for the GHG emissions released within the city boundaries), which may be considered as the mitigation potential under the capacity of the city. Although beyond the competences of the city, emissions from scopes 2 (accounting for the electricity grid related emissions) and 3 (accounting for the emissions embodied in the goods and services consumed within the city) could lead to significant changes in the urban GHG inventories if considered.

On this concern, some studies remarked that the main reductions may be originated from factors outside the decision-making capacities of cities. Kennedy et al. [52] and Azevedo and Leal [56] stressed that most of the main reductions achieved at local level were related to the decarbonisation of the national electricity grids (scope 2), thus out of the range of the competences of municipalities. Reductions due to other factors like demographic and socioeconomic changes could also exceed the reductions achieved by the actions planned and carried out by local authorities [56,57]. The effect of these exogenous impacts should be isolated when crediting cities for their achievements, so that the real contribution of cities to national/global goals is not blurred, overestimated, nor wrongly calculated.

2.3. The multi-scope urban decarbonisation challenge

The different challenges faced in the definition and accomplishment of urban climate related targets indicate the need of a holistic approach when planning and carrying out climate actions at local level. Cities do not act as isolated energy systems but are rather embedded in a complex and wide network where energy, climate change and land-use interact, having an impact across different space and temporal scales (municipal-short term, country/regional-medium term, and global-long term) [14,16]. As stated by Thellufsen et al. [58] municipalities should find their part to play in a way that the whole system is benefited. Cities should act locally but being aware of the national and global context in which they are framed. Maya-Drysdale et al. [15] argued about the need of an integrated approach to decarbonise the energy systems of European cities. The authors pleaded for the development of holistic long-term strategic visions, and open-minded scopes when considering structural changes in the energy system. Reviewing the Danish planning framework, Krog and Sperling [59] stated that national, regional, and local levels should be considered simultaneously when conducting strategic energy planning. The authors added that the neglect of national targets by cities could lead to sub-optimisation and potential non-achievement of national goals. It is also worth to note that energy modelling is neither exempted from this need of integrating multiple scales, in order to effectively support multi-level governance of energy transitions [60].

Energy use that occurs in urban areas does not only depend on the consumption sources lying within the city borders but is also influenced by external factors which have an impact on the city itself. National/supranational policies and regulations are out of the jurisdiction of municipal authorities but exert a relevant influence in the energy performance and decarbonisation strategies of the city too [61,62].

External impacts out of the scope of the city competences should be considered and jointly managed by local and supralocal entities in order to handle their effects on the city energy consumption. Hsu et al. [63] remarked the need of the integration of governance levels “beyond and below the state”. Holtz et al. [64] developed a framework to support low-carbon transition developments considering the contribution and competences of urban areas. Corfee-Morlot et al. [65] advocated for an intertwined framework in which urban initiatives would improve nationally led policies by providing lessons learnt, while the upper policies would foster more efficient and tailored locally led climate strategies. Sperling et al. [66] stated that municipal energy planning should be framed within the national energy strategy while at the same time responsibilities should be given to local institutions along with the required support and tools to carry out energy planning. Pietrapertosa et al. [20] highlighted that municipalities may require attention and support from higher instances to conduct climate actions in a coordinated way. The CoM tried to find a solution to this problem through the creation of the “Covenant Territorial Coordinators” (CTCs) formed by provincial, regional, metropolitan, or groupings of local authorities, which support smaller municipalities in their contribution and coordination towards the fulfilment of objectives set for larger territorial areas [19].

Altogether, harmonisation and integration of policies between institutional levels and across jurisdictional borders is still required, along with the alignment of targets and measures [32,37,59]. Cities may have jurisdiction over core energy elements such as buildings, public transport, or urban planning (which out of the scope of national frameworks may provide additional reductions), but would often need support from national governments to be successful in carrying out integrated energy plans, as they lack from financial resources and legislative capacities to enact effective energy policies [16,37]. Hence, local governments should be granted with competences and executive authority to enforce energy and climate actions with deeper impacts and supported with sufficient funding. To achieve this, an integrated governance environment comprising the multiple levels involved in the energy transition should be put in place too [16,32].

2.4. Contribution to existing literature

The evaluation of the effectiveness of climate governance at subnational level stills a field of further research [63]. Indeed, few information is available on the accomplishment of urban climate targets, and the impact of mitigation actions at local scale remains uncertain or even non-evaluated [32]. Literature on the assessment of cities and other subnational entities contribution towards global and national climate targets is fragmented [67] and opposing views can be found. On the one hand, some studies concluded that the implementation of climate-related actions by local and other subnational actors would slightly complement the reductions managed by national entities but would not be enough to reach the Paris Agreement goals [18,68,69]. On the other hand, some authors suggested that efforts made by subnational entities would be in line with upper goals [17,70], and may even overachieve national-set targets in some cases [34,71].

To assess the share of cities in the fulfilment of national climate objectives, the previous studies based their approach on the scale-up of low-level actions to estimate the impact of their net aggregation at national level. Hsu et al. [34], Kona et al. [70], Reckien et al. [17], and Salvia et al. [18] focused on the aggregation of targets in urban energy plans to evaluate if cities were on track to fulfil the goals set by their respective countries. Kuramochi et al. [71] aggregated the impact of commitments by Non State Actors (e.g. regions, cities and businesses) to quantify their emissions reduction potential, while Roelfsema et al. [69] used an Integrated Assessment Model to evaluate the reduction potential of Transnational Emission Reduction Initiatives. Both studies estimated the overlap between these low-level initiatives and the national-driven measures. Ramaswami et al. [72] developed a methodology to measure the effect of local actions toward China's national mitigation target. This aggregation focus is however often incomplete as remarked by Hsu et al. [73]. The authors highlighted the complexity of quantifying the impact of climate change mitigation actions carried out by subnational actors. They stated that the contribution of these players remained uncertain mainly due to disperse data, overlap issues, and the absence of methodologies to consistently account for this subnational scale contribution.

Conversely to these bottom-up methods, a top-down approach is proposed in this paper: starting from the national level, a share of savings to be achieved by the city is allocated to it. That is, national targets are adapted and transferred downstream from the country to the local level. Downscaled goals can be compared with the ones from existing urban energy plans, allowing to assess the current and the expected contribution of urban areas towards national energy objectives. Moreover, the novelty of this approach also derives from its applicability to design municipal targets aligned with national goals. For instance, Geissler et al. [74] detected the need to downscale national targets. Centred on the alignment of municipal spatial planning and national energy and climate plans, the authors performed a guideline to assist municipal policymakers by looking at diagnosis, legal competences, potentials, and coordination. Present study goes in the same direction but focusing on the harmonisation of national and local energy planning, supported by modelling results. On this concern, Hofbauer et al. [60], stated that it is very important to understand to what extent model-based analyses explicitly integrate assumptions regarding another governance scale. Not only through exogenous inputs concerning macro assumptions such as energy costs or national-level decisions (e.g. national grid development) like in the work of Yazdanie et al. [75], but considering hypotheses with a higher detail and specificity applying to the local context (e.g. households to be renovated or vehicles to be removed from the streets). In that sense, current work presents an innovative approach based on the transposition and further modelling of national energy targets and measures at city level, that pursues to be in the vanguard of performing better and more robust urban energy and climate plans.

Finally, since most of the key energy planning and policymaking are still decided at the national level [76], the downscaling approach will serve to accurately translate this strategic planning to a lower level and to establish local strategies aligned with upper goals. It also fills the gap regarding the guidance required by local authorities to carry out effective and coordinated actions on their own [37,66]. Finally, the proposed methodology complements the works by Leal and Azevedo [36] and Gao et al. [77] who developed methodologies for target-setting at city level. Indeed, these works allocated total emissions reduction quotas for the whole city based on per capita metrics. Conversely, the present study defines energy savings targets for particular measures based on measure-specific criteria.

3. Method

The increase in the recent years of national climate commitments to decarbonise the economy and accelerate the energy transition should be reflected and translated to local strategies so that the build-up of city targets could drive new projects and more ambitious measures at urban level, while achieving national targets too. However, the current lack of coordination between cities and higher instances is hindering the efforts towards the fulfilment of this assignment. Thus, the correct and coherent downscaling and adaptation of national policies into urban strategies and plans is extremely relevant in order to structure an integrated and harmonised energy transition strategy. At the same time, this is a very challenging task due to local specificities, economic structures, and jurisdictional competences. Furthermore, no criteria is set in how cities should adopt national objectives.

The aim of this study is to overcome these issues by determining how to adequate measures from the national plan (which by virtue of responsibility and competence fall under the scope of municipal stakeholders) to the urban level. To support the design of local strategies harmonised with upper ones and coordinate the decarbonisation efforts from both levels, the proposed method is based on the downscaling of national measures to the local scale. Specific goals and actions are transposed and allocated to the city according to its characteristics and capacities, while complying with national main objectives. In addition, the suggested approach also allows to assess the performance of current urban energy plans regarding their alignment with the national strategy by quantifying the degree of compliance of the local-implemented measures with the corresponding ones from the national plan.

Not all the measures from national plans are or can be transposable to the urban level. Local specificities and jurisdictional frameworks hamper the downscaling of certain measures. The proposed method targets the ones eligible at local level, i.e. measures from urban end-use sectors on which city stakeholders can act. Whereas some measures lie under the jurisdiction of national authorities (e.g. national power grid development), others are usually left to municipal responsibility. That is, national administrations may transfer a set of competences to local authorities in certain domains. Accompanied by funding, municipalities are then responsible for converting these grants into projects and specific measures at urban level. Thus, energy and climate actions centred on fields out of municipal competences are not contemplated (e.g. industry, agriculture, inter-cities mobility, or national electricity system). Conversely, the methodology is focused on the transposition of measures which fall under the competence of local stakeholders such the energy efficiency measures in the building and intra-mobility fields.

The overall procedure of the methodology is described in Fig. 1. On a first step, matching measures from both national and city energy plans are identified from the ones within the competences of local stakeholders. Secondly, these measures are downscaled and adapted to the local conditions through the use of specific and coherent criteria. Third, the adjusted measures are modelled and finally their achieved savings compared to the estimated reductions presented in the energy plan of the city. This allows to quantify to what extent measures from the former comply with what is assigned to the city by the national plan. Hence pointing out urban planners if the city plan is in line with the national strategy, or whether it needs an overhaul.

The downscaling criteria used in this method relies on accessible data and the selected factors are coherent with the sectors in which they are applied. Their selection is based on specific indicators for each end-use sector (e.g. building or vehicle stock, and expenditures on home appliances) and which are usually available for both levels (national and local). The proposed methodology is yet open to use other criteria to downscale the national measures to the local level based on data availability, thus making easier the replication of the method to other cities. Furthermore, the downscaling approach can be used not only to assess existing plans, but also to develop new urban energy plans and set-up city goals in accordance with national ones.

4. Case study

In this section, the methodological approach described in the previous section is illustrated using the Spanish case of Valencia, which

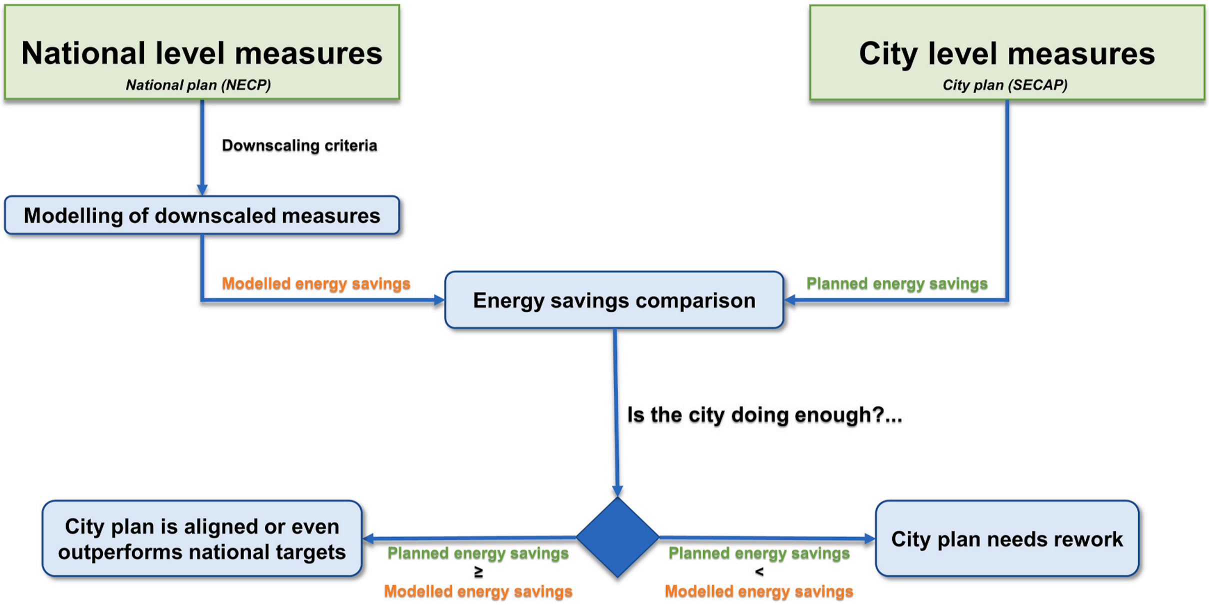

Fig. 1. Methodological approach for the coordination of national and local energy planning.

amongst the three most populated cities in the country (Madrid, Barcelona, Valencia), is the only one with updated 2030 mitigation goals. First, Spain's and Valencia's energy and climate plans are reviewed. Second, the considered measures in the analysis from both levels are explained. Finally, the downscaling and modelling of the assessed measures is described.

4.1. National and city energy and climate plans review

4.1.1. Spanish NECP

Framed on the national long-term strategies through which EU countries aim to comply with the Paris Agreement goals and the EU long term strategy, the Spanish National Energy and Climate Plan [78] represents the roadmap in which the country defines its energy strategy until 2030. Like the rest of the NECPs, the Spanish one is structured into five main dimensions. For each one of them, objectives and measures are included. The plan comprises a total of 78 measures. A description of the dimensions and their specific 2030 targets is shown in Table 1.

The plan was developed using the TIMES-SINERGIA model in combination with other macroeconomic, health, power system and environmental models. The TIMES-SINERGIA is a bottom-up optimisation model developed within the TIMES modelling framework [79], which covers the useful energy demand for different energy services through a combination of operational and investment decisions, minimising the cost of the energy system over the considered horizon, for the different scenarios proposed in the model [78]. Indeed, two scenarios were created: a scenario With Existing Measures (WEM) and a scenario With Additional Measures (WAM). The former creates a trend vision without new additional measures, whereas the latter includes the planned measures that lead to the fulfilment of the 2030 objectives. The plan includes the evaluation of the current situation and the projections for both scenarios, as well as the environmental and macroeconomic impact assessment of the planned measures.

Last but not least, the Spanish plan remarks the role to be played by

Table 1
Description of the Spanish NECP dimensions and their associated targets.

Dimension	Main goals	Specific targets	Number of included measures
Decarbonisation	• Decarbonisation and electrification of the end-use sectors • Renewable energy sources integration in both final energy consumption and power generation	23% reduction of GHG emissions compared to 1990 42% use of renewable energy sources in final energy consumption (31% in heat & cold sector and 28% in transport sector) 74% use of renewable energy sources in power generation	26
Energy efficiency	• Energy efficiency improvement • Long-term building renovation strategy • Energy efficiency in public buildings strategy	39,5% energy efficiency improvement compared to the EU PRIMES reference scenario 2007 36.809 ktep total cumulated savings in final energy consumption in the 2021–2030 period	17
Energy security	• Energy dependency reduction • Diversification of energy sources and supply • Preparation against possible limitations or interruptions in the energy sources supply • Flexibility increase of the national energy system	Reducing the energy dependency from 73% in 2017 to 61% by 2030	6
Internal energy market	• Electric interconnection improvement • Renewable energy sources integration in the national grid • Optimisation of the electric market • Strengthening of the gas market • National Strategy against Energy Poverty	Reaching a 15% interconnectivity by 2030	11
Research, innovation and competitiveness	Development and funding of research and innovation programmes	Investments of at least 2,5% of the GDP in research and innovation programmes	18

Table 2
Valencia's SECAP 2030 objectives.

	Base year (2007)	Objective (2030)
40% reduction GHG emissions (kton $CO2_{eq}$)	2.684	1.610
27% energy savings (GWh)	9.698	7.079
27% RES in final energy consumption (GWh)	32	1.911

national, regional, and local administrations. Sharing competences in several topics, the participation and coordination between the different levels is required to achieve the transition to a low-carbon society and the decarbonisation of urban areas.

4.1.2. Valencia SECAP

Located by the Mediterranean Sea and with a population of 800.215 inhabitants (2020), Valencia is Spain's third largest city. The city signed the CoM in 2009 and published its Sustainable Energy Action Plan (SEAP) for the period 2010–2020 the following year [80]. In 2015, the city renewed its commitments and launched its SECAP [81] in 2019.

SECAPs are the result of the pledges of cities to the CoM initiative. This initiative fosters the development of urban energy planning by committing the partner cities to mitigate and adapt to climate change. Table 2 shows the 2030 objectives to which the city of Valencia has engaged itself, including the main commitment of the CoM signatory cities of reducing 40% their emissions by 2030 (with respect to the base year of their choice).

As determined by the CoM commitments, the SECAP includes a baseline emission inventory and a climate risk and vulnerability assessment. The plan includes 123 mitigation and 86 adaptation measures.

4.2. Measures downscaling

Within the Spanish NECP measures, only the ones eligible at the city level have been considered. From Table 1, measures included in the “Energy security”, “Internal energy market”, and “Research, innovation and competitiveness” dimensions have been excluded as their actions concern national-level competences.

Energy supply related measures included in the “Decarbonisation” dimension of the national plan have been excluded from the analysis. While the development of decentralised renewable energy generation systems within municipalities is a key issue in city energy plans, direct comparison with national energy supply strategy is not possible, as the former is mostly related to large renewable energy installations which have no place in urban environment.

Finally, the “Energy efficiency” dimension integrates measures from the building, mobility, industry, and agriculture sectors. Out from the 17 measures included in this dimension, 7 have been extracted and matched with 14 corresponding measures from the city plan. Indeed, only the ones with quantified targets, directly transposable to the urban level, and applicable to city end-use sectors (where local stakeholders have the capacity to act) have been selected and compared. This results in the measures analysed being essentially distributed amongst the building and urban mobility sectors, where the municipality has the power to intervene (e.g. through the renovation of specific city areas, traffic restrictions, or public transport promotion). On the contrary, agriculture and industrial sectors, besides from being normally located outside urban borders, remain outside the jurisdiction of local authorities. Moreover, regarding the relevance of buildings and transport-related measures, it should be noted that the Spanish NECP estimates that 69% of the cumulated savings to be reached in total final energy consumption in the 2021–2030 period (see Table 1) is to be achieved within these sectors. Actions in these areas can therefore be considered a priority.

The downscaling of the national-level measures and their linkage with the city-level ones are further described in the next sections, while achieved savings from the downscaling of the NECP measures to the local level are compared to the estimated SECAP savings in section 5.

4.2.1. Residential buildings

To quantify the savings obtained through the downscaling of the measures at local level, the energy characterisation and further modelling of Valencia's residential building stock has been performed combining a bottom-up approach with top-down data. Indeed, following a bottom-up perspective, the residential building stock of the city has been clustered by construction period and typology (i.e. housing blocks (HB) or single family houses (SFH)) thanks to cadastral data [82]. Moreover, different combinations of energy systems for space heating and domestic hot water (DHW) have been defined for each household typology based on regional statistical data [83]. Table A.1 in appendix shows the final disaggregation of Valencia's residential building stock. For each construction period and building typology, useful energy demands for every energy service in the residential sector have been considered based on the EU EPISCOPE-TABULA project [84] (see Table A.2 in appendix), along with efficiencies for each energy system (see Table A.3 in appendix). Lastly, the distribution and efficiency data of space heating and DHW systems have been adjusted to match the actual final energy consumption reported in the city statistical yearbook [85], which in turn has been disaggregated by energy service based on regional statistical data [86] Disaggregated residential sector final energy consumption is shown in Table A.4 in appendix.

With the building stock characterised, building-related measures are downscaled and their implementation at city level modelled. Assessed measures from both national and urban plans are displayed in Table 3, as well as their description and their national-local relationship.

4.2.1.1. Measure “2.6 energy efficiency in existing buildings of the residential sector”. This measure consists of two specific actions: the renovation of the dwellings envelope and the renovation of the energy systems for space heating, DHW, ventilation and cooling. The first step consisted in determining the number of renovated households envelopes and renovated energy systems which should be allocated to the city. This assignment has been performed based on the Spanish long-term energy

Table 3
Residential sector assessed measures.

NECP measure	NECP measure description	SECAP measure	SECAP measure description
2.6 Energy efficiency in existing buildings of the residential sector	Envelope renovation of 1.200.000 households by 2030 (from a considered package of 16.598.127 [87])	M.d.5 Building envelope renovation	Renovation of the thermal insulation and enclosures in around 2%–4% of the city's dwellings
	Heating and cooling systems renovation in 3.000.000 households by 2030	M.d.9 Boilers renovation	Renovation of the thermal energy systems and diversification of the fuels used for heat applications in around 5%–15% of the city's dwellings
		M.d.10 Cooling equipment renovation	Replacement of the old cooling systems by more efficient ones in around 10%–30% of the city's dwellings
2.7 Renovation of the residential equipment	Substitution of 2.443.000 old appliances annually	M.d.4 Appliances renovation	Replacement of the low-graded appliances by highly efficient ones in around 10%–30% of the city's dwellings

renovation strategy in the residential sector [87] (aligned with the Spanish NECP) which allocates the number of households (separating them by typology and construction period) whose envelopes are to be renovated for every Spanish region. Based on statistical data from national [88] and regional [89] databases, the specific number for the city has been extracted and is shown in Table 4. It should be noted that the national renovation strategy do not consider the households built after 2007 to be renovated. Also, in the case of Valencia's region, the renovation strategy neglects the housing blocks from 1981 to 2007, as it considers they are not a priority.

From Table 4 it can be found that households that renovate their envelopes in Valencia represent 1,24% from the targeted national stock. The same percentage has been considered for the households which should renovate their heating and cooling systems. Thus, if the national plan establishes that 3.000.000 households should replace their heat and cold systems at national level, 37.167 dwellings in Valencia should substitute theirs. It should be noted that households whose envelopes are renovated (14.868 dwellings) are considered to renovate their energy systems for space heating and cooling as well. Hence, from the 37.167 dwellings that renovate their heating and cooling systems, 22.299 do so without renovating their envelope. Fig. 2 shows the yearly number of households in Valencia that whether sustain the renovation of both their envelopes and heating and cooling systems or only renovate the latter. Nevertheless, the impact of both actions (envelope renovation and heating and cooling systems renovation) is assessed jointly.

To calculate the energy savings achieved, it has been assumed that the envelope renovation entails a reduction in the space heating and cooling useful energy demands of the old dwellings that are renovated. Considering that, renovated households manage to reach the post-2007 dwellings standards (see Table A.2 in appendix). Regarding heating systems renovation, old boilers and heaters are replaced by new condensing boilers and new heat pumps in a 30%/70% proportion respectively, thus assuming the partial electrification of heat demand. Improved efficiencies of the new energy systems are shown in Table A.3 in appendix.

4.2.1.2. Measure "2.7 renovation of the residential equipment". This measure establishes the annual renovation of 2.443.000 home appliances like refrigerators, freezers, washing machines, dishwashers, dryers, and ovens at national level. This number has been downscaled at local level, and a number of devices to be yearly replaced have been allocated to the city.

Firstly, considering an average price for such devices [90], the total expenditure associated to this measure at country level has been estimated. Secondly, the average expenditure per person on home furnishings and appliances at both city and country level have been extracted from Ref. [85]. Considering the respective populations, it has been estimated that 1,9% of these expenses at national level takes place in the city of Valencia. Thus, it has been determined that 45.771 devices should be annually replaced in the city. Table A.5 in appendix shows the considered assumptions to calculate the achieved savings through the replacement of home appliances.

Table 4
Households whose envelopes are to be renovated by 2030 in Valencia and Spain according to Spanish NECP.

	Construction period	Valencia	Spain
Single Family Houses (SFH)	<1900	144	25.377
	1901–1940	299	40.973
	1941–1960	590	83.203
	1961–1980	834	167.067
	1981–2007	447	241.662
Housing Blocks (HB)	<1900	275	9.094
	1901–1940	697	20.002
	1941–1960	1.705	73.345
	1961–1980	9.877	388.302
	1981–2007	0	151.054
	TOTAL	**14.868**	**1.200.079**

4.2.2. Private tertiary and municipal buildings

As for the residential sector, the energy characterisation of the tertiary buildings has been carried out. On the one hand, private and public services aggregated final energy consumption has been extracted from the city statistical yearbook [85]. On the other hand, the gross floor area of the city tertiary sector has been extracted from the latest cadastral data available [82]. Regarding municipal buildings, their gross floor area has been issued from city statistics [85]. Final energy consumption has been disaggregated by energy service using the European Commission and Joint Research Centre database [91]. Final results are shown in Table A.6 in appendix, while Table 5 summarises the assessed measures in the private tertiary and public buildings.

4.2.2.1. Measure "2.8 energy efficiency in buildings of the tertiary sector". This measure focuses on the implementation of energy efficiency measures (comprising the renovation of buildings envelopes, heating and cooling systems, and lighting devices) in private and public tertiary buildings. To allocate a yearly amount of floor area to be renovated in the city, the number of tertiary buildings from both local [82] and national level [92] databases has been compared, observing that 1,94% of the country's tertiary buildings are located in Valencia. Accordingly, a proportional allocation of the floor area which should undergo an energy renovation has been assumed. Considering that the measure from the Spanish NECP establishes that 5.000.000 m^2 should be yearly renovated at national level, 1,94% of this floor area (96.978 m^2) has been assigned to the city. Moreover, it has been also considered that 3% of the municipal buildings gross floor area endure energy efficiency improvements. Hence, 42.317 m^2 of municipal public buildings and 54.661 m^2 of private tertiary buildings should sustain energy efficiency measures every year in the city of Valencia according to the NECP measure downscaling. Table 6 shows the current city's tertiary gross floor area and the total gross floor area to be renovated by 2030 separated by municipal and private tertiary buildings.

Regarding the modelling of the savings in this sector, reductions shown in Table A.7 in appendix have been considered. This table displays the energy savings achieved in the different tertiary buildings energy uses thanks to the implementation of energy actions such envelope renovation, heating and cooling systems replacement and lighting renovation [87]. Achieved savings in the buildings of the sector have been calculated considering the yearly floor area that sustain energy efficiency measures and applying the estimated savings (see Table A.7 in appendix) to the final energy consumptions defined for each subsector and energy service (see Table A.6 in appendix).

4.2.3. Transport

For the calculation of the energy savings achieved by the downscaling of NECP transport-related measures to the local level, LEAP energy modelling tool [93] has been used. LEAP features a transport analysis method which computes the final energy consumption of the transport sector based on the expected evolution of vehicle stock (current stock, vintage profile, and sales of road vehicles in the city have been issued from Ref. [94], average mileage from Ref. [95], and fuel economy from Ref. [96]). Vehicle stock is calculated based on sales data and the decommissioning of old vehicles (i.e., vehicle stock evolves as a result of the retirement of old vehicles and the introduction of new ones). Table A.8 in appendix shows the final disaggregation of the city's vehicle stock and summarises the different assumptions, whereas Table 7 describes the transport sector assessed measures and their national-local linkage.

Addressing the same action field (transport needs reduction and modal shifts), NECP measures "2.1" and "2.2" have been downscaled, modelled, and compared against their corresponding SECAP measures

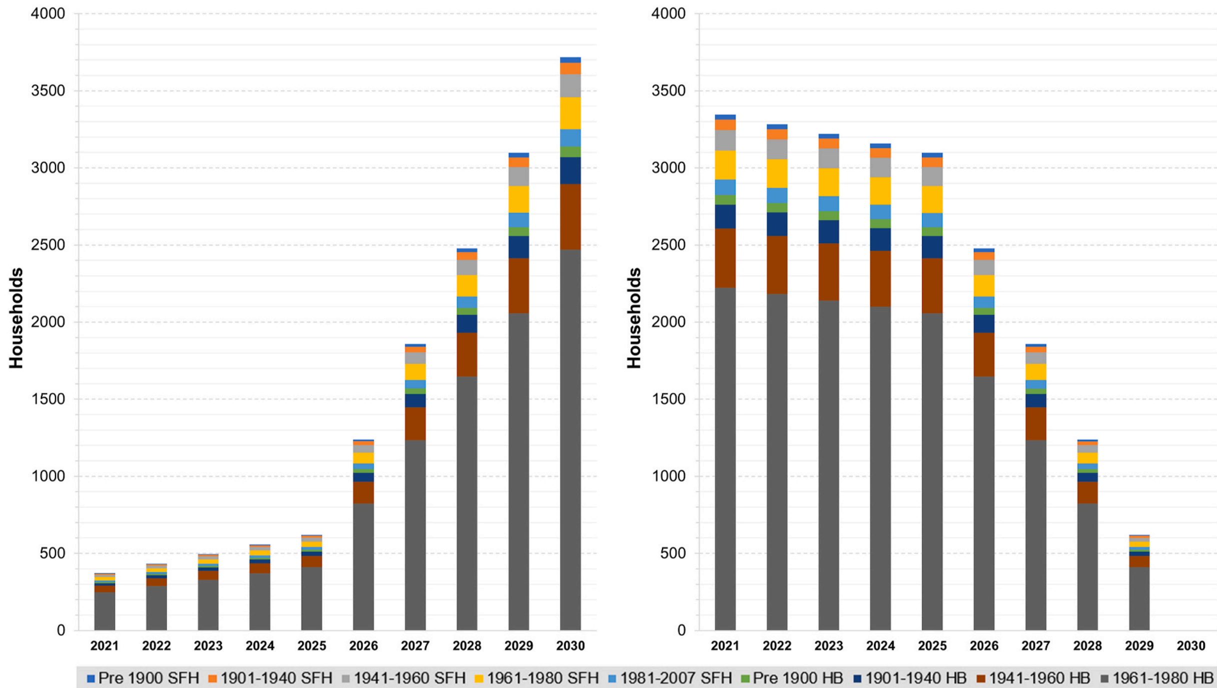

Fig. 2. Households renovating both their envelopes and heating and cooling systems (left) and only renovating their heating and cooling systems (right) every year in Valencia.

Table 5
Private tertiary and municipal buildings assessed measures.

NECP measure	NECP measure description	SECAP measure	SECAP measure description
2.8 Energy efficiency in buildings of the tertiary sector	Yearly energy renovation of 3% of the public buildings' gross floor area	M.a.13 Lighting renovation	Replacement of lighting devices in the concerned buildings
		M.a.14 Indoor lighting presence control	Installation of motion sensors in the concerned buildings
		M.a.15 Climatisation demand optimisation	Envelope renovation, energy systems renovation, management and control of the energy demand in the concerned buildings
	Yearly energy renovation of 5.000.000 m^2 gross floor area from tertiary buildings (both private and public)	M.e.7 Lighting renovation	Replacement of the old lighting bulbs by more efficient ones in the concerned buildings
		M.e.8 Building envelope renovation	Renovation of the thermal insulation and enclosures in the concerned buildings
		M.e.11 Boilers renovation	Renovation of the thermal energy systems and diversification of the fuels used for heat applications in the concerned buildings
		M.e.12 Cooling equipment renovation	Replacement of the old cooling systems by more efficient ones in the concerned buildings

jointly. The same approach has been adopted for the measures "2.3" and "2.4" (fleet renovation and electrification). Table 8 describes the specific modelling assumptions of the two assessed packages of measures which are developed in the next sections.

4.2.3.1. Measures "2.1 low emission zones and modal shifts" & "2.2 efficient use of transport". Spain's NECP considers feasible to reduce traffic by 35% in urban environments by 2030. Similarly, 15% of interurban transit should decrease by 2030. Both reductions should be achieved through the establishment of Sustainable Urban Mobility Plans at local levels and Travel to Work plans, fostering the reduction of transport demand, modal shifts towards public transport and non-motorised means as walking or cycling, and optimising the journeys.

To assess the impacts of the adaptation of the national measures to the city's scale, the mileage of the vehicles has been lowered to model the traffic reduction assumed by the national plan. In line with this one, a 35% reduction of all vehicles mileage has been established by 2030. This reduction is considered to affect the journeys which take place within the city boundaries. Aligned with the Spanish NECP too, and concerning the interurban trips, an additional 15% mileage reduction allocated to the distance travelled inside the city has been assumed. Moreover, starting from this baseline reduction, a modal shift has been considered assuming the modal changes estimated by the national plan. Table 9 displays the changes in mileages due to the transposition of the national transport-policies targets.

The assumed reductions and shifts within the road vehicles mileage

Table 6
Municipal and private tertiary current gross floor area and gross floor area to be renovated by 2030 in Valencia.

	Municipal buildings	Private tertiary buildings	TOTAL
Total gross floor area (m^2) (2018)	1.408.898	14.276.509	15.685.407
Total gross floor area to be renovated (m^2) (2030)	423.169	546.613	969.782

Table 7
Transport sector assessed measures.

NECP measure	NECP measure description	SECAP measure	SECAP measure description
2.1 Low emissions zones and modal shifts	This measure includes: • 35% reduction of passenger-km in urban areas by 2030 (and 1,5% reduction annually in inter-urban commutes) through modal shifts • Establishment from 2023 onwards of delimited central areas with restricted access to the most emitting and polluting vehicles in all the Spanish cities with more than 50.000 inhabitants • Development of Sustainable Urban Mobility Plans and Travel to Work plans	M.f.5 Sustainable Urban Mobility Plan	Drafting and implementation of a Sustainable Urban Mobility Plan. (Includes actions such as walking and cycling promotion, regulation to the city centre, restrictions on polluting vehicles, public transport fostering)
		M.f.20 Travel to Work plans	Travel to work and freight transport routes optimisation
2.2 Efficient use of transport	Foster a more rational use of transport by optimising the freight transport and by promoting the shared mobility concept	M.c.2 Efficient driving courses for municipal and public transport services employees	Raising awareness amongst professional drivers and training them to save fuel by means of efficient driving techniques. Already tested courses in the city reached 14% saving in fuel consumption
		M.c.3 Speed controllers in public cars	Installation of speed controllers in the concerned municipal vehicles to limit speed
		M.c.8 Routes optimisation	Routes optimisation of public transport and municipal services vehicles. The plan estimates a 1%–3% travels reduction
2.3 Vehicle fleet renovation	Promotion of more efficient vehicles to achieve additional savings to those obtained by the natural renovation of the vehicle fleet	M.c.5 Public vehicle fleet renovation	Replacement of the old vehicles by new ones using electricity or biofuels
		M.c.9 Public transport fleet renovation	Replacement of the old vehicles by new ones using electricity or hybrid/natural gas technologies
		M.f.2 Private vehicle fleet renovation	Replacement of the old vehicles by new ones using electricity or biofuels. The plan estimates that between 10% and 30% of the private fleet will use alternative fuels by 2030
2.4 Electric vehicle fostering	Introduction of 5.000.000 electric vehicles (EVs) by 2030	Measure implicitly considered in M.c.5, M.c.9, and M.f.2	

Table 8
Modelling assumptions of the two assessed packages of transport measures.

	Measures 2.1 & 2.2	Measures 2.3 & 2.4
Stock evolution/ renovation rate	Stock renewal follows the historical trend	Stock renewal follows the historical trend
Fuel economy	Introduced new vehicles have improved fuel economy. Besides, fuel economy of all vehicles worsens as vehicles age	Introduced new vehicles have improved fuel economy. Besides, fuel economy of all vehicles worsens as vehicles age
Mileage	Distances travelled by all vehicles are reduced. Besides, all vehicles drive less kms as they age	Distances travelled by all vehicles remain constant. Besides, all vehicles drive less kms as they age
Sales evolution	Introduced new cars are predominantly fossil-fuelled with a shift from diesel to gasoline in line with the pattern of the recent past years. Penetration of alternative fuel vehicles stays low	Penetration of new EVs is increased. Sales of fossil-fuelled vehicles are reduced to a very low level (especially in motorcycles, light utility vehicles, and buses)

implicitly contemplate the transport demand decrease and the change towards other means of transport (e.g. walking, cycling, or rail transport). Additionally, a 10% fuel economy improvement by 2030 is also taken into account representing the implementation of efficient driving techniques for professional drivers as stated in the national plan. This efficiency improvement is considered in light utility vehicles and buses.

4.2.3.2. Measure "2.3 vehicle fleet renovation" & "2.4 electric vehicle fostering". The Spanish national plan underlines the role of the vehicle fleet renovation in the improvement of the energy efficiency in the transport sector. It is important to highlight that the NECP does not assume a faster or more aggressive rate of vehicle renovation but aims at a higher penetration of alternative-fuelled vehicles following the natural renewal of the fleet. The national plan focuses on the renovation of cars, two wheels, light utility vehicles, and buses and their substitution by more efficient and less pollutant ones (measure "2.3"). Alongside this natural renovation, the plan envisages the introduction of EVs replacing the old ones (measure "2.4"). Hence, additional savings to the natural fleet renovation are achieved through the introduction of more EVs, modelled via an increase of these vehicles total sales as shown in Fig. 3.

Table 9
Considered mileage changes in the downscaling of the NECP measures 2.1 and 2.2

Vehicle type	Urban traffic reduction	Interurban traffic reduction	Modal shift	Total mileage reduction by 2030
Cars	−35%	−15%	−5%	−55%
Two wheels	−35%	−15%	0%	−50%
Light utility vehicles	−35%	−15%	0%	−50%
Buses	−35%	−15%	+3%	−47%

The number of EVs allocated to the city has been calculated as follows. The Spanish NECP plans the introduction of 3.000.000 electric cars and 2.000.000 electric two wheels, light utility vehicles, and buses by 2030. Following the national current stock distribution and the share of Valencia's vehicles over the national aggregate [94], Table 10 shows the EVs to be introduced in Valencia by 2030.

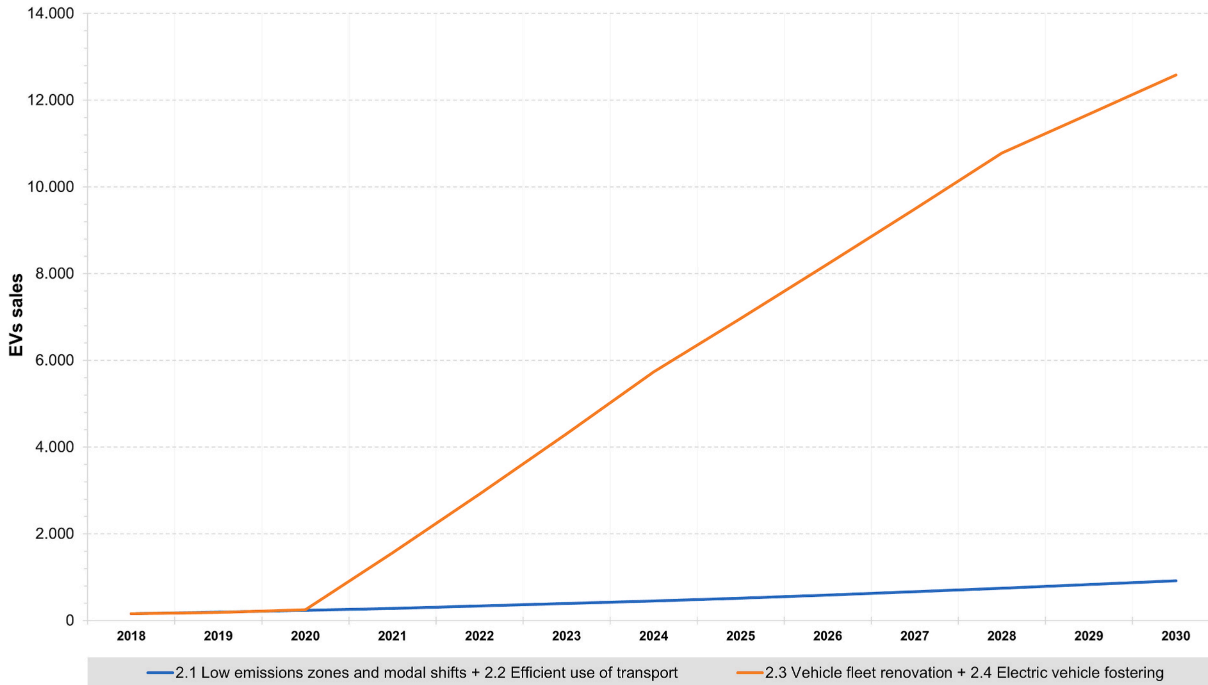

Fig. 3. Comparison of EVs sales in Valencia in the two modelled packages of transport measures.

Table 10
Number of EVs to be introduced in Valencia and Spain.

Vehicle type	Share of Valencia's fleet over national fleet	2030 national EVs objective	2030 EVs allocated to Valencia
Cars	1,47%	3.000.000	44.052
Two wheels	1,79%	1.183.036	21.149
Light utility vehicles	0,97%	796.884	7698
Buses	1,73%	20.080	348

5. Results and discussion

5.1. Modelling results

After modelling the downscaled measures of the Spanish NECP to the city of Valencia, results obtained by 2030 are compared to the savings expected by the city's SECAP measures. Fig. 4 shows the comparison results between the SECAP estimated savings and the downscaled modelled results from the NECP for the buildings-focused measures of both plans.

In the residential sector, SECAP measures associated to the NECP measure "2.6 Energy efficiency in existing buildings of the residential sector" report a saving of 45.151 MWh in 2030 against the resulting 77.015 MWh from the NECP downscaling. In a similar way, SECAP only estimates a reduction of 35.637 MWh by 2030 as opposed to the 112.914 MWh obtained from the adaptation to Valencia of the NECP measure "2.7 Renovation of the residential equipment". These results show that SECAP measures do not meet the targets set by the NECP downscaling for the residential sector.

Concerning tertiary buildings, SECAP measures estimate a total saving of 13.778 MWh by 2030 in public buildings, whereas the downscaling of the NECP measure "2.8 Energy efficiency in buildings of the tertiary sector" only yields a reduction of 9.319 MWh. Regarding private buildings, SECAP targets a total saving of 67.201 MWh by 2030, while the national plan only allocates a reduction of 15.969 MWh to the city.

These results show that the tertiary buildings energy reduction target allocated to the city by the national plan is considerably lower than the one estimated by the city plan. This means that either the city SECAP is highly ambitious or the adaptation of the NECP is too conservative. On this concern it should be remarked that the Spanish NECP only assumes that a considerably low 5% of the national gross floor area of the tertiary sector would sustain energy efficiency measures by 2030. As it can be extracted from Table 6, the downscaling of the measure results on a 6% of the tertiary gross floor area of the city to be renovated by 2030. Thus, the implementation of energy measures is carried out on a very small amount of area, therefore yielding low energy savings. On the other hand, it should also be noted the low traceability of the energy savings estimated by the city's SECAP: neither the considerations for the savings estimation nor the number of buildings where the plan measures are implemented are detailed.

Fig. 5 displays the comparison of results between the estimated savings by the city plan and those obtained from the downscaling of the national one for the transport measures taken from both plans.

On the one hand, the downscaling of the Spanish NECP measures "2.1 Low emission zones and modal shifts" and "2.2 efficient use of transport" achieves a total saving of 803.194 MWh by 2030, while the corresponding measures of the SECAP estimate a reduction of 903.181 MWh. On the other hand, the SECAP only returns a reduction of 133.115 MWh by 2030 compared to the 201.001 MWh calculated through the adaptation of NECP measures "2.3 vehicle fleet renovation" and "2.4 Electric vehicle fostering" to the city level.

Regarding the differences obtained in the transport measures some remarks can be made. SECAP measures focusing on modal shifts return higher savings than the downscaling of the NECP measures, indicating that the local plan outperforms the reductions allocated by the national strategy to the city. Nevertheless, the considered SECAP measures such as the SUMP and Travel to Work plans do not detail the specific actions carried out within them nor how they achieve the resulting savings. This may warp the planned reductions. Concerning the renovation and electrification of the vehicle fleet, the SECAP intends to reach 1%–3% EV by 2030, whereas the downscaling of the NECP measures achieves a 14% electrification of the city's fleet (see Table 11). The SECAP assumes however the introduction of other type of vehicles (hybrids and biofuels)

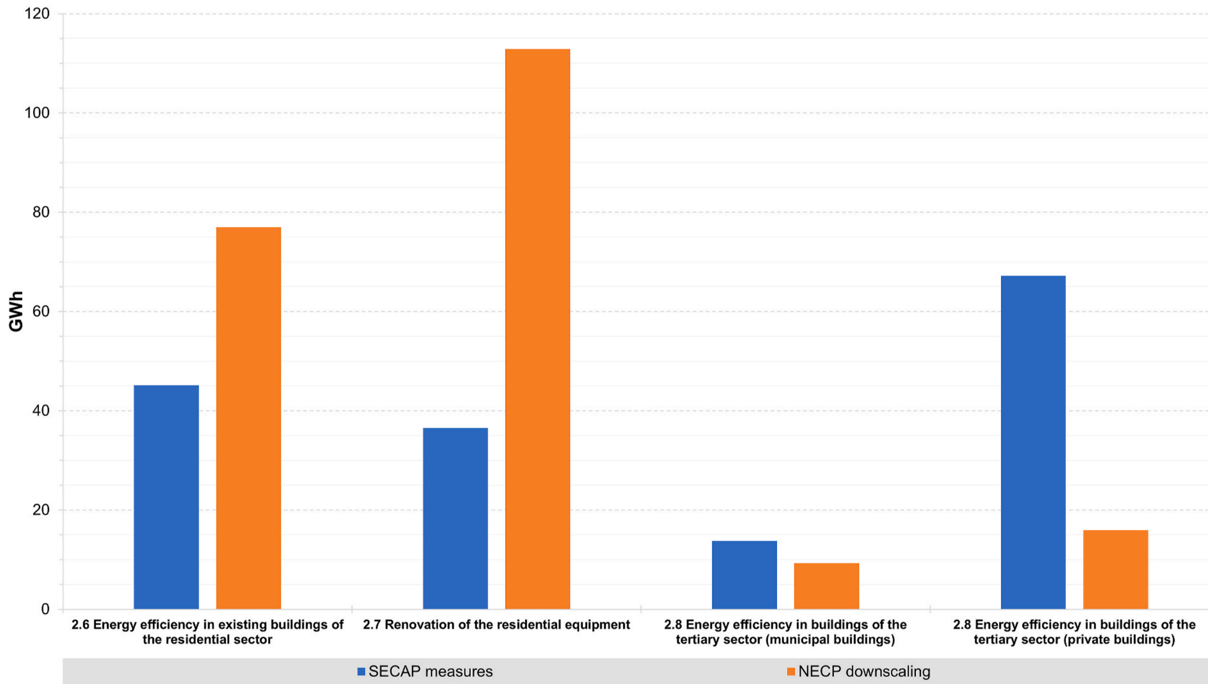

Fig. 4. Comparison between the achieved savings (in final energy consumption) estimated by the city SECAP and the ones obtained from the downscaling of NECP measures for the residential and tertiary sectors.

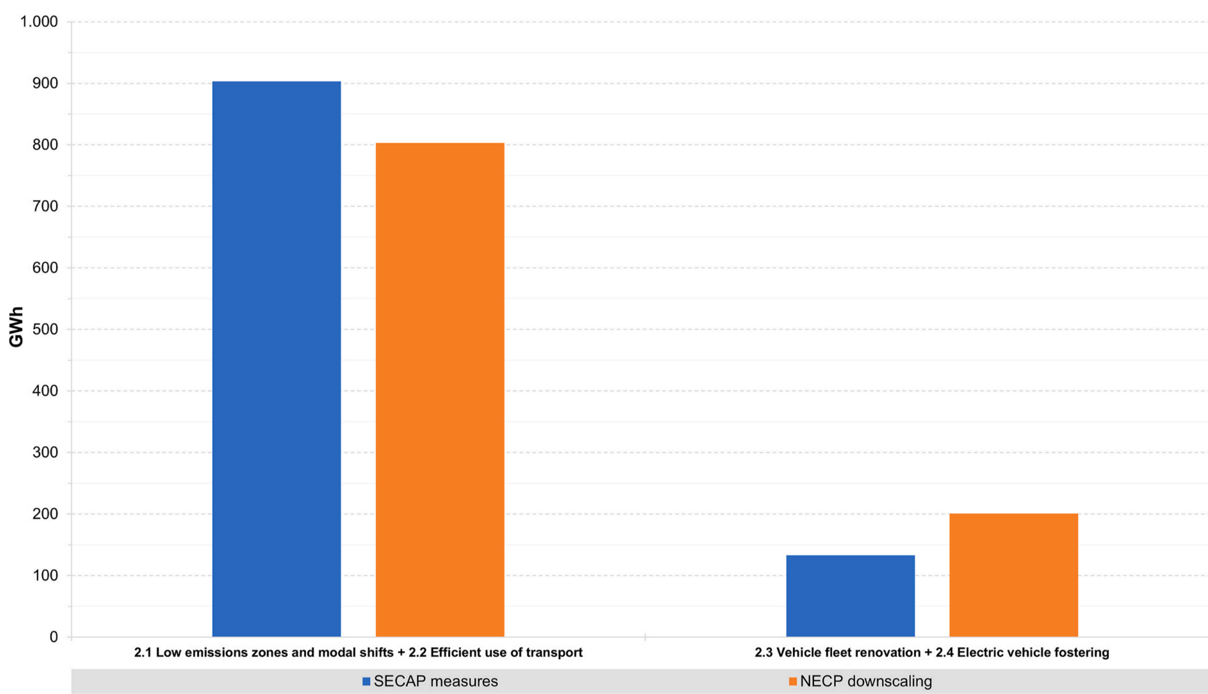

Fig. 5. Comparison between the achieved savings (in final energy consumption) estimated by the city SECAP and the ones obtained from the downscaling of NECP measures for the transport sector.

which have not been considered in the downscaling of the measures (as the national plan does not specify them) and that may explain the relative high compliance with the downscaled national measure despite the low electrification ratio of the city's fleet planned by the local plan. As a summary, Table 11 displays in quantified specific actions the out-performances and shortcomings of the city's SECAP with regard to the NECP.

Altogether, the results show that the city's measures were not fully aligned with the national plan. Valencia should increase its efforts in the residential sector by raising the number of buildings to be renovated and appliances to be replaced. Similarly, the city should apply more aggressive actions to reach the number of EVs allocated by the national plan to it. Not aligned, but in a positive way, the city measures planned in the tertiary sector (and especially in private tertiary buildings) achieved higher savings than those allocated by the national plan. This effort could be however oriented to fulfil the fields where the city

Table 11
Specific actions comparison between the measures from the SECAP and the downscaling of national measures to the local level.

SECAP measure	NECP measure	Specific action	SECAP quantification	NECP transposition quantification	Downscaling criteria
M.d.5		Dwellings to renovate their envelopes	2–4%	5%	Dwellings to be renovated according to [87]
M.d.9	2.6	Dwellings to renovate their heating systems	5–15%	13%	Transposed from the dwellings to renovate their envelope
M.d.10		Dwellings to renovate their cooling systems	10–30%	13%	Transposed from the dwellings to renovate their envelope
M.d.4	2.7	Dwellings to renovate their appliances	10–30%	42%	Average expenditure on home appliances
M.a.13, M.a.14, and M.a.15	2.8	Tertiary floor area to renovate its envelope, heating and cooling systems, and lighting devices (municipal)	Non specified	30%	City/country tertiary buildings ratio
M.e.7, M.e.8, M.e.11, and M.e.12		Tertiary floor area to renovate its envelope, heating and cooling systems, and lighting devices (private)	Non specified	4%	City/country tertiary buildings ratio
M.f.5, M.f.20	2.1	Traffic reduction	Non specified	−35% urban traffic (and −15% inter-urban traffic)	Directly transposed from NECP
M.c.2, M.c.3, M.c.8	2.2	Driving optimisation	Non specified	10% efficiency improvement	Directly transposed from NECP
M.c.5, M.c.9, and M.f.2	2.3 + 2.4	Share of EV in city fleet by 2030	1–3%	14%	City/country vehicle fleets ratio

underscores.

5.2. Discussion

In light of the results, the accurate transposition of national measures and their adaptation to local conditions is essential. Actions implemented at urban level must be planned with a comprehensive approach and coordinated through the multiple levels in which the city is framed in order to be effective. The downscaling methodology presented in this paper allows to allocate and to distribute targets from the national to the urban level, while considering the local context and its specificities.

When developing urban energy strategies, the setting of feasible local targets is key. These should be based on the correct adaptation of national measures to the local conditions and on the accurate estimation of obtainable savings at city level. The wrong transposition of measures and the wrong calculation of their impacts could lead to the establishment of reduction targets which may look easily reachable, but which are in fact unachievable at local level. Indeed, there is an uncertainty in the estimation of savings planned in Valencia's SECAP. Most of the measures contemplated in it rely on indirect actions (e.g. awareness campaigns, taxation policies, or subsidy programmes) whose impacts are hardly quantifiable. Moreover, with an action range limited to municipal assets, Valencia's SECAP relies on indirect tools to influence private stakeholders. Urban policymakers should consider how to act upon fields out of their direct scope and define targets and measures in a clear and realistic way. Unachievable and meaningless actions should be avoided. Furthermore, the method to calculate the impacts of the actions of the city plan needs to be reviewed and fine-tuned to prevent oversized or hardly justifiable results. Energy modelling may serve as a powerful instrument in the definition of feasible targets and strategies, and to accurately estimate the impacts of measures. At national level, NECPs base their goals and actions on the modelling of energy scenarios. At local scale, the modelling of city energy scenarios would support the development of urban energy plans [97]. Drafted strategies can be accurately assessed and different pathways to comply with national targets can be explored.

Besides the reworking of cities methods to calculate the impacts of their measures, the selection of the downscaling criteria used in this case study might be revised too. Indeed, since data availability may differ depending on the city and country, other factors could be considered (e.g. climatic conditions for heating and cooling related measures, building and vehicle stock age to determine buildings to be refurbished or vehicles to be replaced, or other socioeconomic indicators to allocate specific goals to the city). Modellers may therefore use other criteria as long as these are consistent with the measures being transposed. Downscaling criteria used in this case study can serve as a reference for using other similar factors that might be available.

Finally, it is worth to mention two relevant aspects in climate governance and policymaking that have not been addressed in this study: the economic and the environmental dimensions. Concerning the cost analysis of the downscaled measures, it should be noted that the measures from the national plan may be considered as mandatory for local and other subnational authorities to implement if the objectives of the national strategy are to be met. Therefore, the prioritisation of measures based on their economic performance would not be the objective here. Instead, the adequate downscaling and distribution of the budgeted investments in the national plan amongst the different administrations and stakeholders would be a more suitable approach in this case. Indeed, the downscaling focus may be of interest to allocate budget lines from the national plan to the different subnational entities. The transposition of specific measures and energy savings to be achieved by cities may allow to quantify the amount of funding to be handed over from the national plan budget to local authorities for them to fulfil these downscaled measures and targets. Regarding the emissions analysis, energy planners and policymakers should be aware in discerning the real impacts allocable to local actions. On this concern, the decarbonisation of the national electricity supply is a nationwide decision which nevertheless has a local impact and could be used to report larger reductions on CO_2 emissions at city level. This in turn may incur on an overestimation of the achievable emissions savings and on the wrong assignment of abatement targets for cities. When establishing CO_2 reduction targets, cities should bear in mind that considering the grid decarbonisation will yield greater savings, yet these will be delusional and blur cities real achievements since these savings would be in part achieved thanks to the decarbonisation of the power supply, which is for the most part not under cities authority. Conversely, not assuming the grid decarbonisation will bring lesser reductions, although these being clearly a result of local efforts. Moreover, whether considering or not the decarbonisation of the grid will benefit and foster specific measures (electrification ones in the case of considering this effect, energy conservation measures otherwise). On this concern it is worth to note that cities should not exclusively hand over the fulfilment of their energy and climate targets to the decarbonisation of the national grid but achieve these goals through the harmonisation of different strategies such as energy demand reduction, energy efficiency, electrification, or RES exploitation. The impact of the grid decarbonisation in the transposition of targets at city level is shown in Figure A.1 in appendix where SECAP emissions reductions estimates are compared with the abatements reached by the downscaled measures considering the grid decarbonisation (through a variable electricity emission factor) or not (through a constant electricity emission factor).

6. Conclusions

The transition towards a low-carbon society involves several actors framed in multiple levels, ranging from supranational institutions to local stakeholders. On the one hand, countries have engaged themselves to tackle climate change via global and regional commitments. On the other hand, from a bottom level, cities are mobilising towards reducing their impact on the environment and improving the quality of life of their inhabitants. Gathering more than half of the world population, urban areas play a relevant role in the achievement of global energy and climate pledges participating in their fulfilment via the development and implementation of climate change mitigation actions at lower level. However, despite cities ambitions, there is a need for coordination in aligning local efforts to successfully contribute to the decarbonisation of national energy systems.

This paper has presented an approach to assess the alignment of local and national energy and climate plans and to transpose national targets to local contexts. Through the downscaling and modelling of the national plan energy measures, the proposed method allocates a saving target to the city. Depending on the measure, different criteria are used. The assigned reductions are then compared with those estimated by the city energy and climate plan showing the extent to which the former complies with the saving targets set for the city by the national plan. This methodological approach could support the update or development of new city energy plans by effectively aligning and coordinating the city plan with the national one, achieving an efficient contribution of urban areas towards higher climate targets.

A case study was carried out downscaling seven measures from the Spanish NECP to the city of Valencia. These were then compared with the corresponding ones in the city's SECAP. The city plan did not meet the expected reductions obtained through the downscaling of the national plan concerning the residential and transport fleet electrification measures. However, Valencia's SECAP proved to be more ambitious than the Spanish NECP regarding the tertiary and transport modal shift related measures: the urban plan yielding greater energy savings than the ones allocated to the city by the national one for these specific measures.

The assessment of the SECAP measures has shown that the impact of these are sometimes difficult to verify either because they are actions not involving direct savings or because the calculation procedures or assumptions are poorly referenced or even opaque. A revision of the methods used for the estimation of SECAP measures would be needed. Further to this, energy modelling reveals itself as a useful tool to estimate the achievable savings in a more accurate and traceable way, besides supporting the setting of feasible energy and climate goals aligned with higher ones.

Since both the national plan and cities plans will be updated in the upcoming years in accordance with their respective commitments, this methodology could be replicated in the revision of these urban energy plans and serve local authorities to design measures and strategies in line with the national plan. Regarding the former, this method may help national governments providing insights on how targets, tasks, competences, responsibilities, and investments should be efficiently distributed amongst the different subnational agents based on their context and capacities. To effectively accomplish targets at all levels, this common process, carried out at national and subnational scale, should be conducted in a joint and harmonised manner across the different administration layers. Moreover, future work may also address the quantification of the collective impact of cities. The allocation from the national plan of savings to key urban areas of the country could be aggregated providing an indication about the joint contribution of cities towards the achievement of national climate targets.

Credit author statement

Iñigo Muñoz: Conceptualisation, Methodology, Formal analysis, Writing – Original Draft, Visualisation, Patxi Hernández: Writing – Review & Editing, Supervision, Estibaliz Pérez-Iribarren: Writing – Review & Editing, Supervision, Diego García-Gusano: Conceptualisation, Writing – Review & Editing, Supervision, Eneko Arrizabalaga: Conceptualisation.

Table A.1
Valencia's residential building stock disaggregation (number of households).

	SPACE HEATING SYSTEM	No heating	No heating	Natural gas boiler	Heat pump	Electric stove	LPG stove	Electric stove	Heat pump	TOTAL
	DHW SYSTEM	Electric heater	Natural gas heater	Natural gas boiler	Electric heater	Natural gas heater	LPG heater	Electric heater	Natural gas heater	
SFH	Pre 1900	174	9	462	81	165	83	331	248	**1.554**
	1901–1940	755	40	1.996	352	715	358	1.431	1.073	**6.719**
	1941–1960	358	19	948	167	340	170	679	510	**3.191**
	1961–1980	337	18	891	157	319	160	639	479	**2.999**
	1981–2007	522	27	1.382	244	495	248	990	743	**4.651**
	Post 2007	102	5	269	48	96	48	193	145	**906**
	TOTAL	**2.248**	**118**	**5.947**	**1.050**	**2.131**	**1.066**	**4.263**	**3.197**	**20.020**
HB	Pre 1900	43	385	1.200	63	757	435	347	385	**3.615**
	1901–1940	153	1.381	4.309	227	2.719	1.562	1.246	1.382	**12.978**
	1941–1960	304	2.738	8.545	450	5.393	3.097	2.470	2.740	**25.737**
	1961–1980	1.414	12.723	39.710	2.090	25.060	14.392	11.479	12.733	**119.600**
	1981–2007	1.347	12.125	37.845	1.992	23.883	13.716	10.940	12.135	**113.982**
	Post 2007	292	2.625	8.194	431	5.171	2.970	2.369	2.627	**24.680**
	TOTAL	**3.553**	**31.977**	**99.804**	**5.253**	**62.983**	**36.171**	**28.851**	**32.001**	**300.592**

Table A.2
Considered useful energy demands for residential energy services (kWh/m^2.year).

	Construction period	Space heating	DHW	Cooling	Cooking	Lighting	Appliances
SFH	**Pre 1900**	10,39	10	7,53	2,93	4,52	20,37
	1901–1940	24,10		6,83			
	1941–1960	12,59		7,07			
	1961–1980	13,33		7,40			
	1981–2007	7,79		7,57			
	Post 2007	5,23		7,94			
HB	**Pre 1900**	13,16	15	5,12	2,93	4,52	20,37
	1901–1940	11,76		4,25			
	1941–1960	14,34		4,23			
	1961–1980	9,20		3,62			
	1981–2007	3,63		3,57			
	Post 2007	3,15		4,12			

Table A.3
Considered efficiencies for residential energy systems.

Space heating		DHW		Cooling		Cooking	Lighting	Appliances
Natural gas boiler	85%	**Natural gas boiler/heater**	69%	**Heat pump**	300%	100%	100%	100%
Heat pump	290%	**Electric heater**	81%	**New heat pump**	400%			
Electric stove	100%	**LPG heater**	60%					
LPG stove	70%	**New natural gas boiler/heater**	85%					
New natural gas boiler	95%	**New heat pump for DHW**	250%					
New heat pump	300%							

Table A.4
Disaggregated residential sector final energy consumption in Valencia in 2018 (MWh).

Energy service		Space heating				DHW				Cooling	Cooking		Lighting	Appliances	TOTAL
Fuel		Electricity	Natural gas	Light heating oil	LPG	Electricity	Natural gas	Light heating oil	LPG	Electricity	Electricity	Natural gas	Electricity	Electricity	
HB	Pre 1900	1.631	1.829	0	805	830	5.862	0	1.070	405	800	242	1.608	7.247	**22.330**
	1901–1940	5.229	5.866	0	2.581	2.978	21.043	0	3.842	1.208	2.873	870	5.773	26.016	**78.279**
	1941–1960	12.650	14.189	0	6.244	5.907	41.731	0	7.619	2.384	5.697	1.725	11.449	51.593	**161.187**
	1961–1980	37.710	42.298	0	18.614	27.448	193.919	0	35.407	9.477	26.473	8.017	53.202	239.747	**692.312**
	1981–2007	14.183	15.909	0	7.001	26.159	184.810	0	33.744	8.905	25.230	7.640	50.703	228.486	**602.770**
	Post 2007	2.661	2.985	0	1.314	5.664	40.015	0	7.306	2.230	5.463	1.654	10.978	49.472	**129.743**
SFH	Pre 1900	624	555	0	121	717	1.267	0	136	269	344	104	691	3.114	**7.942**
	1901–1940	6.254	5.569	0	1.212	3.099	5.479	0	587	1.055	1.487	450	2.989	13.469	**41.651**
	1941–1960	1.552	1.381	0	301	1.472	2.602	0	279	519	706	214	1.419	6.396	**16.841**
	1961–1980	1.544	1.375	0	299	1.383	2.446	0	262	511	664	201	1.334	6.012	**16.031**
	1981–2007	1.399	1.245	0	271	2.145	3.792	0	406	810	1.029	312	2.069	9.322	**22.800**
	Post 2007	183	163	0	35	418	739	0	79	166	201	61	403	1.817	**4.265**
	TOTAL	**85.620**	**93.365**	**0**	**38.798**	**78.220**	**503.706**	**0**	**90.736**	**27.938**	**70.967**	**21.491**	**142.618**	**642.692**	**1.796.151**

Table A.5
Assumed hypotheses for the modelling of measure 2.7.

	Refrigerator	Freezer	Washing machine	Dishwasher	Dryer	Oven	Source
% of households equipped	100%	14,6%	99,5%	42%	21,5%	94,9%	[89]
Devices in Valencia (devices to be replaced annually)	320.612 (12.287)	46.809 (1.794)	319.008 (12.226)	134.657 (5.161)	68.931 (2.642)	304.260 (11.661)	[89]
Specific consumption per device in Valencia (kWh/device)	962	820	374	360	375	336	Adjusted from [86]
Achieved saving due to energy labelling improvement	52%	52%	31%	31%	47%	49%	[90]

Table A.6
Tertiary sector final energy consumption by energy service and fuel.

Municipal buildings						
Final energy consumption (MWh)	Space heating	DHW	Cooling	Appliances	Lighting	**TOTAL**
Electricity	11.021	7.610	13.237	20.059	39.276	**91.203**
Natural gas	6.856	1.846	0	0	0	**8.702**
Light heating oil	796	224	0	0	0	**1.020**
TOTAL	**18.638**	**9.671**	**13.237**	**20.059**	**39.276**	**100.880**
Final energy consumption (kWh/m^2.year)	*13,23*	*6,86*	*9,40*	*14,24*	*27,88*	**-**
Private tertiary buildings						
Final energy consumption (MWh)	Space heating	DHW	Cooling	Appliances	Lighting	**TOTAL**
Electricity	146.042	100.849	175.404	265.805	520.454	**1.208.554**
Natural gas	105.359	28.365	0	0	0	**133.724**
LPG	0	27.042	0	0	0	**27.042**
TOTAL	**251.401**	**156.255**	**175.404**	**265.805**	**520.454**	**1.369.320**
Final energy consumption (kWh/m^2.year)	*17,61*	*10,94*	*12,29*	*18,62*	*36,46*	**-**

Table A.7
Assumed savings for the modelling of measure 2.8 modelling (From Ref. [87]).

Energy action	Energy service	Final energy saving
Envelope renovation	Space heating	14%
	Cooling	13%
Heating and cooling systems renovation	Space heating	30%
	Cooling	0%
	DWH	15%
Lighting renovation	Lighting	50%

Table A.8
Valencia current vehicle stock disaggregation and considered modelling hypotheses.

Vehicle type	Powertrain	Stock (number of vehicles)	Urban fuel economy (kWh/100 km)	Annual urban mileage (km)
Cars	Diesel	183.911	72	5.694
	Gasoline	173.414	75	5.694
	Electricity	123	17	5.694
	CNG	19	64	5.694
Two wheels	Gasoline	84.111	42	1.347
	Electricity	223	10	1.347
Light Utility Vehicles	Diesel	17.159	103	8.748
	Gasoline	5.646	107	8.748
	Electricity	28	24	8.748
	CNG	2	92	8.748
Buses	Diesel	1.040	438	23.449
	Electricity	0	103	23.449
	CNG	47	563	23.449

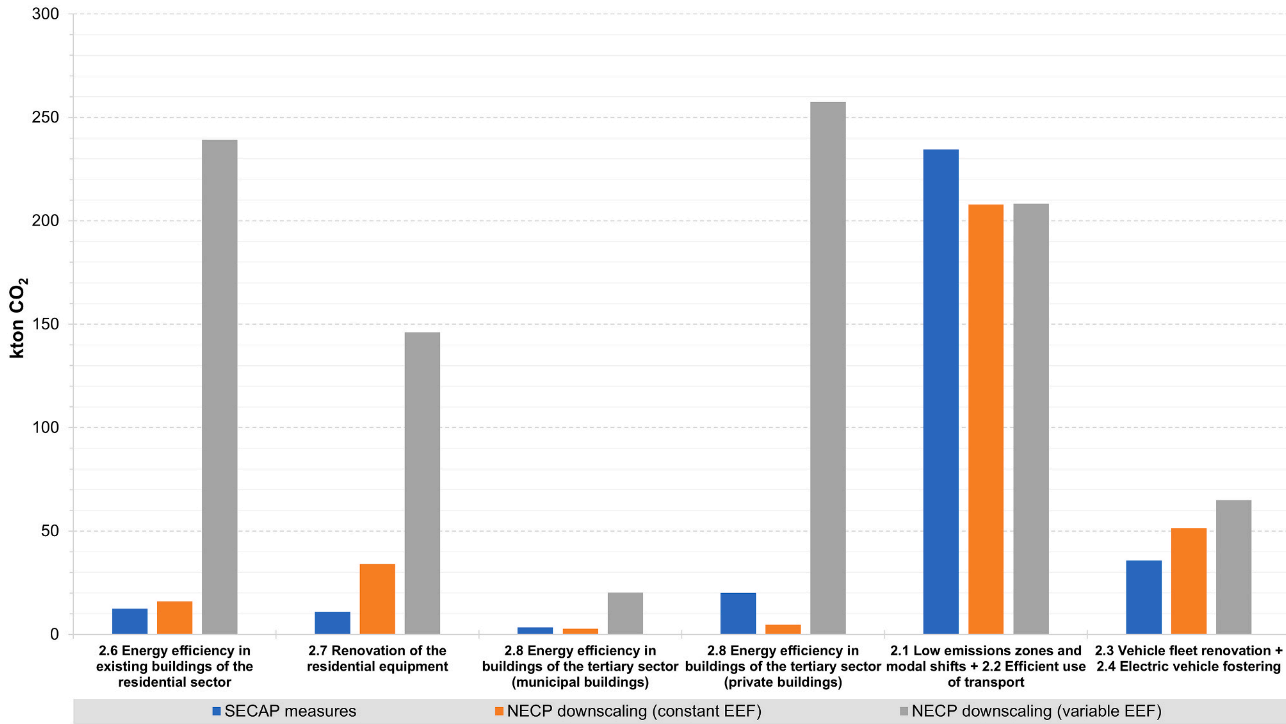

Fig. A.1. Comparison between CO_2 abatements estimated by the city SECAP (which assumed a constant electricity emission factor (EEF)) and the ones obtained from the downscaling of NECP measures considering the grid decarbonisation (variable EEF) or not (constant EEF). When not considering the grid decarbonisation, results are similar to the ones obtained in terms of energy, as the assessment is focused on the comparison of achieved relative savings and the same emission factors are used in both local and national levels. If the decarbonisation of the power supply is considered in the transposition of measures at city level, the city SECAP is far from reaching the allocated target for CO_2 savings. The differences whether considering a constant or variable EEF are greater in more electric-intensive sectors (like buildings), indicating that bigger reductions are achieved in these sectors when a variable EEF is assumed.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data used for the research described in the article is publicly available.

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