ENERGIS: Decision-Support Tool for the Implementation of Energy Policies at Urban and Regional Level

G Hernández Morala, V I Serna González, G Massa and C Valmaseda Tranque

CARTIF Technology Centre, Energy Division, Valladolid, Spain

gemher@cartif.es, vicser@cartif.es, giumas@cartif.es, cesval@cartif.es

Abstract. The implementation of energy policies to reduce CO₂ emissions poses specific challenges, especially to public authorities, who should define specific objectives, and evaluate the adequacy and impact of energy actions proposed. Nevertheless, an appropriate analysis is highly time-consuming due to the lack of tools. In this process, the first step is to establish the baseline energy status of the area of study. Only with this knowledge, in particular of the residential sector (main CO₂ emissions contributor in cities), is it possible to plan for a low carbon economy. In this context, the ENERGIS tool will support energy planners by mapping energy demand of the residential sector at different scales, as a first step towards CO₂ emissions calculation. To do so, a nationally validated Energy Performance Certification (EPC) tool has been automated, its results at building level mapped and aggregated at different scales. By basing the proposed platform on EPC calculation methodologies supported by the Energy Performance Directive of Buildings (EPBD 2010/31/EU), the ENERGIS platform achieves two main goals: it aids in the implementation of energy directives and energy actions by offering an easy to use tool to identify areas in need and, secondly, it promotes the EPBD, by making use of one of its main instruments to measure energy performance: the EPCs.

1. Introduction

Growing CO₂ emissions have increased the concerns with respect to Climate Change, which has been especially acknowledged by the United Nations with the signature of the Paris Agreement [1]. In this ambitious, universal agreement some guidelines and objectives were set to provide a way forward to fight against climate change and to stop the current temperature rise below 2 degrees. The main source of these emissions is the deployment of fossil fuels for heating and cooling purposes, which in the end can be translated to the energy consumption produced by this type of fuels. In Europe, one of the main sectors contributing to the increase of CO₂ emissions is the built environment, and, in particular, the residential sector accounting for 25.4% of the share according to Eurostat figures [2].

These facts describe a reality where it is necessary to act upon, to implement regulations that enable to control the energy consumption and thus be able to secure a low carbon environment, which in the end will contribute to the fight against climate change. In this line, the European Commission has proposed a package of Energy Directives “Clean Energy for All Europeans” [3], which aims for three main goals: putting energy efficiency first, achieving global leadership in renewable energies and providing a fair deal for consumers. It includes as well eight different legislative proposals that tackle, among other, Energy Efficiency, Energy Performance in Buildings, Renewable Energy and Governance.

These directives set certain objectives to Member States (MSs) and should be transposed by each nation in order to comply with them by establishing plans and strategies. Depending on the
administrative structure in each country, the plans can either be established at national level, or some high level guidelines at national level can be set and then specific objectives at regional level implemented. After each MS has carried out his strategies, the results are to be reported at EU level.

In particular, when considering EPCs, and based on the requirements imposed by the recast of 2018 [4] of the Energy Performance of Buildings Directive (EPBD, 2010/31/EU) [5], MSs of the EU are required to make mandatory the submission of an EPC for every dwelling, building block, or commercial premise to be leased or sold, as well as for every new construction and public buildings. In order to assure coherence among the results obtained in each Member State, a methodological framework is described in the annex of the aforementioned Directive. This annex does not exactly set the formulas to be deployed, but instead presents the type of calculations to perform or which aspects to consider (for instance, thermal bridges). Therefore, each MS has the obligation to transpose this framework in their country and develop either a concrete methodology or develop specific tools to serve this purpose, leading sometimes to inhomogeneous approaches within the EU.

2. Energy planning context in Europe and state of the art

The implementation of European Energy Directives and energy planning are closely intertwined. The achievement of the first in different Member States is performed differently depending on the administrative structure of each country. Thus, these authorities will have to further detail the specifications established at European level and set plans for a determined period of years to comply with European goals. In particular, the general stages within the energy planning process and the roles of these authorities and involved stakeholders are the following:

1. **Stage 1: development of the enforcing norm.** Before transposing the goals established at European level, it is of the utmost importance to have a clear idea of what the current status of the country or the region is in terms of energy needs so as to be able to define realistic goals to be complied with. Having a clear basis will grant the establishment of coherent goals at national or regional level that can be achieved in a reasonable manner.

2. **Stage 2: definition of energy actions.** Once the EU Directive has been transposed at national or regional level, the corresponding public authorities (regional or local) should define the action plans and specific energy actions should be carried out, such as refurbishments of districts or buildings. At this stage, not only authorities, but also energy planners, energy service companies or investors will be willing to know how to target their resources effectively, that is, knowing which urban area counts with the most adequate conditions for an energy action to be implemented. For instance, if it is the most unfavourable in terms of building construction, energy demand, or it is a socially deprived area, or other criteria that can be measurable and analysed.

3. **Stage 3: evaluation of different scenarios.** Once a determined area has been selected, the design and implementation of a specific energy action needs to be defined and tailored specifically to the area at hand. At this stage it is crucial for energy planners or designers to be able to compare the effect different actions can have in comparison to the current status of the area (the baseline). By performing an intense study and comparing a number of possibilities (different scenarios), the most adequate one can be selected according to the criteria of the designer or energy planner (for instance, reducing energy consumption without exceeding a certain investment amount).

4. **Stage 4: monitoring the results of the energy actions.** Once the optimal energy action has been implemented, the impact obtained in terms of achieving the established goals should be measured and compared with the initial status. This monitoring process, apart from enabling the reporting of results as the norm demands, it allows for further reflection on the impact each measure has had. This way, it fosters a better decision making in stages 2 and 3, by feeding them with knowledge and experience generated in implementing energy measures, as well as objective indicators that measure the positive impact of each measure.

For a successful decision making at all of the stages a great deal of analysis and simulation of results is required. These processes, when seeking for accuracy are extremely time-consuming. Also, because of the amount of data involved it can tend to be an error-prone process when performed by humans, leading to uncertainty and inaccuracies, thus, to inadequate decisions.
For all of these reasons, there is a need for tools that automate all of these processes, which can provide an adequate accuracy for the decision making at urban level, to be able to cover all of the abovementioned stages. However, while there are a great amount of tools for dynamic simulation at building level (requiring a high amount of input data) in the energy field, there are not many tools to simulate at urban level energy related aspects.

Some examples of projects tackling these problems [6][7][8] approach them from different angles to that of ENERGIS. For instance, the “Estimated total annual building energy consumption at the Block and Lot level for NYC” [9] focuses its attention on the final energy consumption of heating, cooling, DHW and electricity in the built environment, which are estimated in a specific city (NYC); whereas in the case of the “Energy label atlas” [10] the geographic coverage is much wider with an extent of the whole country (Netherlands), but aims at the estimation of the energy labels based on a typology analysis and comparing it as well with real EPCs performed by qualified experts. Other new approaches also include the possibility to analyse the impact of the implementation of energy conservation measures, such as the ENERSI project [11], but it is constrained to a certain region.

These projects represent interesting approaches to the energy planning problem, by providing basic information on the energy status of a city (in the case of NYC) or of a country (in the case of the Netherlands). However, worth highlighting are the main differences to the ENERGIS platform, which are related to the calculation methodology, automatization of the process and the scale tackled. Firstly, the calculation methodology used in ENERGIS is considered highly relevant in order to provide accurate results. Therefore, instead of deploying estimated approaches in order to calculate consumption (as in the NYC case) the ENERGIS project is constrained to the estimation of the energy demand. This is due to the fact that there is no source of public information that can provide information on energy systems, rendering it inaccurate to assume the existence of a determined energy system. The approach used in NYC to calculate consumption, that is, assigning an energy system according to the typology of the building would be highly beneficial if applied within ENERGIS and would improve the quality of the platform. However, since there is no available database where these systems are described in Spain, no reliability can be assumed from this process. Moreover, the calculation is focused on the automation of validated tools to generate EPCs in Spain. This fact ensures a determined level of precision and veracity to the results obtained, opposed to the abovementioned approaches.

With respect to the scale considered, aggregation possibilities are granted as in the case of the NYC map, but the unit of measure used to estimate the demand is the block, as in both showcased projects. Nevertheless, the scope to which the ENERGIS platform can be applied is the same as in the Netherlands case (country level), since the main source of data is the Spanish Cadastre [12] which covers the whole country.

3. ENERGIS platform: scope and main objectives

The ENERGIS platform’s main objective is to provide an easy to use energy decision-support tool to map energy demand at urban and regional level calculated through validated methods. To this end, public data is collected, analysed and processed; the energy demand building by building is automatically calculated using a validated Energy Performance Certificate tool; and all of the information is mapped in friendly web maps, making use of the functionalities provided by Geographic Information Systems (GIS). Therefore, the three main pillars of the platform, which are closely related to the modules into which the platform is divided, are:

1. To exploit publicly available repositories: all of the data deployed within the platform are publicly available and maintained by official authorities. The main data source is the Spanish Cadastre, which provides information on the geometry of buildings and semantic data on them, such as the year of construction or the number of floors. The collection and processing of the required information will be performed by Module 1 and will be later used by Module 2.
2. **To implement a demand calculation method based on validated methodologies:** automating Energy Performance Certificate tools (Module 2). To this end, the four validated tools at national level in Spain were analysed and one of them (CE3X) chosen as the base for the energy demand estimations displayed in the platform. The objective of this module is to automatically create the input files and run the process to obtain results of the buildings’ energy demand at block level.

3. **To exploit mapping and visualisation capabilities:** using Geographic Information Systems (Module 3). A great amount of synergies can come from linking GIS with planning because of the nature of both disciplines. The ENERGIS platform will therefore display a coloured map, corresponding to the Energy Label scale, at three geographical scales and providing different data to be shown and a range of filtering capabilities.

It is important to note that Module 1 and Module 2 operate in an initial phase in which data are generated. These data will be saved and displayed in by Module 3 at a later stage. This last step offers the functionality that will most valuable to the end-user: the visualisation of the information in a user-friendly way. The platform scheme can be seen below:

![Figure 1. Scheme of the ENERGIS platform.](image)

**Figure 1. Scheme of the ENERGIS platform.**

3.1. **Information processing and treatment (Module 1)**

The basis of the platform is the use of open public data from official sources to be deployed in the estimation of the energy demand. Besides, these public data must be retrieved automatically from different sources. Therefore, after being gathered, these data should be processed and transformed.

There are three main types of data required by the platform: (1) geometry data on buildings, (2) climate zones and (3) building thermal properties, explained below.

For the **geometry data on buildings** the key data source is the Spanish cadastre [12]. The cadastre provides geometrical information and general semantic information per building that will be used in order to identify and to characterize each of the buildings. This information is mainly the geo-located footprint of the building, the number of the building floors above ground, and below ground, the year of construction, current use of the building and the address of the building. The geometry information automatically collected is processed, on the one hand, in order to generate the information for the different envelope elements of the building, with their dimensions and the orientation, and, on the other hand, to produce shadows patterns with façades information of neighbouring buildings.

For **climate-related data**, the National Code for Building Construction [13] in Spain was queried, since it establishes reference climate zones.

In the case of the **building thermal properties** the National Building Code was consulted in order to identify the parameters to be used. Based on several studies, a Catalogue of building elements and materials was generated. The ENERGIS platform is able to use this catalogue in order to consider different building characteristics, where, according to the type of element, the year of construction and the climatic zone, some thermal characteristics and other parameters are assigned in the same way that the EPC tools use this catalogue of building elements.
3.2. Estimation of the energy demand (Module 2)

The estimation of the energy demand is the core of the platform. This estimation is based on the automatic operation of one of the EPC calculation tools recognized by the Spanish government for the energy certification of existing buildings. An analysis was done in order to select the best calculation tool among the four validated tools available to the public (free of charge) in Spain: Herramienta Unificada Líder-Calener (HULC), CE3, CE3X and CERMA. CE3X tool was finally selected, since data requirements of this tool are totally covered with the information available with public sources and the accuracy behind the results has been tested and considered sufficient. Moreover, CE3X files are the reference in terms of data model at national level: the data model proposed at national level to represent information related to EPCs follows the same structure as the output of CE3X.

The operation of the estimation engine consists in two steps: (1) the creation of files that are used in the CE3X tool, collecting the information retrieved in the previous stage and parsing them in the right format and (2) the automatic execution of the CE3X tool using the file created in the immediately previous step. The results obtained are the energy demands of the building: cooling, heating and global energy demand. The estimation process and the results obtained were validated as it shown later.

3.3. Mapping and visualisation (Module 3)

The output information of the ENERGIS tool is stored in a geodatabase, which is structured into three tables: one table for buildings, one for blocks (groups of buildings) and one for cadastral zones (neighbourhood), which are the three scales provided by the Spanish Cadastre’s online services. These three scales are defined and set in the INSPIRE Directive (which deals with the harmonization of geolocated data) [14], and which is followed and implemented in the data offered and the services provided by the Spanish Cadastre. For the building demand, the information from the previous Module 2 was used, while for the demand in the blocks and the cadastral zones the results are obtained by aggregation operations of the buildings’ demand results.

The results are shown to the public through the ENERGIS online platform. The data will be presented with the geo-referenced values and with a recognisable colour code that corresponds to the Energy Label scale used in Energy Performance Certificates, as it can be seen in the Figure 2. The additional information and filtering capabilities available in the online web platform are expected to help the planner in identifying districts or zones with high energy demand.

Figure 2. ENERGIS platform screenshot.

In addition, an online web portal with further information of the platform (information about EPCs in the ENERGIS platform, instructions on how to use the tool, etc.) has been implemented in the following link: http://api.voxel3d.es/examples/ENERGIS/portal/.
4. Tool validation
Several types of validations have been performed during the design, development and validation process of the ENERGIS platform. Firstly, once the tool had been selected, hypothesis and simplifications with respect to geometry issues such as thermal bridges, windows, etc. have been tested. These hypotheses were based on a set of tests performed on a model by model comparison, where the objective was to test how much do the definition of thermal bridges, windows and other elements of the envelope affect the results. Secondly, once the platform was developed, the final results obtained with it when automatically retrieving the data from the public data sources, processing it and automatizing the process were analysed. Finally, a change of scale was implemented and the results obtained were analysed.

4.1. Testing the capabilities and how the program works.
After having selected the calculation tool (CE3X) and having analysed both the data required and the available data in public data sources, it became apparent that some of the geometric data was not directly available in public data sources. Therefore, an estimation to calculate openings, thermal bridges and shadows was required, as it has been previously mentioned. To test if these hypotheses were reasonable in terms of precision deviation (i.e. their Energy Label did not vary) from a real EPC, real cases were tested. These real cases were selected buildings in Valladolid (Spain), of which detailed data to perform energy simulations, was available. The EPC of real buildings was calculated based on information coming from detailed CAD plans, as if they had been performed by a certifier. The numbers of elements, their surfaces, as well as the final EPC results were contrasted and the result was satisfactory in terms of accuracy. As a consequence, the hypotheses were calibrated and developed into the platform.

4.2. Testing the results obtained.
Once the hypothesis had been validated from an accuracy point of view, it was necessary to test that the process designed was responding as expected. To this end, the real calculations previously performed were compared to the results that would have been obtained manually by performing the geometric estimations proposed and also with the results obtained from Module 2. In this validation process, different approaches were used in order to implement an effective comparison and test the accuracy of the results proposed by Module 2. The methodology was focused on the three approaches used for the introduction of data in order to calculate the EPCs of real cases: the results obtained with the automatized process of Module 2 were compared with a (1) simplified and (2) manual introduction of data, and with a manual introduction of data using the approach defined in ENERGIS (3). This validation allowed the evaluation of the automatized process and its effectiveness in contrast with the manual introduction of data as if the analysis would have been realized by a qualified expert. This evaluation pointed out those geometric characteristics that were not collected as expected. The most recurring errors were related to the generation of shadow patterns and the assignment of thermal characteristics according to the envelope’s surfaces. In order to solve these issues, the extraction process of data coming from the cadastre, and the generation process of shadow patterns were redefined and improved.

4.3. Large-scale validation.
Since the platform allows the estimation and the visualization of the energy demand of urban areas, a wider validation was implemented. By expanding the point of view, several errors that were not detected in the previous tests, were highlighted. For instance, some aspects that have been detected affecting significantly the calculation of the energy demand are the assignment of the climatic zone and the extraction of geometric data. The assignment of the right or wrong climatic zone can cause a deviation up to 30% in the results of energy demand. However, the errors generated with the extraction of geometric data presented a higher complexity, due to the information stored in the cadastre. One of the errors encountered is that sometimes this data source heterogeneously assigns
a cadastral reference to a single block or in some cases to a group of buildings, generating errors in the extraction of data by the geometric script.

Corrections have been applied to reduce the margin of error and refine the criteria to ensure more precision in the results. Finally, periodic updates to Module 1 and to the geometric script will be implemented with further updates of the cadastre.

5. Lesson learned
The development of the ENERGIS platform to support energy planning has provided knowledge that will be actively taken into account in future projects. This knowledge has its source in the implementation of the work with public data as a basis for energy planning based on existing validated energy tools. Problems mainly appeared at two different points: at the building level and at city level.

On the one hand, at building level the problems were related to the calculation methodologies, the lack of exact data needed for the EPC tools, and the heterogeneous definition of the Spanish Cadastre. With respect to the calculation methodologies implemented, several stumbling blocks were encountered. Firstly, the analysis of the EPC tools showed great differences among each other, mainly in the input data process and file formats. Once the information needed by the estimation module was identified, the problem was to find this information in the public data sources, due to the lack in public databases of relevant geometric information that has an impact on the energy results. Estimations on the dimensions of openings, lengths of thermal bridges, etc. had to be applied according to the types of buildings to consider these aspects in the energy simulations. Also, the work with building typologies, year of construction, climate zones and locations was necessary in order to apply thermal characteristics to the building elements considered, since they are not available in public sources. Moreover, even when these assumptions were implemented in the platform, issues arose with respect to the geometric definition of the buildings encountered in the Spanish Cadastre, where not all the information was homogeneously defined.

On the other hand, other type of problems arose when the scale of the validation grew (for example at district level or citywide). One problem at this scale is collecting and managing all the information needed. In the case of medium-sized cities, tens of thousands of buildings were worked on, generating hundreds of thousands of intermediate files. As a result, space and processing needs increased drastically. Besides, public sources did not allow querying such amount of data at the same time, and it sometimes led to the interruption of the process. Because of this problem, an automatic supervisor to control the possible errors was developed.

However, despite the difficulties described, having analysed citywide data, it was shown that this platform can have a high potential in supporting energy planning activities of local authorities.

6. Conclusions and future work
The ENERGIS platform combines public data, validated calculated methodologies and GIS to offer a complete and powerful product to support energy planning. The process to define, design and develop the platform has followed several stages, which involved the analysis of data coming from public sources, working with EPC tools, the validation of results at all stages and working with GIS in order to explore its full potential. Difficulties in this process involved mainly the work with public sources of data, in particular the Spanish Cadastre. The main problem was the lack of a standardised approach in the definition of geometric data. This fact would be solved with an adequate implementation of the INSPIRE Directive [14], which would guarantee homogeneous information of the buildings.

The platform provides users with energy planning capabilities which will aid in the decision-making process when generating energy plans, by providing with maps showing the energy demand of cities and urban settings. It will reduce uncertainties and provide a knowledge base upon which to ground decisions. In particular, when attending the different planning stages, the ENERGIS platform can aid in the first and second stages (development of the enforcing norm and definition of energy actions); whereas the expected future platform scope will enable to cover the whole chain (evaluation of different scenarios and monitoring the results of energy actions) by: (1) enhancing the displayed
data (providing consumption estimation), (2) performing calculations at dwelling level, or (3) offering new functionalities, such as capacity to introduce improvement measures.

All in all, by supporting energy planning, the adequate allocation of resources will be fostered to detect shortcomings in terms of energy demand, which are related to CO$_2$ emissions. This will help comply with energy directives’ objectives and thus, energy retrofitting interventions will be boosted. As a consequence, the energy consumption of buildings will be reduced, resulting in lower emission rates, which will finally contribute in the fight against climate change, advocated by the United Nations with the signature of the Paris Agreement.

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