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Make your home carbon-free. An open access planning tool to calculate energy-related carbon emissions in districts and dwellings

Ivan Ligardo-Herrera [a,*], Alberto Quintana-Gallardo [b], Christian Wolfgang Stascheit [c], Tomás Gómez-Navarro [c]

[a] Faculty of Technology, Policy and Management, Delft University of Technology, Jaffalaan 5, 2628BX Delft, The Netherlands
[b] Centre for Physics Technologies (CTFAMA), Universitat Politècnica de València, Camino de Vera s/n, 46022, Valencia, Spain
[c] Research Institute of Energy Engineering IU-IIE, Universitat Politècnica de València, Valencia 46022, Spain

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ABSTRACT

Reducing the carbon emissions of buildings and whole districts is one of the main objectives of sustainable development goals. Both policymakers and end-users need reliable information to take actions that lead to achieving those goals. For this, an innovative open access planning tool has been developed to assess the effect of energy consumption on the overall carbon emissions of districts, buildings, and house units. When it comes to the end-users, it would help them know the actual environmental impact of their homes and make environmentally and financially sound decisions before investing in new equipment. The tool is meant to be an online planning service for dwelling end-users and policymakers alike; thus responding to a still unresolved demand. For this, firstly, the study focuses on the obtention of a complete catalogue of open-source conversion factors, which convert the different energy sources to carbon dioxide emissions per unit of energy. Secondly, it presents two case studies to illustrate the use of the tool. The first case study explains how an end-user could estimate the energy savings that may result from changing his domestic energy habits, equipment, and sources. The second case study uses actual data from a district in Valencia (Spain) to show how renewable sources would affect the carbon footprint of an apartment block. Both study cases show greenhouse gas emissions savings by replacing the existing equipment with more efficient ones such as heat pumps or renewable energy-based power systems like photovoltaic panels. This study concludes that providing smart tools is pivotal to planning nearly Zero-Energy Districts (nZED).

1. Introduction

As the third decade of the twenty-first century begins, the need to reduce the impacts humans have on the environment is more apparent than ever before. Due to the global warming effect produced by greenhouse gases (GHG), climate change is currently the main environmental concern worldwide (Anon, 2020). All economic sectors are responsible for climate change; however, their contribution is far from being the same.

As stated by the Intergovernmental Panel on Climate Change (IPCC) (Intergovernmental Panel on Climate Change, 2014), electricity and heat production for buildings accounts for 25% of the total carbon emissions in the world, greater than any other sector. According to the European Commission, buildings are responsible for half the materials extracted in the European Union and half the energy consumption (European Commission, 2014). In the Basket of Products indicator on Housing report, developed by the Joint Research Centre (Baldassarri et al., 2017), it is stated that the use phase of buildings represents 41% of the total energy consumption at the European level. Despite the massive environmental impact of material extraction and building operation, numerous studies indicate that the use phase of buildings is the main contributor to carbon emissions in buildings, (Baldassarri et al., 2017; Monteiro et al., 2020; Cabeza et al., 2014). Therefore, it is crucial to analyse how energy is consumed in buildings and to find ways to reduce it.

Cooling and heating, lighting, domestic hot water, and other domestic devices require a great amount of energy that rarely comes from renewable sources (Yuping et al., 2021; Khan et al., 2020; Famiglietti et al., 2021). For example, currently in Spain, less than 25% of the city districts' energy mix comes from renewable resources: 4.6% from solar power and, 19% from wind (Eurostat, 2021). Therefore, identifying and implementing cleaner

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[*] Correspondence to: Delft University of Technology, Faculty of Technology, Policy and Management, Department of Engineering Systems and Services, Jaffalaan 5, 2628, BX, Delft, The Netherlands.

E-mail addresses: i.e.ligardoherrera@tudelft.nl (I. Ligardo-Herrera), alquigal@upv.es (A. Quintana-Gallardo), c.stascheit@tu-braunschweig.de (C.W. Stascheit), tgomez@dpi.upv.es (T. Gómez-Navarro).

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energy sources while fostering the use of efficient technologies is a matter of great relevance (Manso-Burgos et al., 2021). The concept of Nearly-Zero Energy Buildings (NZEB) is currently gaining popularity and norms and regulations are starting to catch up.

In this context, projects like Tabula and Episcope successfully accounted for the relevance location has over the energy consumption of buildings (Anon, 2021a). However, while very informative, the results represent only the average typologies of each time and location. Due to the orientation, shape, and other specificities of each building, there can be a great disparity between the results of apparently similar buildings. Information adapted to specific sets of buildings and areas is needed to make smart and educated decisions regarding energy consumption in buildings (Sorknæs, 2021).

In recent years, several studies and research projects have scaled up their scope to focus on the energy consumption of districts rather than only focusing on individual buildings (Prades-Gil et al., 2021). In the same way as it was done with NZEB, the concept was named Nearly-Zero Energy Districts (NZED) (Marique and Reiter, 2014). Aspects like the position of public spaces, geometry, and the arrangement of buildings, on top of the ones above mentioned regarding energy sources, greatly influence the district's performance (Saheb et al., 2019; Amaral et al., 2018). Other projects have also dealt with the idea of creating Smart Grids for sharing clean energy in neighbourhoods (Loureiro et al., 2019). However, it is still difficult for local governments and the end users of the buildings to know the impact of such measures environmentally and economically (Fuster et al., 2020). The total cost of assessing the energy performance of each building individually would be enormous.

With the intention of finding a solution to those issues, the Urban Energy Transition Chair of the Universitat Politècnica de València (Catenerg-UPV) is currently developing a project to estimate the energy demand of each district in the city of Valencia (Aparisi-Cerdá et al., 2021). By using real building data, which in the case of Spain can be obtained from the national Cadastre (Prades-Gil et al., 2021; de Catastro, 2021), the aforementioned projects: Tabula and Episcope, and norm ISO 52016-1:2017 (ISO, 2017), it is possible to obtain a realistic approximation of the energy demand a building or a housing unit would have. The objective is to integrate all that information into a web mapping service, allowing access to both the local government and the end-users. Besides the calculation of energy consumption, another main point of this web service will be the assessment of the carbon emissions generated during the use phase.

Effectively, depending on the different sources of energy and the machinery involved, the energy consumption would have a different impact on Climate Change. The tool aims to inform how altering those parameters would affect the carbon emissions of a dwelling, building, or the whole district. Local governments are often reluctant to change due to the lack of reliable information about the impact their decisions would have. Developing tools such as this one can play a decisive role in helping policymakers make well-informed environmentally-oriented choices, clearing the path towards NZEDs. Besides, it would be a way of empowering the general population by letting them know how they can reduce their carbon footprint.

This study elaborates on the way the tool will deal with assessing the carbon emissions of districts, buildings, and house units. The development of an open-source database with the conversion rate from different energy sources, the outline of the inputs and outputs the tool will have, and two study cases are the main points this study covers. This involves analysing how to convert the energy consumption into Greenhouse gas emissions (i.e. CO_2e emissions) and how they will vary depending on the load curve, the energy source and machinery involved.

Due to this need to be an open access tool, obtaining open data is crucial. There are many reliable commercial databases, but free and comprehensive impact databases are scarce. Regarding the collection of the mentioned data, it must be taken into fact that, to be considered an open tool, the data supporting the tool needs to be open-source data. It also entails the early stage of the user interface, deciding which of the necessary inputs to perform the calculations will be provided by the user of the tool and which ones are inferred by the tool itself. Besides explaining the development of the tool as a whole, this study provides a framework on how to obtain reliable open-source data on conversion factors from energy sources to CO_2e emissions. The intention is to provide enough information to make this work transferable to other built environments around the globe.

The main contribution of this study is, on the one hand, to put forward a tool (the NZED CO_2-visual Planner module) that is neither too complex for the layman, the end user, nor too simple to be accurate. It fills a gap within the elaborated carbon footprint calculators, and the overall conversion factors. On the other hand, it is dedicated to Energy Transition in the built environment, a field of application in which there are still few proven calculators (Piccardo et al., 2020). Existing environmental impact assessment tools (The British Standards Institution (BSI), 2008; ISO the IO for S ISO 14064, 2009) and carbon footprint calculators (Carbon Footprint Ltd., 2002; EPA (USA), 2008; WWF, 2002; EPA Victoria and Education Services Australia Limited (Australia), 2011; The Nature Conservancy organization and CoolClimate (USA), 2015) require a high degree of precision and specialization of data, which is unknown to non-specialists (the majority of the population) in environmental assessment issues. Therefore, a new tool is needed that just requires input data known to all people, such as the address of their home, the load curve, or the energy consumption data (kWh/month) that they can easily find on their electricity or gas bill. In fact, the objective of this work is aligned with that of the Renewable Energy Directive (EU) 2018/2001 by which marketers are obliged to inform their consumers about the fuel used for electricity production and the energy efficiency of the system (European Union, 2018).

The NZED CO_2-visual Planner module is part of a set of modules under development by different research teams within the framework of an umbrella Project named "Nearly-Zero Energy Districts (NZED) in the city of Valencia" (Prades-Gil et al., 2021; Aparisi-Cerdá et al., 2021). To develop this novel module, conversion factors with open-source data have been designed. Also, the module's data inputs have been articulated with other modules' data outputs, all part of the umbrella project. In this way, the data generated by other modules, such as thermal demands of the buildings based on the data of the climate, the typologies of the buildings and the thermal loads inside and outside, or the feasible photovoltaic energy generation at the rooftop, feeds the NZED CO_2-Planner module directly. This allows the results of this tool visualized by maps and bars, to be aligned with the real needs of the district under study.

Therefore, the research question that this paper seeks to answer is: *How can a non-expert citizen (or policy-maker) calculate the greenhouse gas emissions generated by their home energy consumption (or those of a district) when thinking of implementing the retrofitting of his house (or a certain district)*?

2. Method

To answer this research question, a method has been designed, to develop a tool for the CO_2e emissions data visualization and energy consumption alternatives at dwellings (house, business, etc.), building and district level. As can be seen in Fig. 1, the method involves two stages: in the first stage, a literature review

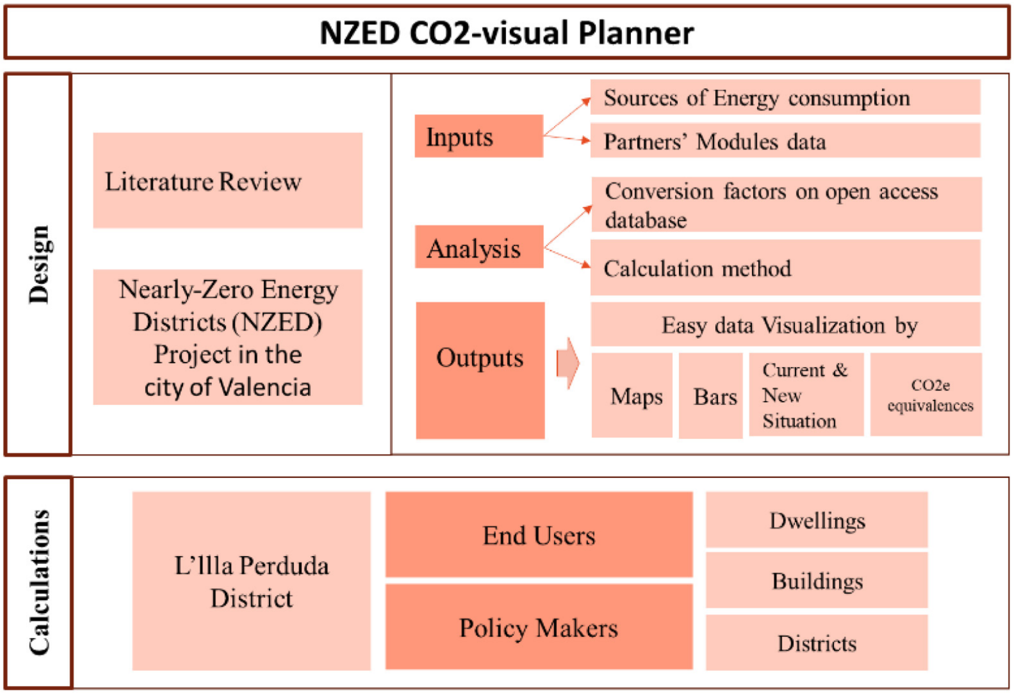


Fig. 1. Proposed method.

on carbon footprint tools and open source databases was carried out. This information was then integrated with the framework of the project "Nearly-Zero Energy Districts (NZED) in the city of Valencia" so that the Data planner could be fed by data from other NZED's project teams. Then the parameters of two methods for calculating carbon emissions, were followed, the input–output (IO) analysis and life-cycle assessment (LCA) (Gao et al., 2014; Peters, 2010). The second stage involved simulations (calculations) providing educational data on CO_2e emissions and energy consumption alternatives by building types, such as house and business units, buildings, and districts. The algorithm and interface are designed to be user-friendly for lay-people: end-users and policy-makers. Further details of the proposed method are described in Section 2.1.

To validate it, the CO_2- planner was applied to the Illa Perduda district of Valencia, Spain (see Fig. 2). Before the 20th century, the area was composed mainly of arable land. In 1962 a set of building blocks were constructed in that area. The Spanish dictatorship subsidized the construction primarily to provide dwellings for the people affected by the flood of the year 1957. Unfortunately for the already unfortunate families, the average quality of the buildings was very poor, like most of the building of that time. The location of the district within the city of Valencia is depicted in Fig. 2.

Today, the neighbourhood has a total area of 0.232 km^2 populated by 9360 inhabitants, so it has a high population density of approximately 40,345 inhabitants/km^2. On the other hand, the incomes of the inhabitants of the neighbourhood are traditionally low. This explains why most of the buildings today still have old and inefficient energy equipment, and a poorly insulated building envelope. Valencia is a city located in the western side of the Mediterranean basin. According to the Köppen classification, Valencia has a hot-summer Mediterranean climate, with mild winters and hot, dry summers (Beck et al., 2018; Pérez Cueva, 1994). The city is oriented opposite to the Atlantic current, which creates stable temperatures that range from 6–16 °C in winter and 22–30 °C in summer. These climate conditions translate into significant energy consumption for heating in winter and also considerable amount of energy for cooling, in those house units that have air conditioning. The average monthly temperatures are depicted in Fig. 3.

Recently, the ERESEE (Long term strategy for energy rehabilitation of the building sector in Spain) was released by the Spanish ministry of transportation, mobility, and urban agenda (Secretaría de estado de transportes movilidad y agenda urbana, 2020). This strategy is based on the Directive 2018/844 of the European Parliament and the Council of 30 May 2018 (Anon, 2018a). The ERESEE classifies the Spanish building stock into several building typologies called clusters. This classification is reflected in Table 1. Most buildings in the Illa Perduda district fit into the Bb 41-60 cluster. Buildings of that period are characterized by the absence of thermal insulation. Therefore, all the above-mentioned features make Illa Perduda interesting as a case study for developing ways of reducing its energy consumption. That is the reason why the municipality of Valencia is especially interested in districts such as this one.

The Basic Document for Energy Efficiency of the Spanish Technical Building Code (DB-HE CTE) classifies Valencia as a B3 zone. The letter refers to the severity of winters on a scale from A to E, and the number to the severity of summers, on a scale from 1 to 4. From 2007 to 2019, the envelope of buildings constructed in Valencia needed to have a maximum thermal transmittance of 0.82 W/m2K. Currently, the DB-HE specifies that the building envelope has to have a maximum thermal transmittance of 0.38 W/m2K, much lower than the standards during the sixties. As mentioned in the previous paragraph, before the passing of the first version of the DB-HE CTE (2007), not using thermal insulation was common practice. The enormous amount of buildings constructed prior to 2007 (Table 1) emphasizes the need for energy retrofitting in Valencia.

The following sections elaborate on the method, showing how the CO_2 planner was designed, and how the data were calculated and analysed.

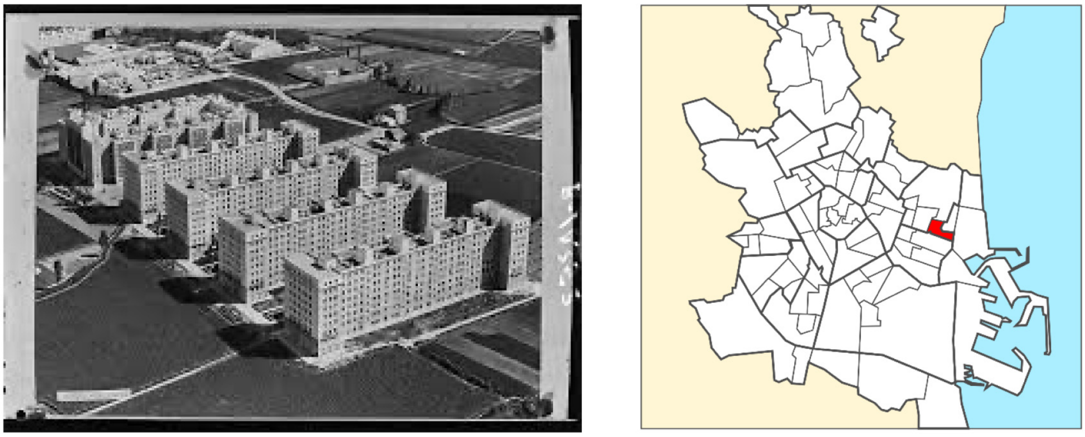


Fig. 2. Old picture (1962) and current location of the Illa Perduda district, well integrated in the city. © Enrique Íñiguez Rodríguez (CC-BY-SA)

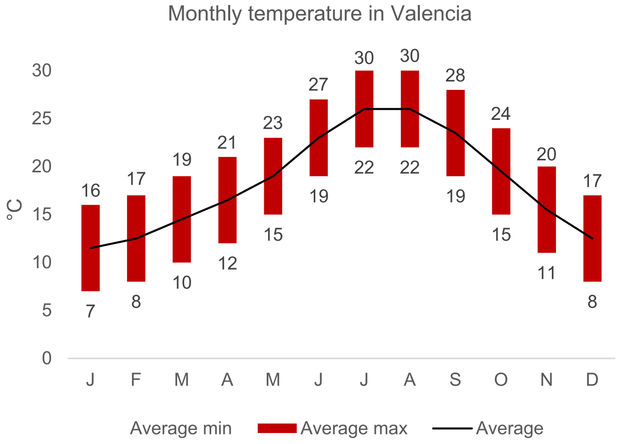


Fig. 3. Monthly temperature in Valencia (Quintana-Gallardo et al., 2021; SG State Meteorological Agency AEMET, 2019).

Table 1
Building clusters in the Spanish Building stock and quantity in the province of Valencia (Ministerio de Fomento G. de E., 2019).

Year of construction	Uu (Single-family house)		Cc (Multi-family house with three or less floors)		Bb (Multi-family house with three or more floors)	
	Code	Quantity	Code	Quantity	Code	Quantity
Before 1940	Uu <40	57,332	Cc <40	29,936	Bb <40	46,814
1941–1960	Uu 41–60	54,258	Cc 41–60	36,246	Bb 41–60	98,256
1961–1980	Uu 61–80	82,151	Cc 61–80	62,047	Bb 61–80	436,914
1981–2007	Uu 81–07	114,451	Cc 81–07	59,750	Bb 81–07	264,481
2008–2011	Uu 08–11	13,909	Cc 08–11	7,003	Bb 08–11	30,091

2.1. NZED CO_2-planner design

2.1.1. Literature review

Following the proposed method (Fig. 1), the first activity of the CO_2 planner design stage was a review of relevant literature. The purpose of such a review being to set the starting point and, from there, to develop the CO_2 planner.

Document analysis was performed as a research method following Bowen (Bowen, 2009). The search followed two avenues, on the one hand, literature on renewable energy resources and technologies for buildings and districts; and carbon footprint tools and open sources databases. On the other hand, conversion factors for the tool (see Table 3) and a combination of the input–output (IO) analysis and life-cycle assessment (LCA) methods to calculate carbon emissions.

The review started by searching for previous studies on the topic (e.g., Brozovsky et al., 2021; Lv et al., 2018; Saad et al., 2021). Those works helped to clarify the research done, the "what's" and "how's" of districts' carbon footprints and open source databases, renewable energy deployment in the built environment. As examples of the multiple findings, there are maps for Valencia of the energy certificates of the buildings (for Valencia, see: https://visor.gva.es/visor/), but energy certificates are not very reliable in Valencia, and they only give a snapshot, are not useful for the research aims. The work MOVIGA (http://mapas.xunta.gal/visores/moviga/) is closer to the aim of this research, but it does not apply to Valencia, and it is not interactive, not allowing to test different decarbonization actions. Nevertheless, it was a great inspiration and was used as reference for the CO_2 planner. Other tools to calculate the energy and emissions savings of some rehabilitation measures were found (for Valencia see: http://renoveu.five.es/#/home), but their catalogue of measures is not complete and the GHG savings are not based on life cycle assessment. LCA-based carbon footprint methodologies like PAS 2050, the Greenhouse Gas protocol, ISO 14067, etc., were reviewed and used to build the calculation algorithm. Other studies like Brozovsky J., et al.

Table 2
Review on renewable energy resources and technologies for dwelling, buildings and districts.

Methodology decarbonizing dwelling, buildings, or districts	Carbon footprint Tool. Conversion factors.	Incorporates renewable energies technologies?	LCA methods; I-O analysis; open sources databases	Include case studies?	References
Yes	–	–	Yes	Yes	Brozovsky et al. (2021), Lv et al. (2018), Saad et al. (2021)
Yes	–	–	Yes	–	He et al. (2017), Ruzevicius and Dapkus (2019)
–	–	Yes	Yes	–	The British Standards Institution (BSI) (2008), ISO the IO for S ISO 14064 (2009), World Resources Institute (2011)
Yes	Yes	Yes	–	–	Saheb et al. (2019), Fuster-Palop et al. (2021)
Yes	–	–	–	Yes	Võsa et al. (2021)
Yes	Yes	–	Yes	Yes	The British Standards Institution (BSI) (2011), Anon (2021b, 2018b)
Yes	Yes	Yes	–	Yes	Brozovsky et al. (2021), Moran et al. (2018)
Yes	–	–	Yes	Yes	Saheb et al. (2019), The British Standards Institution (BSI) (2008), ISO the IO for S ISO 14064 (2009), Ruzevicius and Dapkus (2019), World Resources Institute (2011)

and Moran D., et al. helped to identify the main barriers to urban decarbonization, the main strategies, and some of the specific actions, all of them included in the CO_2 planner. However, based on the literature review, there is no tool like the one proposed in this paper, while its necessity was totally confirmed.

As the tool had to introduce some simplifications, conversion factors, calculation methods, and databases had to be as accurate as possible. Hence, the search focused only on scholarly publications as the so-called "grey sources" (blogs, news, seminars, etc.) were found to be inappropriate for the goals. Table 2 summarized the review's results.

The results in the table show that no sufficiently peer-reviewed scientific or technical proposal could be found that would allow the development of a tool that would answer the research question of this paper. Furthermore, the results show that in general and specifically in the construction's field the operation of existing tools and calculators for environmental impact assessment require precise data that the majority of the population (not specialists in environmental assessment) is not aware of. Therefore, a tool that requires information that is known to the majority of the population is needed. In addition, a combination of selected outcomes from these studies set the starting point for the design of the CO2 planner intended in this research.

2.1.2. NZED CO_2-planner design

The proposal is to design an NZED CO_2-visual planner that allows end-users and policy-makers to visualize CO_2 emissions and energy consumption alternatives in dwellings, buildings, and districts. For this, the literature review identified several guidelines and standards: PAS 2050 (The British Standards Institution (BSI), 2008), GHG Protocol Product Standard (World Resources Institute, 2011), ISO14067 – 2018 (Anon, 2018b), Inventory of Carbon & Energy (ICE) Version 2.0 (Hammond and Jones, 2011), Sustainability Disclosure Database (Global Reporting Initiative (GRI), 2017) and 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Eggleston et al., 2006) among others. Based on these recommendations, the design includes the following features:

1. Few inputs requested from the user, such as address or a map to point to, load curve (Prades-Gil et al., 2021; Aparisi-Cerdá et al., 2022) or monthly electricity and natural gas bill in kWh, amount of consumed butane gas bottles, type of heating, and domestic hot water (DHW) production.
2. Conversion factors for calculations. To calculate the amount of CO_2 emitted, the calculations were supported by LCA-based, open access conversion factors found in the literature. See Table 3.
   The calculation is given by the following equation:
   $$\sum_{i=1}^{i=n} L_i \times CF_i \tag{1}$$
   Where:
   L = Load
   CF = Conversion Factors
   i = Consumption
   This Eq. (1) calculates the amount of CO_2 emitted by the selected dwelling, building, or district.
3. Calculation and simulation method with visualization of the current and new state of consumption for a dwelling, building or district and the amount of $kgCO_2e$/year emitted, detailed for their respective sources of consumption, whether for photovoltaic or thermal solar panels, air to water heat pump, electricity, natural gas or butane gas.
4. Equivalences. For better illustration and appropriation by the end user or policy-maker, open-source equivalencies were implemented to better interpretation $kgCO_2e$: Number of private vehicles on the road for 1 year, persons for 50 years smoking, and trees seedlings grown over 10 years needed to absorb a $kgCO_2e$.
5. Energy-saving visualization with a money-saving perspective, to add the cost and monetary component in the user's decision making. Calculated based on the variable price of electricity and a percentage of the fixed price, since the power factor of the consumption would be reduced.

The flowchart the tool will follow is depicted in Fig. 4. The flowchart shows that the data acquisition will have two different phases. The first consists of obtaining data from the Spanish Cadastre to classify the building or house unit according to the clusters defined in the ERESEE (Ministerio de Fomento G. de E., 2019), as described in Table 1. Then, the energy consumption of

Table 3
Open access conversion factors used.

Power supply	Range of technologies		Conversion factors (gCO_2e/kWh)	Source
Solar photovoltaic panels	Crystalline technologies	Single crystalline silicon cells (sc-Si) Multi-crystalline silicon cells (mc-Si)	43.00	Milousi et al. (2019)
	Thin-Film Technologies	Copper-Indium- diSelenide (CIS) Amorphous cells (a-Si)		
Solar thermal panels	Flat plate collector Vacuum tube collector		32.50	Milousi et al. (2019)
Air to water 10 kW Heat pump[b]			14.40	Dones et al. (2007)
Electricity from the grid (Spanish electricity mix)			304.00	EEA (2020)
Natural gas from the distribution system[a]			202.00	Miteco and OECC (2020)
Butane gas (distributed in gas cylinders)[a]			233.02	Miteco and OECC (2020)

[a] Note the conversion factors of the fuels were increased by 3% to take into account the GHG emissions of all the other life cycle stages, as calculated in (Rodrigo et al., 2008).

[b] Note the emissions of the Heat pump are those corresponding to all stages of its life cycle minus the electricity consumption during use, which depends on the emissions set for the calculations.

each building is estimated using information extracted from the project TABULA (Loga et al., 2016) for building characterization, the SPAHOUSEC study (Institute for Energy Diversification and Saving - IDAE, 2016) for electric appliances simulation, and the work by Prades-Gil et al. (2021), applying the norm EN ISO 52016 (de Normalizacion y Certificacion , AENOR), backed by calculations made with DesignBuilder Software Ltd (Anon, 2021b). In all cases, the user will be able to add their energy consumption manually. Otherwise, the tool assumes the most plausible, DHW, electric appliances and HVAC system configuration according to the data obtained from the embedded data bases. The user will then have the opportunity to check if it coincides with the reality of the housing unit or building. If it does not, it will be possible also to adapt it to the existing system.

Once this process ends, the program runs the simulation responding to the load curve, the performance of the equipment chosen in each simulation, and its energy consumption (Prades-Gil et al., 2021), and the yearly energy consumption is calculated. Then, the GEI results will be computed using Eq. (1). After the results are obtained, the user will be able to repeat the process of changing the HVAC, DHW system, etc., iteratively to compare their emissions.

2.2. Case studies on an urban district of the city of Valencia, Spain

Following the literature on nearly zero energy districts, the "Nearly-Zero Energy Districts (NZED) in the city of Valencia" project guidelines, and the methodology proposed in Fig. 1, to carry out the simulations, a district in the city of Valencia was looked that, due to its characteristics, will present a lot of homogeneity in its buildings. In this way, the information to support the calculations of possible installations of renewable energy sources will apply to the greatest number of dwellings (or buildings) and be as accurate as possible.

The NZED CO_2-planner was performed on two case studies, one for end-users (dwellings), and the other for policy-makers (buildings and districts). In both, simulations were carried out, and the energy consumption from different sources and the amount of CO_2 emitted were calculated.

3. Results

3.1. NZED CO_2-planner to calculate emissions in urban districts

The result of the design stage that was described in Section 2.1.1 is an NZED CO_2-planner interface with two screens. One screen designed to be intuitive so that any user, just by entering simple information will be able to visualize the amount of CO2 emitted by his/her dwelling, building or district. The parameters asked by the tool as inputs have been simplified as much as possible since the tool is intended for be use by non-specialists in environmental assessment. This information can be easily found by the user on their electricity or gas bill.

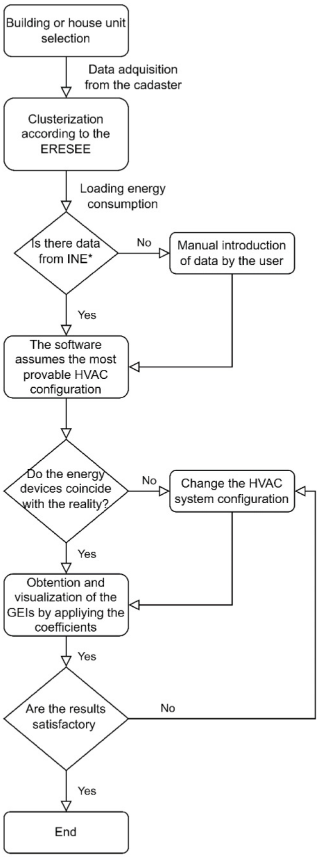
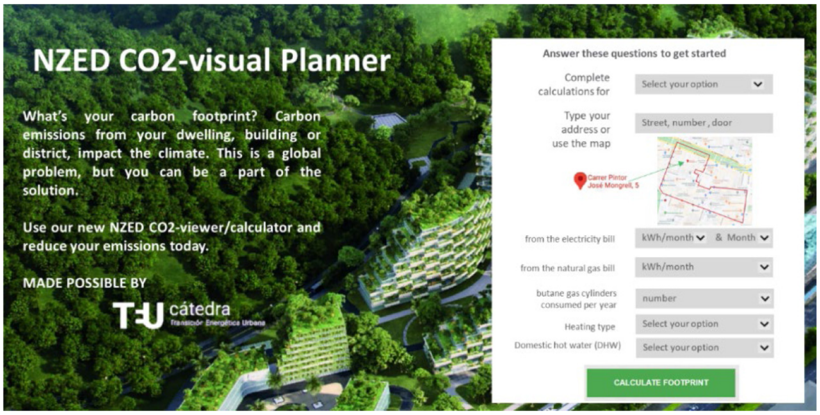


Fig. 4. Flowchart of the tool.

As shown in Fig. 5 below, the inputs requested in the first screen are: (i) *Set your role:* there are two types of roles, one for end-users (dwellings), and the other for policy-makers (buildings and districts). For the former the inputs will be related to one dwelling and for the latter will be related to more than one dwelling, here the module will ask for the inputs of each dwelling


NZED CO2-visual Planner

What's your carbon footprint? Carbon emissions from your dwelling, building or district, impact the climate. This is a global problem, but you can be a part of the solution.

Use our new NZED CO2-viewer/calculator and reduce your emissions today.

MADE POSSIBLE BY

Fig. 5. NZED CO_2- planner description. Input data screen 1.

(of the building or district) one by one and then they will be addressed in an aggregated way. (ii) *Address:* here the tool allows the user to type in the address or use the map to point it out. (iii) *Electricity and natural gas:* the user will type in information related to electricity or natural gas consumption, which can be easily found on their monthly bill. The tool has by default the information of the electrical and gas load curve as was explained in Section 2.1. (iv) *Butane gas:* this input is related to estimations of the number of butane gas bottles consumed per year, which still is the third most traditionally used energy source in Mediterranean cities. (v) *Heating & DHW:* the last input requested is the information related to heating type (electric/natural gas) and domestic hot water type (electric/natural gas).

In another screen (illustrated in Fig. 6 below) with the previous inputs requested the tool defines a profile with the current and new state of consumption for a dwelling, building or district and the amount of $kgCO_2e$/year emitted. In this stage, the NZED CO_2-planner allows to visualize opportunities of renewable energy technologies installation such as Photovoltaic solar panels, Solar thermal panels, Air to water heat pump, etc.,. Additionally, the tool includes the possibility to edit the load curve data for electricity and gas consumption, update conversion factors, electricity costs, CO_2e equivalents for better comprehension by the user, or even add a new renewable energy technology.

Next Sections 3.2 and 3.3 describe in more detail the case studies performed with the NZED CO_2-planner, for both, end-users (dwellings), and policy-makers (building and district).

3.2. Case study results for end-users

In this case study, the NZED CO_2-planner was performed for a single end-user. The dwelling is located in the Illa Perduda urban district previously described. It is a family home, where butane gas is used for cooking, electricity for heating and natural gas for hot water.

As a result, after simulations were carried out with the NZED CO_2-planner, Fig. 6 shows the annual emissions for this case with 1119.35 $kgCO_2e$/year. This amount of emissions are expressed in terms of kilometres driven by an average passenger vehicle, the number of cigarettes smoked for 50 years, and tree seedlings needed to absorb CO_2 to generate a better understanding of the result by the user of the NZED CO_2- visual planner.

The simulation also shows how, by implementing a renewable energy technology, in this case photovoltaic panels, the user reduces electricity consumption from 2225.86 kWh/year to 1093.05 kWh/year and natural gas consumption from 1641 kWh/year to 1215 kWh/year. For a total energy saving of 1448 kWh/year. The user can also see how the CO_2 emitted is reduced from 1119.35 $kgCO_2e$/year to 630.96 $kgCO_2e$/year. Finally, the tool reminds the user that all these reductions not only represent an impact on the environment, but also on their pockets, by reminding them that they would also be saving money.

3.3. Case study results for policymakers

This second case study exemplifies the way local authorities would use the tool. Local authorities will have access to a section of the tool where it is possible to study whole buildings, groups of buildings, or even entire districts. A block located at the *Pintor José Mongrell* street in the Illa Perduda district was chosen, Fig. 7.

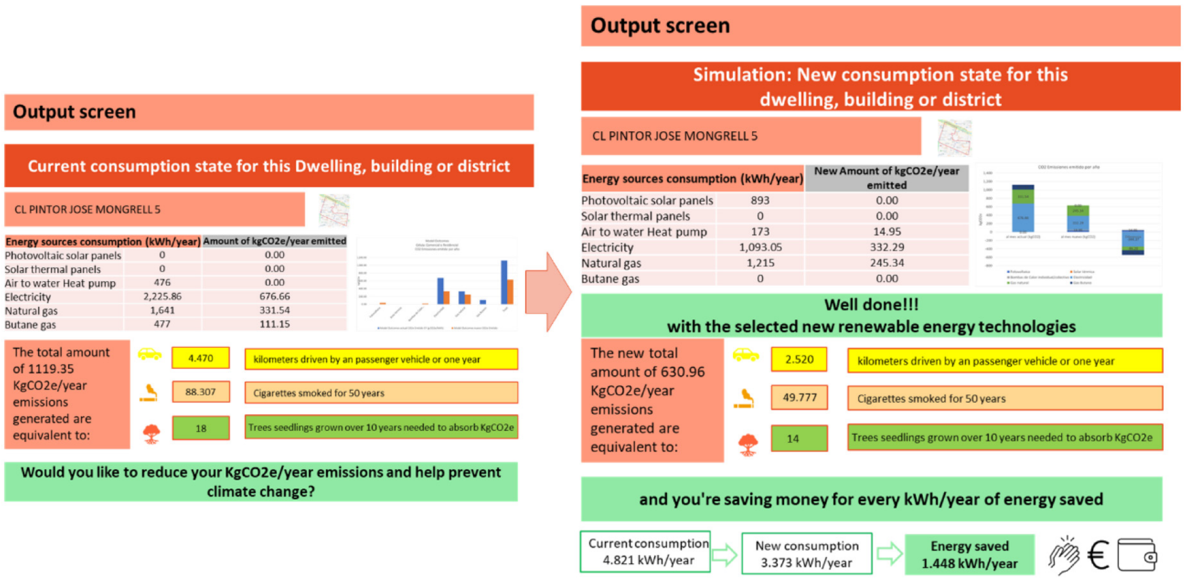
The energy data has only been used for illustrative purposes, and it should not be understood as an accurate representation of the actual energy consumption of the block. The details about each building in the block are described in Table 4.

According to the cluster characterization reflected in Table 1, this building can be described as a Bb 61-80. Bb indicates a multifamily building with more than three floors, and 61-80 points out that it was built between 1961 and 1980. The Bb 61-80 buildings are the most common in the province of Valencia, accounting for 436914 house units (Table 1). In that period, thermal insulation was not mandatory, and most buildings did not include it in their building envelope. That is the case of this building block, which has a cavity wall without any insulating material in its cavity. The outer bricklayer is load-bearing, and the inner layer is composed of hollow bricks, Fig. 8.

The frame is made of reinforced concrete pillars and beams. The slabs dividing the floors are composed of joists and small vaults topped with a layer of concrete with a steel mesh, Fig. 9.

The windows are made of aluminium without thermal break. This kind of construction does not meet the current standards specified in the Basic Document on Energy Efficiency of the Spanish Technical Building Code. Cavity wall façades without thermal insulation are the common denominator of almost every building constructed between 1961 and 1980 (Ministerio de Fomento G. de E., 2019). This block is considered representative of the kinds of multi-family buildings of that period, which, as it is reflected in Table 1, account for almost one-third of the current building stock in the province.

The heating has been assumed to be done using conventional boilers fuelled by natural gas. Although some of the house units might have butane gas cylinders, the use of natural gas is considered to be the most likely scenario. Policymakers would be able to select buildings or groups of buildings and assess their current emissions based on the energy generation. Based on that information, they would have the possibility of altering the energy configuration and knowing the environmental effect beforehand.



Output screen

Current consumption state for this Dwelling, building or district

CL PINTOR JOSE MONGRELL 5

Energy sources consumption (kWh/year)		Amount of kgCO2e/year emitted
Photovoltaic solar panels	0	0.00
Solar thermal panels	0	0.00
Air to water Heat pump	476	0.00
Electricity	2,225.86	676.66
Natural gas	1,641	331.54
Butane gas	477	111.15

The total amount of 1119.35 KgCO2e/year emissions generated are equivalent to:

4.470	kilometers driven by an passenger vehicle or one year
88.307	Cigarettes smoked for 50 years
18	Trees seedlings grown over 10 years needed to absorb KgCO2e

Would you like to reduce your KgCO2e/year emissions and help prevent climate change?

Output screen

Simulation: New consumption state for this dwelling, building or district

CL PINTOR JOSE MONGRELL 5

Energy sources consumption (kWh/year)		New Amount of kgCO2e/year emitted
Photovoltaic solar panels	893	0.00
Solar thermal panels	0	0.00
Air to water Heat pump	173	14.95
Electricity	1,093.05	332.29
Natural gas	1,215	245.34
Butane gas	0	0.00

Well done!!!
with the selected new renewable energy technologies

The new total amount of 630.96 KgCO2e/year emissions generated are equivalent to:

2.520	kilometers driven by an passenger vehicle or one year
49.777	Cigarettes smoked for 50 years
14	Trees seedlings grown over 10 years needed to absorb KgCO2e

and you're saving money for every kWh/year of energy saved

Current consumption 4.821 kWh/year ⇨ New consumption 3.373 kWh/year ⇨ **Energy saved 1.448 kWh/year** €

Fig. 6. NZED CO_2-planner assessing the emissions for dwellings. Output data screen 2.

Table 4
General information about the block under study.

Pintor José Mongrell street building number	Number of dwellings	Number of businesses	Dwellings area (m2)	Businesses area (m2)
11	24	1	2219	43
9	17	0	1429	0
7	16	0	1351	0
5	17	0	1343	0
3	17	0	1428	0
1	24	0	2202	0

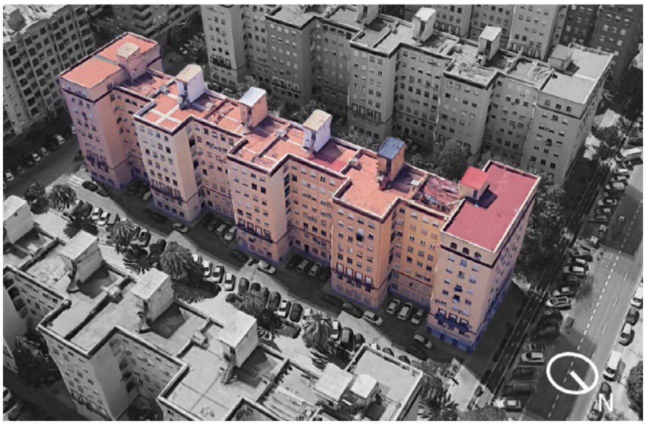


Fig. 7. Block used in the case study.

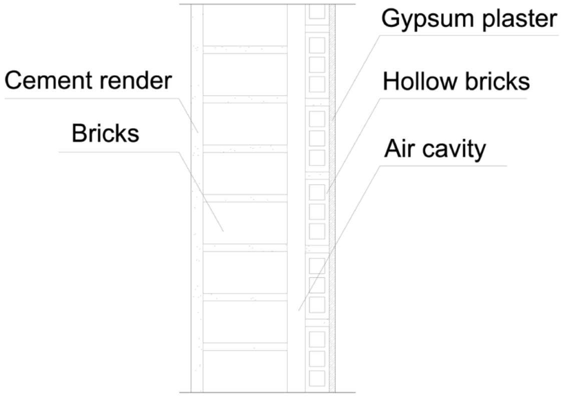


Fig. 8. Layer Illa Perduda district building block.

The study case was divided into two parts, explaining the tool's functionalities. The first part evaluated the effect of installing a community-owned air to water heat pump. The second one studied the combination of a heat pump with photovoltaic solar cells.

Due to the variability between buildings in the same district, the user will be able to select buildings and individually change their parameters. If not, the tool will automatically infer the most likely energy configuration. An outline of the process is depicted in Fig. 4. The energy consumption and energy generation of the current state and the two possible scenarios are specified in Table 5. The carbon emissions associated with that energy consumption are depicted in Fig. 10.

As was expected, installing a community-owned heat pump would result in a significant decrease in carbon emissions with respect to a conventional natural gas boiler. Similarly, installing photovoltaic solar cells on the roof would lead to a reduction of the amount of electricity supply taken from the grid, therefore lowering the CO_2 emissions. It is important to note that the emissions related to the manufacturing and the installation process of those pieces of equipment are also accounted for in the data employed. Providing the policy-makers with that information could have an important influence on their decisions and might contribute to the creation of new regulations that foster carbon neutrality. Without quantified data, it is harder for the political representatives, both at a local and a national level, to make conscious decisions on issues related to sustainability.

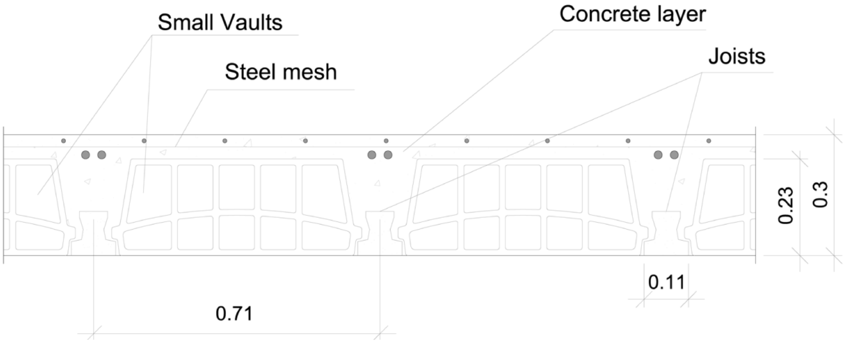


Fig. 9. Frame Layer Illa Perduda district building block.

Table 5
Block annual energy consumption and generation.

	Current state (kWh)	Case 1 (kWh) [1]		Case 2 (kWh) [2]	
		Energy consumption	Energy generation	Energy consumption	Energy generation
Electricity	415,399.38	415,399.38	415,399.38	309,991.00	309,991.00
Heat pump	0.00	16,135.21	340,632.20	16,135.21	340,632.20
PV solar cells	0.00	0.00	0.00	12.76	90,235.73
Natural Gas	747,960.00	558,781.00	558,781.00	558,781.00	558,781.00
Total	1,163,359.38	983,141.49	1,163,359.49	892,642.79	1,163,359.11

[1] Installing a community owned air to water heat pump.
[2] Installing a community owned air to water heat pump and PV cells.

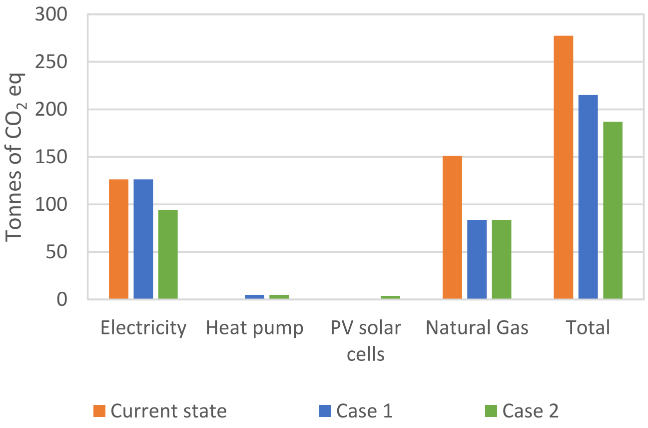


Fig. 10. Sample of the comparative results of the tool. Block's annual tonnes of CO_2 eq.

4. Discussion

The question asked in this paper is how can a citizen or policy-maker assess the greenhouse gas emissions generated by their energy consumption when implementing the retrofitting of a house/district? The answer to this question was to design an online planning service to calculate CO_2 emissions for the end-users of dwellings and policymakers. Then, to validate the use of the tool in two case studies. The first case for citizens and the second case for policymakers. In this way, it fills an unfulfilled niche, that of energy planners at the household user level.

Many actors in the energy transition are making a major effort to simplify information on climate change and its relation to housing and its use. However, in almost all cases, the proposals are unidirectional (from expert to neighbour) with very little interactivity. The work presented here overcomes this limitation as the users can interact with the tool by learning why they emit GHGs, understanding the magnitude of their emissions, and testing solutions in terms of environmental but also economic improvement.

The results confirm, on the one hand, that the tool would help the end-users to know the actual environmental impact of their home and to make environmentally and financially sound decisions before investing in new equipment. On the other hand, in the case study for policymakers, the tool uses real data from a district in Valencia (Spain) to show how renewable sources would affect the carbon footprint of an apartment block.

An important aspect to discuss, besides the sources of energy, is the improvement of the thermal insulation of the building envelope. Improving the thermal insulation allows for a significant reduction in the energy demand of two of the most important sources of energy consumption, cooling, and heating (Han et al., 2021; Bilardo et al., 2021; Tang et al., 2020). In recent decades, building regulations in Spain, and other southern European countries, are putting emphasis on reducing the thermal transmittance of the elements that compose the skin of the building (López-Ochoa et al., 2019). Those elements are mainly doors and windows, the exterior walls, thermal bridges and the roof. As it is mentioned in previous sections, the European Commission is making an effort to support the energy retrofitting of older buildings financially. Plans such as PREE (Institute for Energy Diversification and Saving - IDAE, 2021) and RENHATA (Anon, 2021a) are offered to the population to help alleviate the economic burden that these kinds of construction works imply. These plans also offer financial support for replacing the natural gas boiler with other more efficient devices such as heat pumps. However, one of the main problems is the lack of awareness in the general population about the existence of such plans. Also, the application process is highly complicated for non-building industry professionals. The CO_2-planer could help to reduce both the awareness and the knowledge gap towards these plans by providing the users with simplified information on the topic while using the tool and linking them to other platforms where they can learn more about it. By replacing the windows and retrofitting the façade, for example, with an exterior insulation and finish system (EIFS) (Dentz and Podorson, 2014), the energy demand would be reduced dramatically (Secretaría de estado de transportes movilidad y agenda urbana, 2020).

As explained in the design section, the tool is based on the combination of the input–output (IO) analysis and life-cycle assessment (LCA) methods to calculate carbon emissions, and standards for carbon footprint calculation and well-recognized databases. For instance, PAS 2050 (The British Standards Institution (BSI), 2008), GHG Protocol Product Standard (World Resources Institute, 2011), ISO14067 – 2018 (Anon, 2018b), Inventory of Carbon & Energy (ICE) Version 2.0 (Hammond and Jones, 2011), Sustainability Disclosure Database (Global Reporting Initiative (GRI), 2017), and 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Eggleston et al., 2006), among others. What makes the tool different is that this tool is supported by open databases and requires very simple data from any citizen and politician to obtain its results. Furthermore, the outcome of the tool is a simplification that allows its users to obtain a rough estimation of the GHG that each building emits annually. Therefore, if the results are encouraging, the tool recommends the user to commission a more specific study by professionals in the field of building energy renovation.

5. Conclusion

The CO_2-planner was designed with the purpose of assessing the effect that the sources of energy consumption have on the overall carbon emissions of districts, buildings, and house units. Moreover, one of the important features of the tool is the gamification component that allows the user to choose between several types of renewable energy technology to simulate the emissions that could be generated. In the same way, the tool provides the conversion of emissions into cars, cigarettes, or trees so that the user, even if not experienced in CO_2 nomenclature, can easily interpret the results. Finally, understanding that the monetary factor is essential to making decisions, at the end of the simulation, the tool reminds the user that they are saving money for every $kgCO_2e$/year not consumed. This way, the tool is useable by the layman, the end user, but still, it is accurate enough. Furthermore, it contributes to the Energy Transition in the built environment by providing necessary data for policy-making. To the authors' knowledge, there is no other tool or proposal as comprehensive as the one presented here.

During the application of the designed tool, a difficulty in envisioning the shift towards renewable energy technologies was highlighted by the users. However, given the didactic component of the tool, both the users of the individual units and the policy-makers were able to imagine what the change of technology would mean for them. Thus, they were motivated to make the decision to switch to renewable energies. The equivalence component of the tool in terms of cars, cigarettes, etc., was useful for this purpose.

The concept of nZED (Nearly zero energy districts) is currently in the limelight. This concept arose from the idea of nZEB (Nearly zero energy buildings). However, the level of complexity of analysing the energy consumption and the environmental impacts generated in districts involves several extra layers of complexity. Not only is there a need to account for the individual dwellings but also to account for decisions that require the involvement of local, regional and even national policymakers.

In this research, the fundamentals of a tool for CO_2 calculation in districts and dwellings have been successfully designed. The implications of this research are manyfold. The planner can easily be adapted to other cities and used in a similar way, provided it is translated to the local language, if necessary. The tool can easily be scaled up to include more functions, which would complete its utility. For example, it could add an algorithm and data for GHG emissions from mobility, informing decisions on the matter like decreasing private vehicle use, using public transport, switching to electric mobility, etc. However, simplicity is the essence, according to the conducted literature review. Another function that could be added to the tool would be to suggest websites and other sources of information for the user's further training (if desired) and the search for subsidies and other support. Finally, another avenue for future upgrades would be to develop an interface that will facilitate its use by a large number of users.

From the case studies conducted, it can be concluded that the tool is up to the expectations. To guarantee that the tool works for all types of users and building blocks, further case studies will be carried out in different locations and with buildings with different characteristics.

CRediT authorship contribution statement

Ivan Ligardo-Herrera: Conceptualization, Methodology, Software, Validation, Investigation, Resources, Writing – original draft, Writing – review & editing. **Alberto Quintana-Gallardo:** Conceptualization, Methodology, Software, Validation, Investigation, Resources, Writing – original draft, Writing – review & editing. **Christian Wolfgang Staschelt:** Methodology, Software, Validation, Resources. **Tomás Gómez-Navarro:** Conceptualization, Methodology, Software, Validation, Investigation, Resources, Writing – original draft, Writing – review & editing.

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 will be made available on request.

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References

Amaral, A.R., Rodrigues, E., Gaspar, A. Rodrigues., Gomes, Á., 2018. Review on performance aspects of nearly zero-energy districts. Sustain. Cities Soc. [Internet] 43 (June), 406–420. http://dx.doi.org/10.1016/j.scs.2018.08.039.

Anon, Typology Approach for Building Stock Energy Assessment - Intelligent Energy Europe - European Commission.

Anon, 2018a. Directive (EU) 2018/844 of the european parliament and of the council of 30 2018 amending directive 2010/31/EU on the energy performance of buildings and directive 2012/27/EU on energy efficiency.

Anon, 2018b. ISO the IO for s. ISO14067-2018 greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification [internet]. https://www.iso.org/obp/ui/#iso:std:iso:14067:ed-1:v1:en.

Anon, 2020. Climate emergency declaration - call to declare a climate emergency.

Anon, 2021. IEE Project EPISCOPE.

Anon, 2021. DesignBuilder Software Ltd. DesignBuilder. Stroud, Gloucs.

Anon, 2021a. Generalitat valenciana. Plan renhata [internet]. [cited 2022 Jan 9]. https://habitatge.gva.es/es/web/arquitectura/ajudes-pla-renhata.

Anon, 2021b. GHG protocol [internet]. [cited 2021 Mar 15]. https://ghgprotocol.org.

Aparisi-Cerdá, I., Ribó-Pérez, D., Cuesta-Fernandez, I., Gómez-Navarro, T., 2022. Planning positive energy districts in urban water fronts: Approach to la marina de valència, Spain. Energy Convers. Manag. 265 (May), 115795.

Aparisi-Cerdá, I., Ribó-Pérez, D., Gómez-Navarro, T., 2021. Planning positive energy districts in urban water fronts: methodology and approach to la marina de valència, Spain. In: 16th SDEWES Conference Dubrovnik 2021. p. 454.

Baldassarri, C., Allacker, K., Reale, F., Castellani, V., Sala, S., 2017. Consumer footprint: Basket of products indicator on housing. p. 231.

Beck, H.E., Zimmermann, N.E., McVicar, T.R., Vergopolan, N., Berg, A., Wood, E.F., 2018. Present and future köppen-geiger climate classification maps at 1-km resolution. Sci. Data 5, 1–12.

Bilardo, M., Sandrone, F., Zanzottera, G., Fabrizio, E., 2021. Modelling a fifth-generation bidirectional low temperature district heating and cooling (5GDHC) network for nearly zero energy district (nZED). Energy Rep. [Internet] 7, 8390–8405. http://dx.doi.org/10.1016/j.egyr.2021.04.054.

Bowen, G.A., 2009. Document analysis as a qualitative research method. Qual. Res. J. 9 (2), 27–40.

Brozovsky, J., Gustavsen, A., Gaitani, N., 2021. Zero emission neighbourhoods and positive energy districts – A state-of-the-art review. Sustain. Cities Soc. [Internet] 72 (April), http://dx.doi.org/10.1016/j.scs.2021.103013, 103–013.

Cabeza, L.F., Rincón, L., Vilariño, V., Pérez, G., Castell, A., 2014. Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: A review. Renew. Sustain. Energy Rev. 29, 394–416.

Carbon Footprint Ltd., 2002. Carbon footprint software [internet]. [cited 2021 Jan 24]. www.carbonfootprint.com.

de Catastro, Dirección General, 2021. Sede electrónica del catastro - españa [internet]. [cited 2021 Feb 14]. https://www.sedecatastro.gob.es/.

de Normalizacion y Certificacion (AENOR), Asociacion Española, 2017. UNE-EN ISO 52016-1:2017 energy performance of buildings - energy needs for heating and cooling, internal temperatures and sensible and latent heat loads - part 1: Calculation procedures (endorsed by asociación española de normalización in december of 2017 [internet]. https://www.normadoc.com/english/une-en-iso-52016-1-2017.html.

Dentz, J., Podorson, D., 2014. Evaluating an exterior insulation and finish system for deep energy retrofits [internet]. In: Related Information: Work Performed By the ARIES Collaborative, New York, New York. http://www.osti.gov/servlets/purl/1123215/.

Dones, R., Bauer, C., Bolliger, R., Burger, B., Heck, T., Röder, A., et al., 2007. Life cycle inventories of energy systems : Results for current systems in Switzerland and other UCTE countries. Data v2.0. Ecoinvent report (5) Project ecoinvent data v2.0. Ecoinvent report (5).

EEA, 2020. CO2 intensity of electricity generation in the EU [internet]. [cited 2020 Apr 6]. CO2 Intensity of Electricity Generation.

Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T., Tanabe, K., 2006. Guidelines for national greenhouse gas inventories. In: IPCC National Greenhouse Gas Inventories Programme. Hayama, Japan.

EPA (USA), 2008. Greenhouse gas equivalencies calculator [internet]. [cited 2021 Jan 24]. https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator.

EPA Victoria and Education Services Australia Limited (Australia), 2011. Australian greenhouse calculator [internet]. [cited 2021 Jan 24]. https://apps.epa.vic.gov.au/AGC/home.html.

European Commission, 2014. On Resource Efficient Opportunities in the Building Sector - COM(2014) 445 Final. pp. 1–10, COM(2014).

European Union, 2018. Directive (EU) 2018/2001 of the European parliament and of the council of 11 2018 on the promotion of the use of energy from renewable sources (recast) [internet], 2018. Official J. Euro. Union.

Eurostat, 2021. Electricity generation statistics – first results - Statistics Explained.

Famiglietti, J., Gerevini, L., Spirito, G., Pozzi, M., Dénarié, A., Scoccia, R., et al., 2021. Environmental life cycle assessment scenarios for a district heating network an italian case study. Energy Rep. [Internet] 7, 368–379. http://dx.doi.org/10.1016/j.egyr.2021.08.094.

Fuster, E., Prades-Gil, C., Masip, X., Viana-Fons, J., 2020. Evaluation of the solar photovoltaic generation potential of a district in the city of valencia. In: 15th SDEWES Conference Cologne 2020. p. 154.

Fuster-Palop, E., Prades-Gil, C., Masip, X., Viana-Fons, J.D., Payá, J., 2021. Innovative regression-based methodology to assess the techno-economic performance of photovoltaic installations in urban areas. Renew. Sustain. Energy Rev. 149 (April).

Gao, T., Liu, Q., Wang, J., 2014. A comparative study of carbon footprint and assessment standards. Int. J. Low-Carbon Technol. 9 (3), 237–243.

Global Reporting Initiative (GRI), 2017. GRI sustainability disclosure database [internet]. [cited 2020 Apr 5]. http://database.globalreporting.org/.

Hammond, P.G., Jones, C., 2011. Inventory of carbon & energy summary tables. bath.

Han, X., Yu, J., Xia, Y., Wang, J., 2021. Spatiotemporal characteristics of carbon emissions in energy-enriched areas and the evolution of regional types. Energy Rep. [Internet] 7, 7224–7237. http://dx.doi.org/10.1016/j.egyr.2021.10.097.

He, H., Guan, H., Zhu, X., Lee, H., 2017. Assessment on the energy flow and carbon emissions of integrated steelmaking plants. Energy Rep. [Internet] 3, 29–36. http://dx.doi.org/10.1016/j.egyr.2017.01.001.

Institute for Energy Diversification and Saving - IDAE, 2016. Project sech-spahousec, analysis of the energetic consumption of the residential sector in Spain (proyecto sech-spahousec. Anál. Consum. Energético Sector Residencial En España). Idae.

Institute for Energy Diversification and Saving - IDAE, 2021. Impulso a la rehabilitación energética y a la disminución del consumo de energía final y de las emisiones de CO2 en el parque de edificios [internet]. [cited 2022 Jan 9]. https://www.idae.es/en/support-and-funding/renovation-buildings/pree-program-building-energy-rehabilitation.

Intergovernmental Panel on Climate Change, 2014. Climate Change 2014. Synthesis Report, Intergovernmental Panel on Climate Change.

ISO, 2017. ISO 52000-1:2017 energy performance of buildings — Overarching EPB assessment — Part 1: General framework and procedures [internet]. https://www.iso.org/standard/65601.html.

ISO the IO for S ISO 14064, 2009. Greenhouse gases – part 2: Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements. Water, Air, Soil Pollut. Geneve.

Khan, H., Khan, I., Binh, T.T., 2020. The heterogeneity of renewable energy consumption carbon emission and financial development in the globe: a panel quantile regression approach. Energy Rep. [Internet] 6, 859–867. http://dx.doi.org/10.1016/j.egyr.2020.04.002.

Loga, T., Stein, B., Diefenbach, N., 2016. TABULA building typologies in 20 European countries—Making energy-related features of residential building stocks comparable. Energy Build. [Internet] 132, 4–12. http://dx.doi.org/10.1016/j.enbuild.2016.06.094.

López-Ochoa, L.M., Bobadilla-Martínez, D., Las-Heras-Casas, J., López-González, L.M., 2019. Towards nearly zero-energy educational buildings with the implementation of the energy performance of buildings directive via energy rehabilitation in cold mediterranean zones: The case of Spain. Energy Rep. [Internet] 5, 1488–1508. http://dx.doi.org/10.1016/j.egyr.2019.10.008.

Loureiro, T., Espeche, J., Vinyals, M., Stecchi, U., Tzovaras, D., Ioannidis, D., et al., 2019. Distributed schemes innovative solutions for smart grids: P2P. Multi-Agent Syst. Blockchain. Proc. 20 (1), 5.

Lv, Y., Bi, J., Yan, J., 2018. State-of-the-art in low carbon community. Int. J. Energy A Clean. Environ. 19 (3–4), 175–200.

Manso-Burgos, A., Ribó-Pérez, D., Gomez-Navarro, T., Alcazar-Ortega, M., 2021. Evaluation of the participation of residential and commercial consumers in energy communities, a case study in valència, Spain. In: Book of Abstracts of the 16th SDEWES Conference. p. 428.

Marique, A.F., Reiter, S., 2014. A simplified framework to assess the feasibility of zero-energy at the neighbourhood/community scale. Energy Build. 82, 114–122.

Milousi, M., Souliotis, M., Arampatzis, G., Papaefthimiou, S., 2019. Evaluating the environmental performance of solar energy systems through a combined life cycle assessment and cost analysis. Sustain. 11 (9).

Ministerio de Fomento G. de E., 2019. Segmentación del parque residencial de viviendas en España en clústeres tipológicos.

Miteco, OECC, 2020. Factores de emisión.

Monteiro, H., Moura, B., Iten, M., Mata, T.M., Martins, A.A., 2020. Life cycle energy and carbon emissions of ergosterol from mushroom residues. Energy Rep. [Internet] 6, 333–339. http://dx.doi.org/10.1016/j.egyr.2020.11.157.

Moran, D., Kanemoto, K., Jiborn, M., Wood, R., Többen, J., Seto, K.C., 2018. Carbon footprints of 13 000 cities. Environ. Res. Lett. 13 (6).

Pérez Cueva, A.J., 1994. Atlas climático de la comunidad valenciana: 1961–1990. In: 1^a. Conselleria de Vivienda OP Y V Del TVGV. p. 205.

Peters, G.P., 2010. Carbon footprints and embodied carbon at multiple scales. Curr. Opin. Environ. Sustain. 2 (4), 245–250.

Piccardo, C., Dodoo, A., Gustavsson, L., 2020. Retrofitting a building to passive house level: A life cycle carbon balance. Energy Build [Internet] 223, 110–135. http://dx.doi.org/10.1016/j.enbuild.2020.110135.

Prades-Gil, C., Viana-Fons, J., Masip, X., Cazorla-Marín, A., Goméz-Navarro, T., 2021. Heating and cooling demand assessment with European standards, degree days approach and GIS-based tools. Climate change impact on demand and retrofitting benefits in mediterranean case study. In: Book of Abstracts of the 16th SDEWES Conference. p. 718.

Quintana-Gallardo, A., Romero Clausell, J., Guillén-Guillamón, I., Mendiguchia, F.A., 2021. Waste valorization of rice straw as a building material in Valencia and its implications for local and global ecosystems. J. Clean. Prod. (June), 318.

Rodrigo, J., Cañellas, N., Meneses, M., Castells, F.SC., 2008. El consumo de energía y el medio ambiente en la vivienda en españa a nálisis de ciclo de vida (ACV) [internet]. [cited 2021 Apr 15]. https://www.fundacionnaturgy.org/,

Ruzevicius, J., Dapkus, M., 2019. Methodologies for calculating the carbon footprint of small organizations methodologies for calculating the carbon footprint of small organizations.

Saad, S., Lahoud, C., Brouche, M., Hmadi, M., Ghandour, M., Mourtada, A., 2021. Advanced tool for elaborating a sustainable energy and climate action plan at municipalities level. Energy Rep. [Internet] 7 (May), 51–69. http://dx.doi.org/10.1016/j.egyr.2021.09.049.

Saheb, Y., Shnapp, S., Paci, D., 2019. From nearly-zero energy buildings to net-zero energy districts - lessons learned from existing EU projects. EUR 29734 EN.

Secretaría de estado de transportes movilidad y agenda urbana, 2020. ERESEE. De la estrategia a largo plazo para la rehabilitación energética en el sector de la edificación en españa.

SG State Meteorological Agency AEMET, 2019. Valores climatológicos normales y estadísticos de estaciones principales.

Sorknæs, P., 2021. Hybrid energy networks and electrification of district heating under different energy system conditions. Energy Rep. [Internet] 7, 222–236. http://dx.doi.org/10.1016/j.egyr.2021.08.152.

Tang, F., Chen, J., Li, J., Rodriguez, D., 2020. Energy saving actions toward NZEBs with multiple-criteria optimization in current residential buildings. Energy Rep. [Internet] 6, 3008–3022. http://dx.doi.org/10.1016/j.egyr.2020.10.069.

The British Standards Institution (BSI), 2008. Guide to PAS 2050 - how To Assess the Carbon Footprint of Goods and Services. The British Standards Institution, London, p. 58.

The British Standards Institution (BSI), 2011. PUBLICLY AVAILABLE SPECIFICATION PAS 2050: 2011 Specification for the Assessment of the Life Cycle Greenhouse Gas Emissions of Goods and Services. British Standards Institution.

The Nature Conservancy organization and CoolClimate (USA), 2015. Carbon footprint calculator [internet]. [cited 2021 Jan 24]. https://www.conservation.org/carbon-footprint-calculator#/.

Võsa, Karl-Villem, Ferrantelli, Andrea, Tzanev, Dragomir, Simeonov, Kamen, Carnero, Pablo, Espigares, Carlos, Escudero, Miriam Navarro, Quiles, Pedro Vicente, Andrieu, Thibault, Battezzati, Florian, Cordeiro, Katia, Allard, Francis, Magyar, Zoltan, Giusy Turturiello, TC, JK, 2021. Building performance indicators and IEQ assessment procedure for the next generation of EPC-s. In: E3S Web Conf (13003). p. 246.

World Resources Institute, 2011. World business council for sustainable development. Product Life Cycle Account. Rep. Standard 2011, 1–148.

WWF, 2002. Environmental footprint calculator [internet]. [cited 2021 Jan 25]. https://footprint.wwf.org.uk/#/.

Yuping, L., Ramzan, M., Xincheng, L., Murshed, M., Awosusi, A.A., SI, B.A.H., et al., 2021. Determinants of carbon emissions in Argentina: The roles of renewable energy consumption and globalization. Energy Rep. [Internet] 7, 4747–4760. http://dx.doi.org/10.1016/j.egyr.2021.07.065.