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D1.3-Tools for modelling energy demand, supply side, simulation of scenarios and estimation of impacts

WP1, Task 1.3

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Abbreviations and acronyms

Acronym	Description
BaU	Business as Usual
BM	Business Models
BSM	Building Stock Models
CAPEX	CAPital EXpenditures
CGE	Computer General Equilibrium
CHP	Cogeneration Heat & Power
DH	District Heating
DHW	Domestic Hot Water
EIA	Energy Information Administration
EE	Energy Efficiency
ENPEP-BALANCE	Energy and Power Evaluation Program - BALANCE
EU	European Union
ESM	Energy Systems Modelling
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIS	Geographic Information System
GVA	Gross Value Added
GWh	Gigawatt hour
HOMER	Hybrid Optimization Model for Electric Renewables
IEA	International Energy Agency
INDC	Intended nationally determined contributions
IO	Input Output
kWh	kilowatt hour
kWh/m^2	kilowatt hour per square meter
LEAP	Long-range Energy Alternatives Planning
LIDAR	Laser Imaging Detection and Ranging
MaaS	Mobility-as-a-Service
MESSAGE	Model for Energy Supply Strategy Alternatives and their General Environmental Impact
MJ	Megajoule
O&M	Operations and Maintenance
OPEX	Operating Expense
OR	Operations Research

Acronym	Description
PED	Positive Energy District
pkm	passenger-kilometre
PV	Photovoltaic
SEAP	Sustainable Energy Action Plan
SECAP	Sustainable Energy and Climate Action Plan
RES	Renewable Energy Sources
SEI	Stockholm Environment Institute
TJ	Terajoule
TNO	Netherlands Organisation for Applied Scientific Research (in Dutch)
TSO	Transmission System Operator
UNFCCC	United Nations Framework Convention for Climate Change
V2G	Vehicle to grid
WIOD	World Input-Output Database

Executive Summary

The present deliverable includes an extensive description of the analytical methods employed within the WP1 "*NEW LONG-TERM URBAN PLANNING TOWARDS 2050*" of the MAKING-CITY Project. More specifically it focuses on the activities carried out in Task 1.3 "*Advanced Long-Term Energy Planning strategies and tools*" which aims at the development of an innovative procedure for LT planning.

According to the targets of MAKING-CITY, the need of envisioning the future of the cities is crucial when creating long-term narratives to fight (or mitigate) climate change. As the project is committed to implement "actions" in different activity sectors (residential, tertiary, transport, etc.), all of them focused on reducing energy consumption, some analyses are required. The actions are understood as systemic implementations behind the Positive Energy District (PED) concept.

Attending to the different types of entities in a city, buildings are amongst the most consuming agents of energy, mostly electricity and natural gas. As people lives in buildings, both private uses and workplaces mostly, it seems appropriate to evaluate the performance of those physical units in terms of energy consumption (or even production). To do so, a first modelling strategy has been deployed thanks to the development of Enerkad, a software platform based on Geographical Information Systems (GIS) where extra information related with the energy profiles of the buildings is added. Consequently, the first analysis corresponds to the Building Stock Modelling (BSM) of the city to deeply understand the way citizens consume energy in different end-use services (heating, cooling, cooking, water heating, lighting, etc.). This evaluation is performed based on GIS data of the cities plus statistics and data from energy certificates.

The main outcome of the BSM is a picture of the city with energy information very disaggregated (types of technologies, types of buildings, consumption profiles and even emissions). Those results will facilitate the identification of areas or buildings where taking actions to invest in energy savings or transform consumption patterns, thus configurating the PED concept. Moreover, the tool could allow to observe the transformation reversely: to impose interventions in the micro-level to reach emissions reductions or energy savings compromised in the macro-level (energy and climate planning goals of the city).

With the building-related approach it is possible to enrich the Energy Systems Modelling (ESM) approach. ESM is a method to evaluate cities, regions, countries or even continents, focusing the evaluation on the energy balances. In that sense, there are many approaches depending on the interests of the modellers (policymaking, decision-making, technical explorations, sectoral optimisation, etc.). In this case, using statistical data from the energy consumption of the cities as well as estimates from residential and tertiary sectors coming from Enerkad, city ESM will be developed to assist MAKING-CITY municipalities in the creation of the 2050 Vision. To do so, the ESM will serve as basis to develop energy scenarios where the energy profile of the city is implemented in addition to evolutions of the demands found on socioeconomic drivers like GDP, population, etc. Finally, those scenarios -a Business as Usual one plus some alternative scenarios- will be discussed to evaluate the energy savings achieved and emission reductions associated when implementing the "actions" within.

In parallel to the BSM (micro-level) and ESM approaches (macro-level), the evaluation of the solutions' convenience appears. Such qualitative-quantitative evaluation is carried out by means of the prioritization of PED solutions. Accordingly, from the picture taken in the building stock modelling plus the macro energy evaluation performed in ESM, the prioritization method will help the selection of measures (solutions, actions) to be deployed in each city according to the PED solutions catalogue.

The last methodological deployment is the evaluation of the socioeconomic impacts derived from the PED application. To perform that analysis, the Input-Output (I-O) method will be selected. Thanks to the I-O method, a recognised methodology to evaluate the impacts on the economy for a region or country

when implementing projects or technologies, it is possible to estimate the economic consequences of such implementations as a variation in GDP (in a monetary basis) and looking at the job creation.

Resulting from the value chain characterisation associated to each solution/action implemented, it will be possible to compare the global socioeconomic impact thus allowing to prioritise among PED solutions. A discussion on the future of Business Models (BM) is also expressed in line with the BM previously selected within the framework of MAKING-CITY.

Finally, the document includes a section that shows both the process followed and the main results obtained from the application of the first phases of the methodology (those that have been completed at this point of the project according to its schedule) to each of the project's cities.

Keywords

Modelling approach, advanced integrated urban planning, long-term city planning, impact assessment, scenario definition.

1 Introduction

1.1 Purpose and target group

This report constitutes Deliverable *"D1.3 - Tools for modelling energy demand, supply side, simulation of scenarios and estimation of impacts"* which is the main intermediate outcome of *"Task 1.3. Advanced Long-Term Energy Planning strategies and tools*".

The main objective of the deliverable is to define the modelling framework of MAKING-CITY project for the Advanced Long-Term Planning. This document includes a previously filtered analysis of the most relevant methodologies that can be used in each of the phases defined. First a review of the literature is included followed by a description of the methodology that will be used in the project and a description of the results that can be obtained from the analysis. Finally, a definition of the data gathering process to be followed is included for each of the sections.

The present deliverable is structured as follows:

The chapter 2 describes the Methodological framework of the Advanced Long-Term Planning defined for the MAKING-CITY project.

Chapter 3 evaluates and describes methodologies for modelling energy demand side following the bottom-up approach for energy characterization of the building stock.

Chapter 4 evaluates and describes methodologies for supply-side modelling, smart city technologies and for scenario analysis to a 30 years vision for energy balance.

Chapter 5 evaluates and describes methodologies to Estimate the impacts of alternative energy scenarios

Chapter 6 is focused on the application of the methodology to the cities of the project and the results obtained.

Chapter 7 includes the main conclusions.

Chapter 8 includes the Bibliography section.

Finally, there are various annexes which include some complementary information to the deliverable content. The annexes related to the implementation of the methodology in its first two stages are highlighted.

1.2 Contribution partners

The following Table 1 depicts the main contributions from participant partners in the development of this deliverable.

Table 1: Contribution of partners

Partner short name	Contribution
TEC	Task and deliverable responsible. General structure and content of all the chapters of the deliverable.
CAR	General review of the work of the task and the deliverable.
TNO	Contributions to Chapter 4, in the sections of “Other modelling tools”
VTT	Contributions to Chapter 4, support to the city of OULU.
GRO	Contributions to Chapter 4, in the sections of “Other modelling tools”. Contribution with data related to the modelling described in Chapter 6.
OUK	Contribution with data related to the modelling described in Chapter 6.
BAS	Contribution with data related to the modelling described in Chapter 6.
LEO	Contribution with data related to the modelling described in Chapter 6.
KM	Contribution with data related to the modelling described in Chapter 6.
LUB	Contribution with data related to the modelling described in Chapter 6.
VID	Contribution with data related to the modelling described in Chapter 6.
TN	Contribution with data related to the modelling described in Chapter 6.
DEM	Contribution with data related to the modelling described in Chapter 6 and review of the deliverable
RUG, UOU, UNI, STU, GSC	Support to cities for the data gathering for the modelling activities
R2M	MAKING-CITY context on Business Models

1.3 Relation to other activities in the project

The following Table 2 depicts the main relationship of this deliverable to other activities (or deliverables) developed within the MAKING-CITY Project and that should be considered along with this document for further understanding of its contents.

Table 2: Relation to other activities in the project

Deliverable nº	Relation
D4.1	The results of this analysis will serve as input in the D4.1 *Capacity building, coaching and mentoring*.

D4.3	The results of this analysis will serve as input in the D4.3 *Analysis of FWC candidate areas to become a PED*.
D4.4	The results of this analysis will serve as input in the D4.4. *Technical design of PED in FWC (Bassano del Grappa, Kadiköy, León, Vidin, Trenčín, Lublin)*
D4.6-D4.8	The results of this analysis will serve as input in the D4.6-D4.8 for the upscaling plan in each city
D4.8-D4.13	The results of this analysis will serve as input in the D4.8-D4.13 for the replication plan in each follower city
D1.2	The content of this deliverable will complement the analysis of the D1.2 *The City Diagnosis*
D1.5 – D1.12 (D1.25 – D1.32, initial versions)	The present deliverable provides inputs for each city for the deliverables D1.5-D1.12 *Long-term city plan (City Vision 2050)*.
D1.13 – D1.20	The present deliverable provides inputs for each city for the deliverables D1.13-D1.20 *New/Updated SECAP of the cities.*

2 Methodological framework of the Advanced Long-Term Planning

This section aims to provide a general overview of the overall methodological approach of the Advanced Long-Term Planning of the MAKING-CITY project, which is closely related to the modelling approaches and the tools that will be used through the entire planning process. The following figure describes in a schematic way the correspondence between each of the phases of the methodology with the different subtasks within MAKING-CITY's Task 1.3. The methodology proposed is composed by four main phases that correspond precisely with the main subtasks of the project.

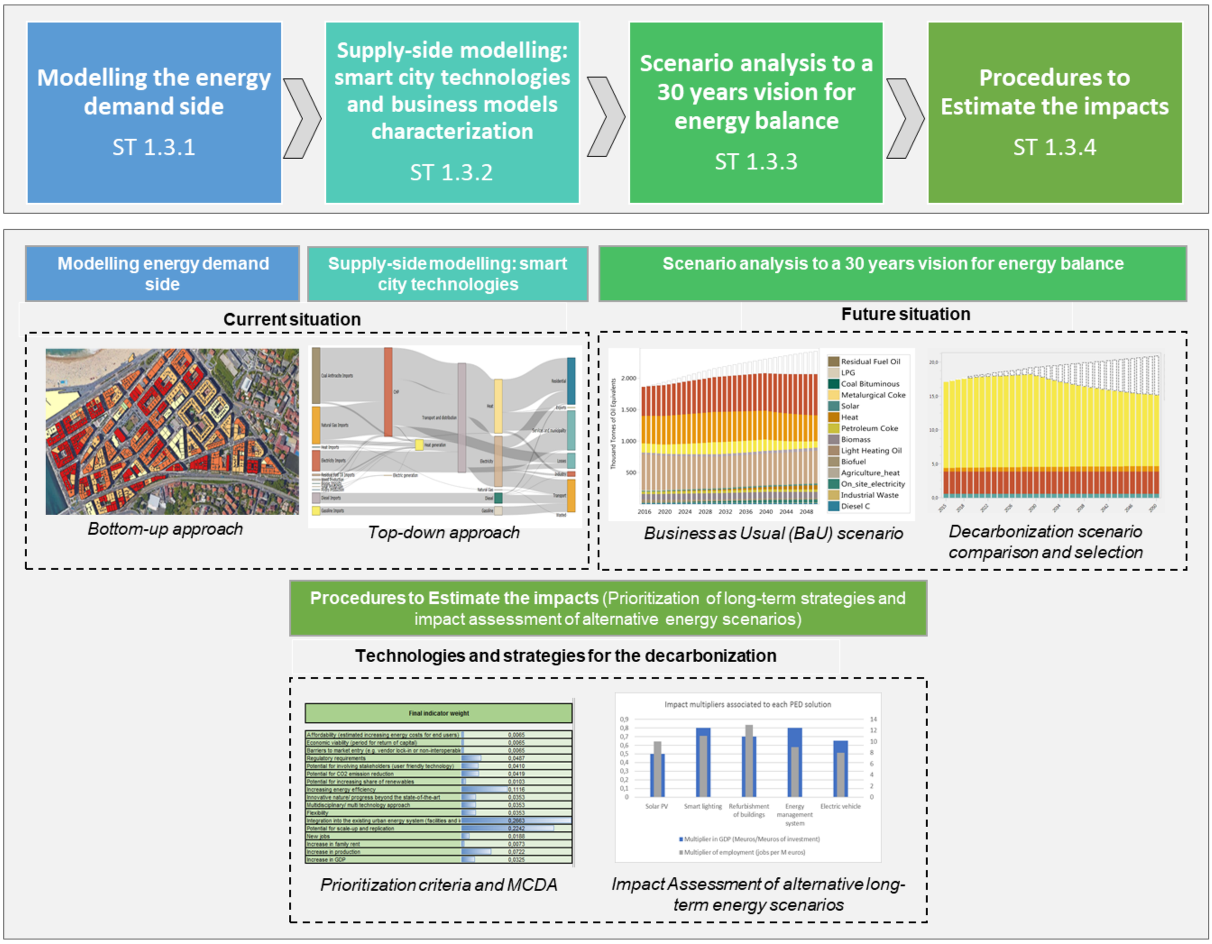


Figure 1: Methodological approach of the Advanced Long-Term Energy Planning Strategies and Tools concept of MAKING-CITY project

As shown in the figure, both the subtasks of the project and the different phases of the defined framework make it possible to support the energy planning process of cities from a modelling viewpoint. This is an interesting aspect to explore the direction of cities' strategy towards a low-carbon future. This analysis can have different time horizons and can have different applications such as the generation of information and criteria for the definition or the updating of SECAPs that will be performed in Task 1.6.

The first phase focuses on the modelling of the energy demand side. This phase makes it possible to establish and characterise the baseline situation (in the reference year) with regards to the energy demand of the city's building stock, as well as their energy consumption and associated emissions (if the required input information is available). This first characterisation of the city is focused on the building sector and is carried out with a bottom-up perspective by evaluating each of the buildings at portal or building block level according to the format of the input information. The resulting hourly energy modeling of buildings is based on basic georeferenced information that is accessible to most cities as cadastral information which are combined with the modelling agorithms.

The modelling procedure is carried out in a way that the model is calibrated as a second step, thus the representation of the results are ensured. The visual representation of the results allows a quick interpretation of the energy needs of the city but also an initial idea of the refurbishment and retrofitting potential or the potential for the implementation of renewable energy technologies such as the solar thermal and the solar photovoltaic systems. This activity is included in the Subtask 1.3.1 for all the cities of the project.

The **second phase aims to develop more in detail the supply-side modelling: smart city technologies**. While in the first phase the activity is mainly focused on the demand side, in this second phase the supply side is evaluated. In addition, the analysis no longer focuses solely on the building sector but covers all sectors of the city from consumer sectors such as the residential, services, transport, industry and primary sectors to the centralized and decentralized generation and distribution of energy.

There is a clear connection between phase one and phase two. The first one will allow a greater degree of detail and observation for the building sector. This means that this disaggregated information can be used as a possible input for phase two, both for the characterisation of the base year and for the proposal of scenarios in a way that the deployment potential of some of the PED solutions and other long-term strategies can be defined in detail. Here, other aspects such as the potential evolution of the business model typologies in long term will be also discussed since there is relevant aspect to be taken into account in order to ensure a realistic deployment of the solutions in the cities. All of these activities are included in the Subtask 1.3.2 for all the cities of the project.

The **third phase focuses on the Scenario analysis to a 30 year vision for energy balance**. An aspect to emphasize this phase is that, at this point, the static vision of the analysis is passed and the evolution of these energy consumptions is evaluated in a prospective way, which will inhebably condition the needs of the city in terms of future energy generation. The generation of this tendencies will be carried out by evaluating the potential connection between the specific energy consumptions per sector and subsector with other socioeconomic and technical parameters of cities.

Here, at least two scenarios will be evaluated. The first one focused on defining the Business as Usual (BaU) situation that represents the tendential evolution of the energy consumptions without considering specific measures, and the second one that represents the low-carbon future scenario proposed for the city. The latter scenario provides a general view of the effect of the simultaneus implementation of long-term measures and strategies in an optimum way in the city. All these activities are included in the Subtask 1.3.3 for all of the cities of the project.

Finally the **fourth phase is focused on evaluating procedures to stimate impacts**. Impact assessment is a very broad topic which can cover different dimensions (economic, enviromental, social) and perspectives. The project aims to advance mainly in the different methodologies to be used for socio-economic impact assessment. One of the most relevant points will be the characterisation of the PED solutions and long term strategies in terms of their cost distribution and supply chain, which will make it possible to determine whether the investments made have a real effect on the local economy and society, or whether, on the other hand, socio-economic development is being favoured outside the intervened city. Besides, a prioritization procedure will be defined (prioritization tool) to evaluate which are the most interesting measures and strategies to be implemented in the cities during the following decades, so that this can contribute to the definition of the city vision and decarbonization scenarios to 2050. All these activities are included in the Subtask 1.3.4 for all the cities of the project.

The methodological framework, proposed for the generation of information through modelling that can be used to provide criteria applicable to long-term energy planning for cities, has been defined. Under the umbrella of this framework, the following sections of the document deal in more detail with each of the phases proposed from a broad point of view, trying to specify the method that can be considered in each of them for the MAKING-CITY project actvities.

3 Modelling of the energy demand side: Bottom-up approach for energy characterization of the building stock

This section of the document is **directly related to the Phase I "*modelling of the energy demand side*"** of the framework defined in the section 2.

The bottom-up modelling explores the building stock in detail, starting the analysis with the maximum level of disaggregation (dwelling, building sub system level...) and then grouping the energy values of the buildings using statistical or deterministic methods and techniques of aggregation, which will represent the entire building stock.

Unlike top-down modelling, bottom-up modelling uses hierarchical information, so that the accuracy of the model will vary depending on the level of disaggregation, that is why in order to develop validated and reliable building stock models, extensive empirical databases are needed.

This type of model is most commonly used to determine total energy consumption and annual CO_2 emission values, since they are a good way to identify the most cost-effective efficiency measures, as well as for retrofitting scenarios and policies to achieve energy consumption and CO_2 emission reduction targets.

3.1 State of the art

The most common classification of the different methodologies to evaluate the building stock distinguishes between top-down and bottom-up methodologies. Detailed reviews of building stock models performed by some authors, [1] [2], show that Top-Down models are not well-suited to model technology related policies, as they do not take into account the behaviour or physical characteristics of buildings or their specific energy systems. The analysis of the top down methodologies will be performed in section 4.

Similarly, bottom-up statistical models are also unable to correctly model or quantify the impact of retrofits. On the other hand, engineering or physics-based building models evaluate buildings' energy performance using thermodynamic equations for the heat transfer calculations, considering the power rating of appliances and equipment, so that they can evaluate the energy performance of each end user. The bottom-up modelling approach is commonly developed through clustering and classification techniques, where archetypes or samples of representative buildings are considered.

In this section an analysis of the different bottom up methodologies and their characteristics will be carried out. Each one will use different calculation or simulation techniques, providing results for different purposes, based on the precision, disaggregation or availability of the input data.

[3] adapted the analysis of the energy consumption calculation tools on district and city scales to the current context. The new classification of typology is described in Table 3

Table 3: Calculation tools typology [3]

Type	Description
Agent based	This type of model is based on individual behaviours. Energy consumptions are attributed to every activity within the city and refined according to the characteristics of buildings and residents. It relies on a global aggregation of individual consumptions.

Economic	These models often based on econometric methods describe the relationship between economic variables: capital, work, energy, demand…
Energy environment	These take into account the complexity of interactions between energy production, energy consumption and its impact on the environment (noise, air quality, climate change, etc.) These models are often based on large scales (city and region)
Morphological	The scale under consideration is typically the district and the city scale. It stresses the impact of urban form on building energy efficiency, taking into account land use, activities, localizations and intensities.

On a lower scale, district or municipality level, building stock energy performance assessment are commonly performed, forming the intermediate level between individual buildings and the national building stock.

These models can assess both individual building or entire cites with thousands of buildings since they are based on simplified simulations or archetypes, so their target audience are typically urban planners, developers, local policy makers.

The Table 4 summarises the classification results of the low scale building stock models previously mentioned.

Table 4: Models for district or municipality building stock assessment [4]

Name/Author and reference	Model Type	Audience/Scope of the application	Country
CitySim [5]	Bottom-up Engineering model	Decision support tool for urban energy planners	Switzerland
District-ECA [6]	Bottom-up Engineering model	Early planning stages decision support for urban planners, housing companies, developers and local political decision makers	Germany
Heeren [7]	Bottom-up Engineering model	Assessment methodology in form of a life cycle-based building stock models	Switzerland
Mattinen [8]	Bottom-up model	Calculation and visualization approach for energy use and GHG emissions from residential stock in a case district	Finland
EQ-tool [9]	Bottom-up model	Excel based tool for calculation of efficiency potentials in the residential building stock and transportation sector	Germany
Mastrucci [10]	Bottom-up statistical model	A GIS based statistical downscaling approach for assessing the residential building stock	Netherlands

Several studies provide an overview of common building stock bottom up modelling techniques, that can be categorised into different groups or typologies. Various authors ([1] [11] among others) classify the bottom up methodologies in 2 groups: statistical and engineering methods differentiating into different techniques for the bottom up engineering model. These techniques can be applied at any level, local (district, municipality) or national level.

Table 5 Classification of methodologies by two different authors

Author	Methodology	Model	Technique
Swan & Ugursal [1]	Top-Down	Econometric	
		Technological	
	Bottom-up	Statistical	Regression
			Conditional demand analysis
			Neural network
		Engineering	Population distribution
			Archetype
			Sample
Kazas, Fabrizio, & Perino [11]	Top-Down	Econometric	
		Technological	
	Bottom-up	Statistical	
		Engineering (physics-based building)	Brute force
			Building Archetypes
			Samples of representative building

Kazas et al. [11] classifies the physics-based bottom up engineering models into three techniques:

- Brute force
- Building Archetypes
- Samples of representative building

The brute force technique performs a simulation of each building in the study area individually. Each building represents a specific physical model, which is, theoretically highly accurate. However, it requires significant computational resources and large-scale simulations may be very time consuming. This method has been used for the simulation of small districts or areas [12].

The other two techniques classify the buildings in clusters, develop representative building models and aggregate them in order to obtain a complete building stock model. These two methods are commonly confused or considered as the same, however, there is a difference in the parameters considered in the building model.

Samples of representative buildings are models of actual buildings selected from the building stock that represent it. Archetypes are models that are created with average parameters of a specific group or cluster of buildings, and, being a simpler building model than the samples of representative buildings, they can represent a larger set of buildings.

Swan et al. considers the “Population distribution technique” instead of the “Brute force” technique proposed by Kazas et al. This technique distributes the appliance ownership and calculates the energy consumption of each end-use considering the use, average rating and the efficiency of each appliance.

The residential energy consumption is calculated by aggregating the appliance consumptions on the level used for the model (national, regional…).

Most of the existing bottom up models base their building stocks heat demand simulations on previously modelled archetypes [13]. By modelling a reduced set of sample buildings, the energy consumption profile and other key characteristics in the buildings can be estimated. However, the modelling of few buildings is not accurate enough to represent the whole building stock.

In order to obtain a representative sample of the city or study area, it is necessary in many cases to generate a large number of building models. When the generated models are very detailed, they represent a very small number of buildings and so that, a very high number of archetypes must be created. The generation and simulation of a wide variety of archetypes requires much time and effort for the modelling and increases the computational time of the simulation part.

In 1991 Huang [14] simulated 481 prototypical commercial buildings to evaluate the potential of cogeneration in big cities in the US and the model developed in 2000 [15] considered 61 prototypical residential buildings; 16 multifamily and 45 single-family buildings, simulated in 16 different regions

Jones [16] created 100 building archetypes commonly found in England, twenty built form types for each of the five defined age groups

This archetype-based technique, as well as the "Building sample" or the "Statistical" techniques, don't consider the particularities of each individual building, like the shadowing, the solar irradiation or the form factor among others. If building stock is modelled in this way, the model cannot be adjusted or validated by comparing actual consumption data with simulation results, since two buildings represented by the same archetype but located in different places and with occupants of different characteristics may have very different energy consumption, whereas there is only one building model against which to compare it.

Most of the methodologies focus only on residential buildings when developing building stock models because of the high impact of the sector in the final energy consumption and GHG emissions in urban areas. 12.71% of GHG emissions and 25.71% of final energy consumption in the EU28 are due to residential building stock.

Another reason why the great majority of models focus on the residential sector is the difficulty when defining occupant behaviour or equipment use patterns in non-residential buildings [17].

However, this problem also occurs when generating building models of the residential sector, due to the difficulty of establishing patterns and schedules that reflect the actual behaviour of each occupant because their unpredictable nature, even though the buildings are represented by the same archetype.

EUROSTAT [18] provides a methodology for the classification of buildings regarding their main use, stating that a building should be classified by the activity that occupies at least half of overall useful floor area. However, Kunze and Hecht [19] remarked the importance of recognizing the non-domestic activities in domestic buildings and considering the buildings with mixed use specially in or near to a town centre.

Some authors do consider the existence of mixed used buildings in their simulations. Nageler et al. [20] recognized mixed used buildings in their dynamic heat demand model of a small town in Austria and Hartmann et al. [21] included mixed-use buildings in their model for the whole of Germany. However, Evans et al. [22] point out the difficulty of finding examples of literature cases where the share of "mixed activity" buildings in the building stock has been quantified

This state-of-the-art review highlights that calculation tools and models based on technical and scientific basis do exist, and that they allow policy makers to develop strategies for efficiency measures and retrofitting scenarios and policies. However, it also shows the structural pitfalls that need to be solved in the future by the research community.

3.2 Methodology and scope

Although the level of detail of the BSMs has increased over the years, most of them are still based on archetypes or samples of representative buildings. The great advantage of these models lies in their simplicity and reduced computational time, which, however, reduces their accuracy at the building level. Therefore, in order to increase the accuracy of the model and obtain a more realistic view of the impacts of urban transformation strategies, it is necessary to consider buildings on an individual basis.

ENERKAD® will be used to generate the models within the MAKING-CITY project. ENERKAD® is a plugin for QGIS which evaluates urban energy scenarios at building, district and city scale and calculates the thermal energy demand and consumption per hour for each building in a district, using cadastral data, basic cartography and climatic information of the study area.

ENERKAD® foregoes the use of representative buildings and uses individual building information for its input data. It takes the basic mandatory parameters from the cadastre, which can be considered as its greatest advantage, since in many cases, detailed information of the buildings is not available to perform more complex simulations and the cadastral data is available to any municipality or city council. The rest of the information comes from different sources like energy performance certificates or municipal datasets. It only uses archetypical data to complete the information concerning the characteristics of buildings contained in its database (e.g. U-values, heating systems efficiency and heating setpoints).

The representation of individual buildings as an alternative of using archetypes increases the accuracy of the demand model and enables a more realistic modelling of the interventions evaluating the costs and benefits of each strategy instead of relying on average values.

One of the advantages of being GIS based that all the results of the simulation and the rest of the real information of each building is geo-localized and, thus, they can be crossed with socioeconomic parameters or building statistics for calculating different indicators or with actual energy consumption for the calibration of the model, increasing its accuracy.

The calibration of the energy models with actual consumption data is crucial to quantify current energy consumption correctly and not to overestimate the reduction potential of the measures applied in future scenarios.

The use of GIS software facilitates the representation of results, so that it is possible to analyse the actual state of energy demand in the city in a visual way and identify the areas with the greatest potential for savings or implementation of planned interventions.

3.3 Description of the method - modelling of the energy demand side - energy characterization of the city building stock

Enerkad® is an urban scenario energy assessment tool which performs energy and environmental evaluation, based on basic cartography, cadastral, and climatic information of the area under study. It calculates annual and hourly energy demand and consumption at building, district or city scale, allowing the analysis and comparison of current and future scenarios based on different strategies. It works with 2D models using a user-friendly interface based on QGIS, easing the visualization of the obtained results.

The only input needed by Enerkad® is a Shape file containing a few mandatory parameters, obtained from the cadastre. If more accurate results are wanted, the software also allows the end-user to include more specific information. The accessibility and simplicity of the mandatory information offers local authorities the possibility of obtaining a general overview of their municipalities in terms of energy consumption to support decision making, in any European country.

The outline of the methodology used is given on Figure 2.

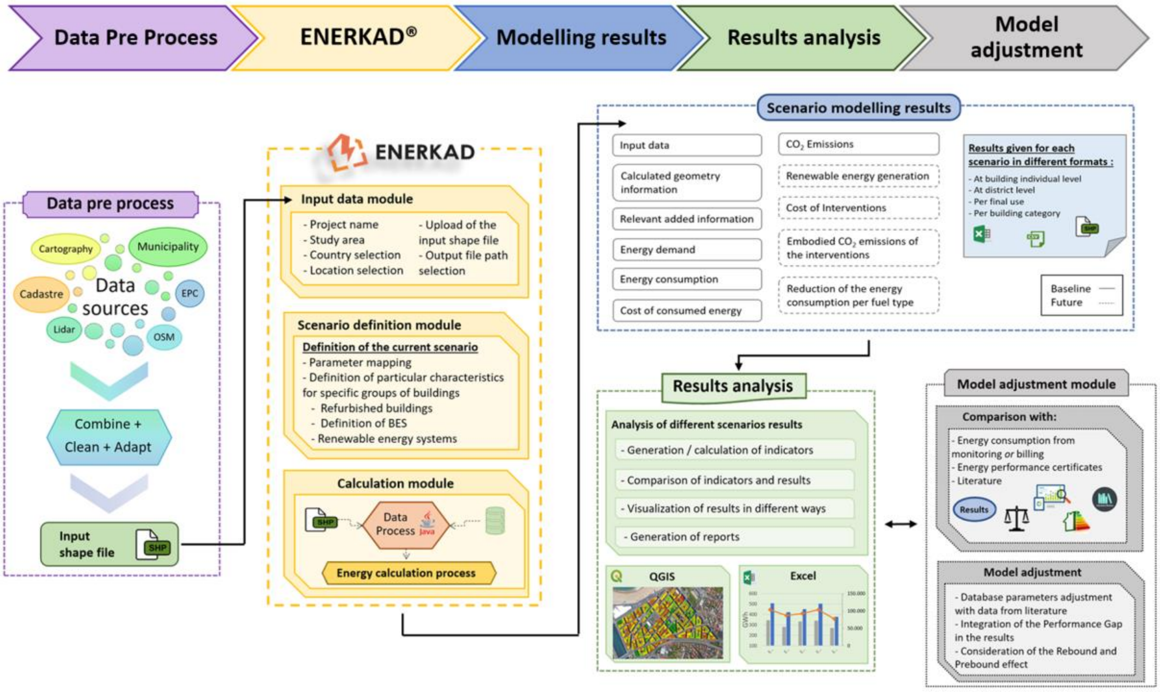


Figure 2: Outline of ENERKAD® methodology

To generate energy demand profiles, Enerkad® bases its calculations on the degree-day method applying a 'bottom-up' methodology, considering different characteristics of each building, like the building use and the construction year, in the calculations. Based on this methodology, it quantifies and stores the georeferenced current and future thermal energy (heating, cooling and Domestic Hot Water) and electricity (lighting and appliances) demand results for each building in the area under study, which will lead to the calculation of the energy consumption, CO_2 emissions, and cost of the consumed energy.

Enerkad® allows the assessment of both baseline and future scenarios. The baseline scenario represents the current status of the area under study and it will serve as the reference frame against which the strategies applied in the alternative scenarios will be evaluated.

The generation of the future scenarios is performed by the implementation of three different strategy types:

- Implementation of passive strategies (refurbishment of building envelope elements)
- Replacement of building energy systems by more efficient technologies.
- Implementation of solar photovoltaic and thermal systems.

3.4 Necessary data and collection process

This section presents the information needed and the pre-process of the data, from data collection to the generation of the urban model with the information in the required format and level of detail.

The objective of the "Pre-process" is to obtain detailed geometry at building level and the greatest number of attributes associated to that geometry. The detailed urban model obtained from the data pre-process will serve as an input for Enerkad®, which will be the tool by means of which the energy analysis of the study cases of the project will be carried out.

In order to obtain reliable results in the energy simulation, a process of adaptation, cleaning and organization of the input data must be done, since the accuracy of the results will depend to a large extent on the level of detail and the veracity of the data of the generated urban model.

Weather data

The weather parameters required for the calculations are taken from *.epw weather files from the Energy Plus database [23] , which contain the hourly values for 25 weather parameters. This weather files provide hourly profiles for different weather parameters, such as dry bulb temperature, solar radiation, wind speed and direction, illuminance, or precipitation, for a large amount of locations worldwide and are free for download from the Energy Plus website.

For the energy demand assessment process hourly profiles of the outdoor air temperature and the solar radiation are used.

Building data

The information related to the buildings can be differentiated into 2 groups: geometrical information and semantic information.

For the basic analysis of the energy demand, only 5 basic parameters are needed, which are normally available in the cadastre of the city or the municipality. The minimum input information necessary to carry out the modelling is the following:

- Building ID
- Footprint area
- Building Height (Height or number of floors)
- Construction year
- Building use

The height of buildings is sometimes not available or is not very precise, but it can be calculated by means of LIDAR files to obtain a precise value in each building. Although the method has been used and validated in previous studies [24], [25], the LIDAR files are not publicly available in all countries and the information related to the height provided in the cadastre has to be used.

Other parameters needed for the calculations, such as the volume, the window area or the adjoining wall surface, are internally calculated by Enerkad®

If more semantic information is available, a more detailed analysis could be carried out. In the following table, all the possible additional inputs are shown. These parameters are not usually included in the cadastre file and must be provided by the municipality from sources such as municipal databases or energy performance certificates. This information should be provided for each building, although some parameters can be defined generically by use and age of the building, such as the Building Energy Systems.

Table 6: ENERKAD® input parameters

Parameter	Mandatory / Optional	Parameter	Mandatory / Optional
Building ID	Mandatory	Roof area	Optional
Footprint area	Mandatory	Energy system	Optional
Building Height	Mandatory / Optional	Boiler type	Optional
Number of floors	Optional	Number of boilers	Optional

Construction year	Mandatory	Number of dwellings	Optional
Building use	Mandatory	Effective roof %	Optional
Protection degree[1]	Optional	Solar irradiance m^2	Optional
Gross floor area	Optional		

3.5 Visualization of the results

The results provided by the model will vary depending on the input information available. In the case of having provided only the mandatory parameters, the energy results obtained from the simulation will be the demand for heating, cooling, DHW, lighting and equipment, while, if information related to the equipment and fuel used in each building is provided, energy consumption will also be obtained, as well as emissions and associated costs.

The main energy related parameters obtained from the baseline scenario simulation are listed in the following table:

Table 7: Main energy related parameters at building level for the baseline scenario

Parameter	Unit	Parameter	Unit
Heating demand	kWh and kWh/m^2	Cooling consumption	kWh and kWh/m^2
Cooling demand	kWh and kWh/m^2	DHW consumption	kWh and kWh/m^2
DHW demand	kWh and kWh/m^2	Lighting consumption	kWh and kWh/m^2
Lighting demand	kWh and kWh/m^2	Equipment consumption	kWh and kWh/m^2
Equipment demand	kWh and kWh/m^2	CO_2 emissions	CO_2 and CO_2/m^2
Heating consumption	kWh and kWh/m^2	Cost	€ and €/m^2

This information together with many other parameters related to the building geometry are provided in shape format at building level and in csv format at building level and grouped ad district or city level.

The different formats of the outputs results allow the user to visualize the results graphically using any GIS tool (shape file) or numerically (using csv files), obtaining an overview of the results, individualized at building level, so that it is possible to see detailed information at the building level or group the information based on the parameter that the user needs.

By using the shape file, it is possible to visualize, together with the results obtained from the energy simulation, building parameters (such as use and age) or any other parameter included in the input shape file, such as the energy performance certificates.

[1] Only used for the future scenario calculations, not for the baseline

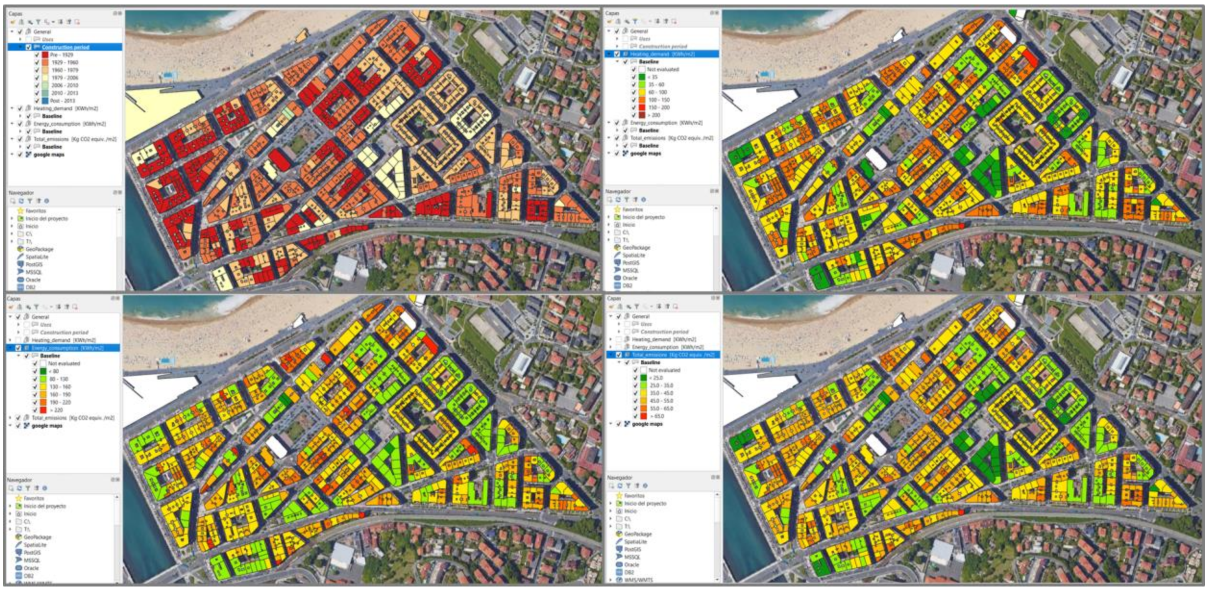


Figure 3: Visualization of the results in QGIS

4 Supply-side modelling: smart city technologies and Scenario analysis to a 30 years vision for energy balance

This section of the document is **directly related to the Phase II "*supply-side modelling: smart city technologies*" and Phase III *"Scenario analysis to a 30-year vision for energy balance"*** of the framework defined in the section 2.

Apart from the work performed regarding geographical and physical nature of cities, to carry out a different modelling based on the characterisation of energy systems is very necessary. In that sense, a city is a complex entity where energy is consumed (predominantly) but not produced (not at the required levels). Accordingly, a key issue in urban planning and city policymaking is how to deal with that imbalance. In addition, there are some other aspects to be considered such as pollution coming from transport, residential and commercial, and even due to the industries within the metropolitan area.

Energy consumed by cities is related with area and population. The larger the city, the higher the energy consumption is. As well, if a city is densely inhabited, such a fact goes to the favour of optimising services and urban planning, thus alleviating energy consumption. On the opposite, very spread-out cities (those with low population density), waste a lot of energy in satisfying urban services. Thus, the characterisation of cities according to their typologies is crucial to better understand the way the cities consume (and produce, if so) energy.

The energy systems modelling (ESM) is a recent research field within the realm of energy planning that encompasses operations research (OR) and other methodologies to assist experts in decision-making processes. The complexity of the energy systems -in here we talk about urban energy systems- makes required to use ESM methodologies and tools.

When we talk about ESM, we are referring to a vast list of strategies, modelling tools, and approaches, which help us to get a simplified but realistic picture of the energy-related aspects of cities. Moreover, main justification to use ESM is also to develop 'what if' narratives to explore alternative evolutions of the energy system evaluated. For instance, what if we go for 50 % electric vehicles by 2030 in our city? And 80 % or 90 %? What if we push the system to behave with predefined limits on CO_2 emissions? Let's say a 90 % reduction (with respect to a specific year) by 2040. Is that possible? What would the optimal energy mix be to satisfy that? In summary, energy-related narratives are the basis to create the so-called energy scenarios.

The use of ESM is founded on the creation of an energy accounting balance with a reference year (or if possible, some historical years up to the last statistical figure) that depicts the nature of the energy system -in our case, a city- as a realistic photo of the energy flows (production, transformations, consumptions) happening in it. To do so, the type of data required is energy production processes (plants) per technology type and by fuel type, as well as energy demands by economic sector (industry, residential, commercial, transport, agriculture, etc.) with the highest possible level of disaggregation (residential sector consumptions by heating, cooling, appliances, lighting, etc., and by fuel type each).

Once all the data regarding energy (electricity, heat, liquid fuels, natural gas, etc.), both generation (sometimes referred as 'production' or 'supply') and consumption (often as 'demand'), is compiled and structured within the modelling platform, the next step is to establish the key drivers that will project the demands into the future. Those key drivers are usually the Gross Domestic Product (GDP), its sectoral version, i.e. the Gross Value Added (GVA), as well as population, GDP *per capita*, and energy prices.

Accordingly, with the design of the accounting balance for the reference year and the selection of drivers to project energy demands it is possible to create the baseline scenario, sometimes referred as Business as Usual (BaU). The BaU scenario corresponds to the set of assumptions including the key aspects of the energy system modelled plus constraints considered realistic and obligations derived from policies and plans which go into the future. If something is not 'real' (for instance, a measure or a commitment enforced by law), it should be understood as an exploration. The evaluation of those exploratory cases is established then as 'alternative' scenarios. Resulting from the comparison between BaU and alternative scenarios, it will be possible to open a discussion on the benefits and disadvantages of pursuing different measures in energy planning (emission reductions, energy savings, costs comparison, among others).

Based on the BaU scenario, alternative scenarios can be developed considering the project's interventions, thus allowing the evaluation of the effect of such measures in the entire city development. The figure below is a visual representation of the scenario modelling approach considered in the project.

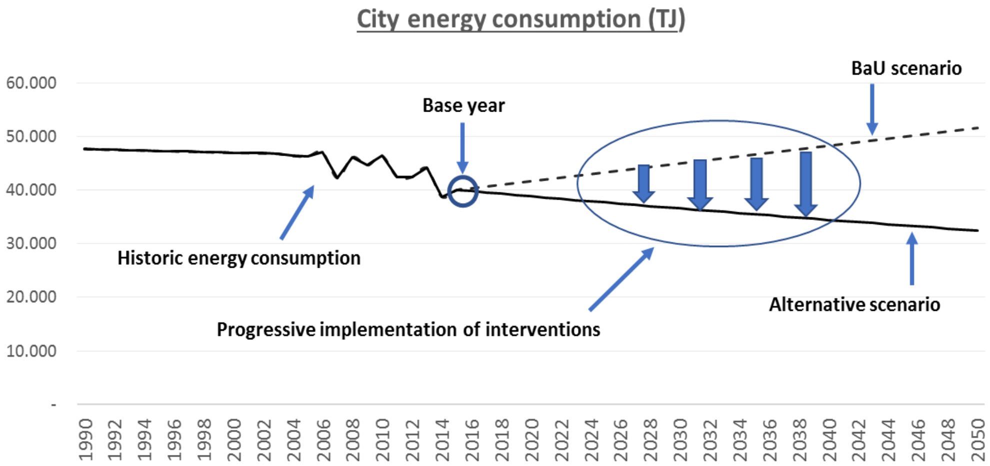


Figure 4: Conceptual example of scenario modelling in MAKING-CITY project

4.1 State of the art

Beginning from the works of Wene [26] and up to the methodological advances from Helgesen [27], two complementary ESM types have been developed to deeply evaluate the connection between energy and economy. Those approaches are the 'bottom-up' engineering approach and the 'top-down' macroeconomic approach.

Grubb [28] stated that the top-down approach is associated with –but not exclusively restricted to– the "pessimistic" economic paradigm, while the bottom-up approach is associated with the "optimistic" engineering paradigm. Therefore, the latter is also referred to as the engineering approach.

The bottom-up approach is conceived as an ESM tactic based on the importance of descriptions of technologic aspects of the energy system as well as its future evolution. Energy demand is typically assumed exogenously, and the models are oriented on how the given energy demand should be fulfilled in a cost-optimal fashion. Due to this cost-related rationale, it is usual to talk about techno-economic models, not only engineering.

On the other side, the top-down models are founded on the macroeconomic behaviour of the system, i.e. they describe the whole economy, and emphasize the possibilities to substitute different production factors to optimize aspects such as social welfare. These models do not include many technical aspects. The interplay between energy and other production factors to create economic growth is apprehended in production functions, and opportunities to make changes in fuel mixes are assumed by elasticities of substitution. The technologic enhancements happening in the energy system are assumed through parameters like the autonomous energy efficiency improvement, which allows the production to improve due to assumed technical improvements [29].

The two approaches differ considerably in their identification of the relevant system and may therefore produce different guidance for policymakers. The production functions in top-down models will usually have smooth substitution - a small price change leads to small changes in the mix of inputs or outputs. The bottom-up engineering models will often react in a more binary way: a small price change can lead to no effect at all, or it can produce large shifts in the mix of inputs or outputs. An evaluation between a few top-down and bottom-up approaches and their usefulness to policy-makers is given in [30].

The main conclusion raised by Helgesen [27] is that both modelling approaches complement each other. Combining bottom-up engineering models with top-down macroeconomic models should be essential when we want to design energy systems compatible with sustainable economic growth.

The categorisation of the bottom-up models, due to its versatility and use in hundreds of case studies at every level is possible. In this sense, according to the work undergone by [27], the author established a simple and useful categorisation of bottom-up ESM approaches based on several review studies [31], [32]: optimisation models, simulation models, accounting models, and multi-agent models.

- **Accounting models** are less dynamic, and do not consider energy prices. These models mainly apply exogenous assumptions on the technical development.

- **Simulation models** constitute a very broad and heterogeneous group. Their modelling aspects depart from the pure optimisation framework. They can include econometrically estimated relations. Large simulation models can include partial optimization (e.g. from a company perspective) and can consist of different modules covering more aspects.

- **Optimisation models** optimise the choice of technology alternatives regarding total system costs to find the least-cost path. Such models are also categorised as partial equilibrium models, since they balance demand and supply in the covered sectors (looking at the energy balance only).

- **Multi-agent models** are a broader modelling class than the optimisation models, since they include the simultaneous optimisation by more agents.

On the opposite, categorising the top-down models is not so reachable due to the multiplicity of facets, the hybridisation among models and the unclear limits of the studies. In [30], top-down models included are limited to a single type, the so-called Computer General Equilibrium (CGE) models. CGE models are a class of economic models that use empirical economic data to estimate how an economy might react to changes in policy, technology or other external factors. A CGE model consists of equations describing model variables and a database consistent with the model equations. The equations are normally neo-classical in character, often assuming cost-minimising behaviour by producers, average-cost pricing, and household demands based on optimising behaviour.

McFarland, Reilly, and Herzog [33] stated that among the various top-down approaches, CGE models are the most complete in representing economy-wide interactions, including international trade, energy supply and demand, inter-industry demand and supply for goods and services, factor markets, and consumer demands. In contrast, they are often the least rich in their representation of technological details.

According to Van Beeck [34], modelling approaches could be categorised into 1) econometric, 2) macro-economic, 3) economic equilibrium, 4) optimisation, 5) simulation, 6) spreadsheet, 7) back-casting, and 8) multi-criteria models. From those types, it is only possible to consider as top-down econometric, macro-economic and economic equilibrium models. The rest are usually bottom-up or hybrids.

4.2 Methodology and scope

There is a wide variety of tools that could be considered for this type of analyses. The review carried out by [35] offers a complete evaluation of the various tools for assessing energy systems at different scales. Such study evaluates tools such as HOMER, LEAP, ENPEP-BALANCE, EnergyPlan, H2RES, MESSAGE, and PRIMES among others, classifying them according to the application scale, the evaluated sectors, the scenario timeframe, the time-step, or the modelling approach.

After evaluating the pros and cons of those tools, the one selected for this study is LEAP (Long range Energy Alternatives Planning[2]). LEAP is software developed at the Stockholm Environment Institute. It is an integrated energy planning software used for making energy plans and policy assessment which includes both supply and demand side analysis, and allows to project fuel consumptions, energy productions and emission derived. This software has been selected because it offers a good compromise between accuracy in results and flexibility for modelling the energy system at different scales (national, regional, urban).

Moreover, it should be noted that most of the software mentioned above are not specifically designed for modelling the energy systems at city scale. The most common use of such type of tools is the national energy modelling and therefore several modifications or considerations must be done for their use at the city level. In this sense, LEAP offers a high flexibility.

The use of LEAP is highly decided by its relevance. LEAP has been assumed by hundreds of organisations in almost 200 countries worldwide. Its users include governments, academics, non-governmental organisations, consulting companies, and energy utilities. It has been used at many different scales ranging from cities and states to national, regional and global applications.

LEAP is fast becoming the standard for countries carrying out integrated resource planning, emissions reduction studies, and even decarbonization strategies particularly in the developing world, and many nations have also chosen to use this software as part of their commitment to report to the U.N. Framework Convention on Climate Change. At least 32 countries used LEAP to create energy and emissions scenarios that were the basis for their Intended Nationally Determined Contributions on Climate Change (INDC): the foundation of the historic Paris climate agreement intended to demonstrate the intent of countries to begin decarbonizing their economies and invest in climate-resilience.

Moreover, due to the diverse nature of countries, regions and cities, there are cases in which LEAP has been used to evaluate energy measures applied at the city level. In the scientific literature it is possible to get some: [36] for La Plata (Argentina), [37] for Tehran (Iran), [38] for Sao Paulo (Brazil), and [39]–[45], for different cities all along China.

4.3 Description of the method: Supply-side modelling: smart city technologies

When beginning with the design of a city ESM, the first step is the modelling of the current situation of the city so that it can serve as starting point for the development of the future scenarios. In this point, the data gathering process is very intensive and will have a direct influence in the level of detail and accuracy of the model developed.

The structure and energy characterization of the city will therefore depend on the data available or the modelling software used, among other aspects. Energy and non-energy related sectors will be as much detailed and specified (and hence scenarios accurateness) as information is accessible. However, it can be said that in most of the cases the city energy system can be characterized in the model by means of the following three main entities (modules):

[2] https://www.energycommunity.org/default.asp?action=introduction

- Demand side
- Supply side
- City resources

4.3.1 Demand side characterization

This module defines the energy consumption of the end-use sectors within the city, frequently understood as the key economic sectors that consume energy to satisfy energy services. Those sectors are often as follows:

- Residential
- Tertiary
- Industry
- Transport
- Primary sector (farming, forestry, mining, fishing…)

In some ESM, preceding categories are slightly different. City-level models usually include extra divisions regarding the intervention level of the municipality, e.g. 'public buildings', 'lightning', 'public transport' could be categories raised at the top of the hierarchy. Besides, it may happen that some other categories do not appear since the nature of a city is very specific (it is likely to not having industry or agriculture within the municipal limits).

Each economic sector can be divided into subsectors or sub-divisions. For example, residential sector can be split into apartment blocks and single-family houses (not only); tertiary sector may be divided into office buildings, educational buildings, healthcare buildings, etc.; industry into iron and steel industry, chemical, consumer goods, etc.; and transport sector could be divided into public/private, road/non- road, passenger/freight, etc.

The energy uses which characterize the demands within each economic sector (e.g. heating and cooling, lighting, appliances, etc.), are usually implemented in the form of representative technologies/devices (e.g. boiler, solar collectors, heat pumps, district heating networks, etc.). Finally, every technology/device needs to be defined by their fuel consumption. Thus, city's energy consumption is determined through a bottom-up approach, with a detailed description of the energy requirements and end-use technologies which satisfy the energy service demands of the population.

In the table below an example of the disaggregation within final energy uses and technologies is included for the residential's subsector of apartment blocks.

Table 8: Most usual disaggregation for the apartment blocks

Subsector	Final energy use	Technology	Fuel
Apartment blocks	Heating and DHW	Boiler	Natural gas
		District Heating (DH)	Heat
		Heat pump	Electricity
		Electric heater	Electricity

	Lighting	Conventional lamps	Electricity
		LED lamps	Electricity
	Home appliances	TV	Electricity
		Dishwasher	Electricity

The cases in which the on-site generation is used (to self-consumption) need to be also considered in this section by defining a relationship between energy consumed and on-site energy produced (usually by renewable energy technologies such as solar thermal or the photovoltaics).

4.3.2 Supply side characterization

The supply module defines the energy production (and consumption) of all those transformation processes/plants within the city boundaries where primary energy is converted into final energy. The supply side may produce total or partially the energy consumed by the end-use sectors of the city described above. In case of not being enough with the indigenous energy generation, the energy needs should be satisfied by making use of the grid (further involving indirect issues such as the way the electricity is produced at the national level).

Accordingly, this module usually includes:

- **Electricity generation processes**: PV plants, hydropower plants, wind farms, other non-renewable processes for electricity production, etc.
- **Thermal energy generation processes**: heat only boiler plants, heat pump plants, etc.
- **Cogeneration Heat and Power** (CHP) plants.
- **Other conversion processes** such as refineries, biomass treatment plants, biofuel production plants, mines, etc.
- **Import/export**: the energy needs that are not met by the local supply side will have to be supplied by neighbouring regions. In the same way, the energy surplus can be exported to those adjacent regions.
- **Heat and electricity networks losses**: characteristics of the city's heat and power grids are mainly focused on transmission losses.

Based on the final energy demand and the characteristics of the supply side (i.e. process efficiencies, plants capacities, DH and power grid losses, etc.), final energy requirements are calculated, and consequently primary energy resources are consumed to produce fulfil those energy needs. Besides, in case that energy needs remain unmet (due to lack of resources, technical problems to install technologies or unrealistic behaviour in terms of costs, for example), the energy gap is calculated. In the same way, if there is an energy surplus situation in the city several exporting options could be modelled.

4.3.3 City resources

In this module the city's energy reserves and renewable energy yields are detailed. Besides, the import/export targets can be fixed. Hence, the possibilities of using alternative resources and the availability of local energy resources can be assessed herein.

4.4 Scenario analysis to a 30-year vision for energy balance

Once the city is characterized and modelled for the base year, the future energy demands can be evaluated through the development of different scenarios. As a starting point the Business as Usual (BaU) scenario will be defined. This scenario is based on forecasted trends which consider the expected evolution of various social and macroeconomic parameters (e.g. population, income, GDP growth), as well as the policies and plans that have been accepted by the base year of the study. This scenario is the reference scenario that will be used to measure the improvements that will be obtained by the new alternative scenario and can serve to measure also the compliance of the defined target for different time horizons.

Alternative scenarios on the other hand, take into consideration not only the mentioned trends and influences of the demographic and economic growths in the future energy demands of the city but also the implementation of new interventions which aim to transform the current situation to the desired future situation.

Therefore, information used for each scenario will be different: The BaU scenario will use the projected evolution of various parameters and data from actual plans. Alternative scenarios on the other hand, can evaluate an endless number of modeler's assumptions and judgements to explore the effect of these implementation in the development of the city.

Two main approaches can be adopted for generation of the alternative scenarios:

- Backcasting: based on a normative view. Starting from the future, it focuses on forthcoming targets and how to reach them. This approach would be useful to assess the energy interventions developed and which seek to fulfil the targets and objectives from policies or climate/energy city's plans such as energy demand reduction, energy efficiency improvements, share increase of RES or CO_2 emissions reduction.
- Forecasting: based on a descriptive/explorative view. Starting from the present, it focuses on exploring alternative developments from the actual situation. This approach would be useful to the technoeconomic assessment and environmental and social impacts evaluation of energy interventions or alternative developments (alternative targets or policies) which for example are not considered in the BaU scenario.

In this project the forecasting approach is adopted considering that is the best option to evaluate the specific effects that the implementation of the interventions that are planned initially for the lighthouse cities can produce.

4.5 Necessary data and collection process

The data collection process of energy-related information is focused on the abovementioned entities, i.e. demand technologies, supply technologies, and data on fuels and emissions. Besides, some specific data are necessary to depict the structure of those entities. For example, some socioeconomic drivers like GDP, population, or energy prices are taken separately to build (in some cases) demand projections. As well, structural data of the energy system like transmission losses in the natural gas network and electricity grid are assumed separately.

Demand technologies are those technologies or technology pathways (depending on the way they are conceptualised within the software) which require an input of energy usually in the form of final energy. It is usual to assume such technologies as demand technologies. In some cases, 'demand' refers to an energy service (e.g. energy required to transport a passenger 1 kilometre: MJ/pkm). In other cases, demand is directly connected to the energy required as an aggregated consumption of a specific fuel (e.g. natural gas consumed in industry). In that case, the impossibility of getting consumption data at technology level makes necessary to overpass this misunderstanding in nomenclature. Regardless of the naming (if energy service demand or just energy demand as consumption), the side of the demand is a compilation of energy consumptions such that, at the end, must match the credited consumption signed by the city in its statistics.

In this sense, sources of information to get data on demand are city statistics offices, annual reports of sectoral associations, vehicles register office, cadastres, among others. Concrete data on technology sectoral data like number of heating and/or cooling systems, lighting devices installed, etc., may be obtained from regional or national offices assigned to ministries.

Supply technologies are those technologies which transform primary energy sources and produce final energy in the form of usable energy carriers -sometimes referred as fuels- such as electricity, heat, etc. Broadly speaking such technologies are sometimes referred as generation technologies or even production technologies. In the case of electricity generation, conventional technologies are coal thermal power plants, natural gas combined cycle plants, nuclear power plants, whereas renewables are wind turbines, hydropower plants, solar photovoltaic (PV) systems, geothermal power plants, biomass combustion power plants, among others. CHP plants produce both heat and electricity so they can be included in different branches depending on the co-product's relevance.

Sources of information in this case are varied. Data on generation of electricity or heat in a city may be collected by city statistics or even by national bodies like ministries. Technical details on exploitation potentials of renewables and resources are related with land availability, roofs and buildings typology so cadastres, and urban studies from municipalities are useful.

Data on fuels are extracted on specific records from prices in gas stations and from data collected by energy companies reporting to the municipality. In this sense, it is relevant to match supply and demand reported statistics regarding self-production and import/export from neighbouring regions to the city. It happens that cities are energy sinks that consume a lot of energy, but they do not produce it at the required level. Therefore, national statistics from transmission systems operators (TSOs), natural gas grid companies, and annual reports from ministries are necessary to complement some gaps of information. Concerning **emissions**, national or regional bodies -even metropolitan areas if cities are large- usually collect data on emissions inventories.

Socioeconomic drivers are those metrics who help to describe the energy system -and its behaviour- at the macro level. GDP is the most relevant one, whereas population, and energy prices are relevant too. GDP measures the market value (monetary) of all the final goods and services within a region or country (usually taken per year). Projections of GDP are taken from national banks' studies or EU bodies. Population projections are normally carried out by the national/regional statistics offices using populational models. Energy prices (electricity, natural gas, diesel, gasoline) projections are taken from international studies such as International Energy Agency (IEA) reports, or the US Energy Information Administration (EIA).

Structural data refers to that information required to deeply detail the nature of the energy system. Transmission losses in the electricity grid as well as losses in transformation from high to medium to low voltage are taken from reports of the national TSOs. Similarly, natural gas losses within the distribution system (pipeline and trucks) are taken from annual reports of the natural gas operator.

4.6 Results and discussion

Depending on the type of data achieved during the collection process, it is possible to design the city ESM with precision. Attending to this limitation, the suitability of the results to raise a discussion on the convenience of pursuing different measures is diverse. The higher the disaggregation of data is, the better the potential discussion carried out later.

There are several outputs resulted commonly from this type of ESM exercises. The final energy demand at the sector (see Figure 5) or sub-sector level (or by fuel type, see Figure 6) allows to observe the behaviour of the consumption in the long-term. This is very helpful to detect undesired trends and taking actions to change that via measures (alternative scenarios). Besides, the final energy demand entails a primary energy consumption. That primary energy is associated to the resources wasted, accessibility and self-sufficiency concerns in the case of cities. Finally, emissions associated to the transformation and consumption of several types of energy result in the model as output (see Figure 7). The application of measures to reduce the energy demanded (the amount of energy consumed) is not the only issue to deal with in ESM.

Additionally, the fight against climate change and atmospheric pollution makes necessary to pursue a transition from a fossil-based consumption to a system founded on renewable energy sources. That transition is understood as a decarbonisation process applying on the entire economy. For instance, a 100% renewable electricity system favours the electrification of other end-use sectors where fossil fuels like natural gas continue being the basis (e.g. industry). If possible, electrification may decarbonise those economic sectors in a direct way (electricity consumption does not release emissions) but also indirectly (a 100% renewable electricity generation mix would not have direct emissions).

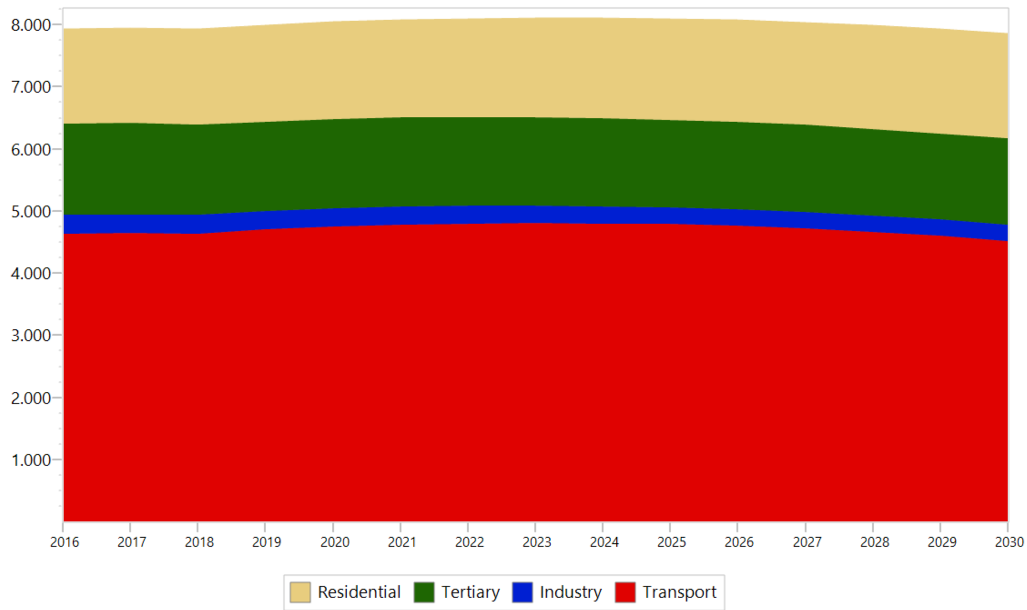


Figure 5: Example of Final Energy Demand (GWh) evolution per sector for a city in a BaU scenario

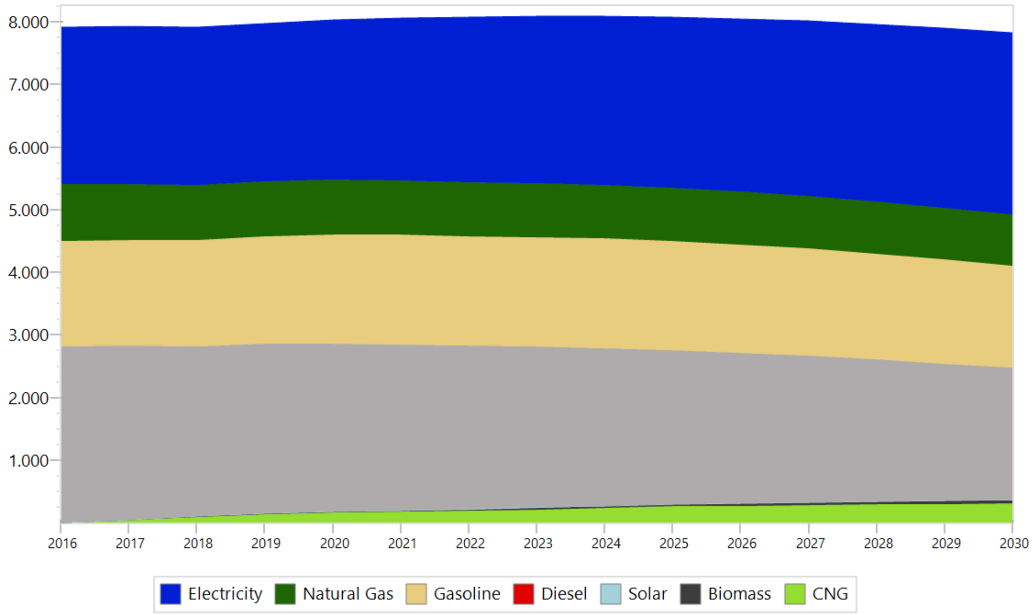


Figure 6: Example of Final Energy Demand (GWh) evolution per fuel for a city in a BaU scenario

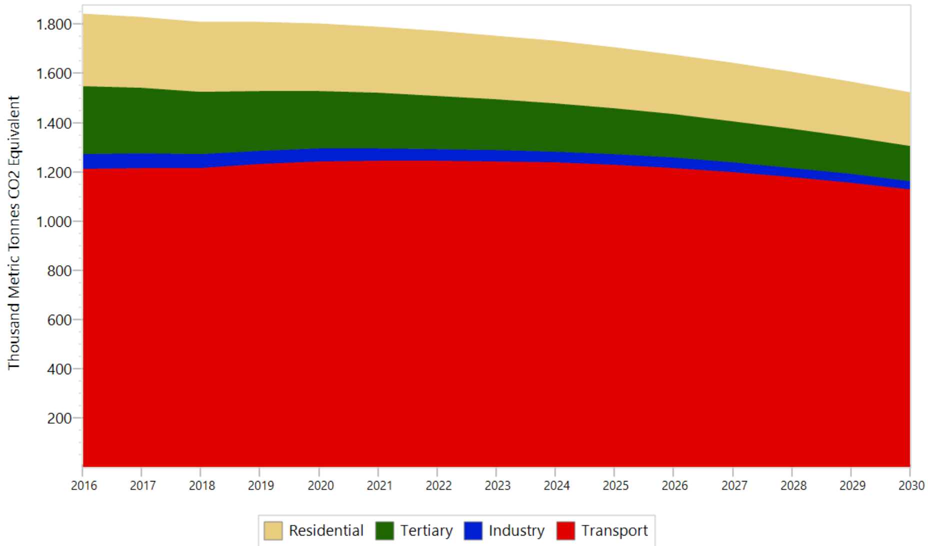


Figure 7: Example of Global Warming (CO_2eq) evolution per sector for a city in a BaU scenario

In Figure 7, a reduction in emissions is observed in a diverse way depending on the sector. Each economic sector contributes differently according to its demanding technologies and the relevance of transport is crucial when undergoing ESM at city level.

Finally, the picture of the entire energy system is represented thanks to a Sankey diagram like the one plotted next:

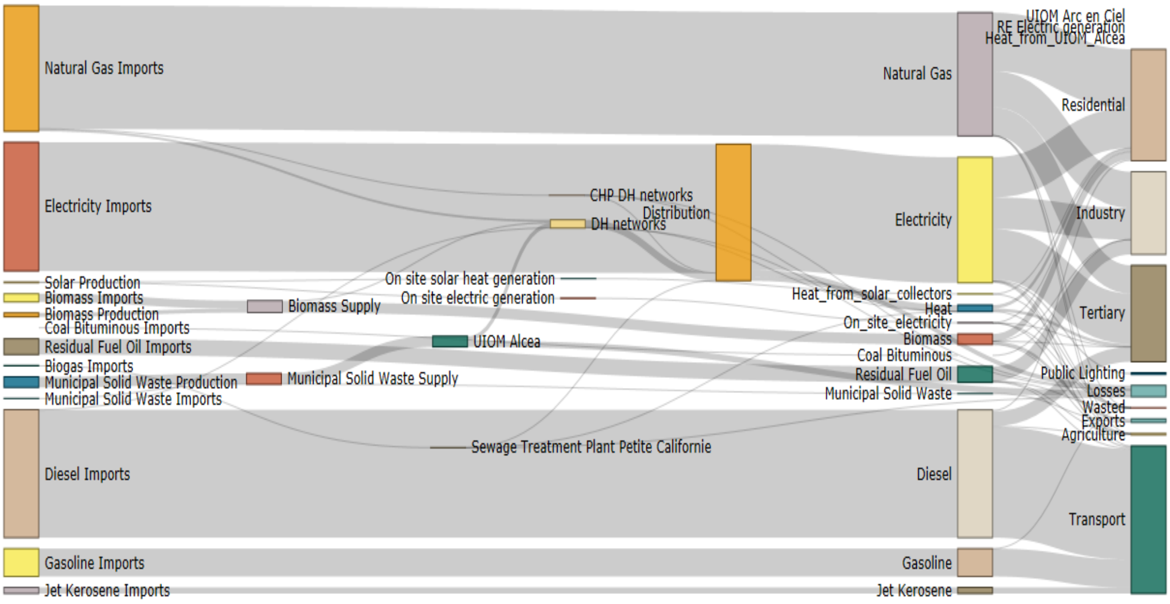


Figure 8: Example of Sankey diagram of the energy system of a city in a specific year

4.7 Other modelling tools

Urban transitions, such as the energy transition, are characterised by unprecedented levels of technological, economic and social complexity with novel technologies and vanishing borders between sectors. Decision makers both in the public and private spheres require fact-based information and process support in order to make coherent, future-proof and effective decisions in order to realize the energy transition. Quantitative models can be applied as tools to support decision makers to improve the understanding of the impact of their decisions on e.g. policies, governance, and investments via a forward looking perspective on transitions [46]. However, these quantitative models have limitations when it comes to the behaviour of stakeholders, the role inertia and innovation and explaining the spatial dimensions of the energy transition [47]. Moreover, the landscape of models has grown immensely and uncoordinatedly leading to a dispersed landscape of energy transition models. The dispersion lies in the organisations developing and using these models, but also in the functionality, availability, and scope of the models. In this context, a study has been carried out of the energy transition models developed for the Dutch situation. In total 32 models were assessed on the geographic scope, phase of the transition targeted, and the functionality (more details can be consulted in Appendix I and Appendix II). The most significant results regarding the gaps in the model landscape were:

- A lack of models on the dwelling level - Only 8 models include the individual agents and dwellings while, for the level of PEDs, models need to pack sufficient detail to support decision making on the city level all the way to the dwelling/agent level.
- A lack of models serving the phase of execution and O&M –There is no model functioning in the execution and operational phase of the energy transition, this would for instance be a model which plans and monitors an optimal retrofit sequence for dwellings towards a PED, taking into account logistics, material supply chains etc. On the other hand, many high-level strategic models are available in the Dutch landscape.
- Majority of the models boast energetic and spatial visualization functionality – The majority of the models focus on the energy generation side of the energy transition. The demand side,

regarding e.g. demand side management and energy efficiency is insufficiently included. In addition, a minority of models include functionality to model energy markets and energy policy.
- Social side is underrepresented – Related to the insufficient inclusion of the demand side, the social aspects of the energy transition are poorly represented in energy transition models.

As can be seen the model landscape is rich, but at the same time dispersed and with gaps regarding the execution and operational phase in the energy transition, the detail level of individual dwellings and end-users, and the inclusion of the social side of the energy transition. A solution would be to link existing model such that the linked models complement each other in the functionality. However, due to the big differences in modelling scope, assumptions made, and the techniques and languages, this is proven an immense challenge. A possible solution might be provided by the uniform modelling language for energy systems developed by TNO: the ESSIM model.

TNO developed the Energy System Description Language (ESDL) to model each object of an energy system in a uniform way. This machine-readable language, may be used for:

- Energy transition calculation models and tools, to specify the format of the inputs and outputs and allow for integration of multiple tools.
- Energy Information Systems, where the energy system of a certain region is registered.
- A language for (local) governments to model, discuss and share their (local) energy system.
- The monitoring of the evolution of an energy system via multiple ESDL snapshots of a certain area over time.
- A format to share data relevant to energy systems or the energy transition, e.g.: CO2 emissions per energy carrier, Technology (costs) factsheets for specific components or installations, and Standard configurations of typical parts of the energy system (e.g. a house with a heat pump, solar panels and an EV charging station)

ESSIM (Energy System SIMulator) is a tool that simulates integrated network balancing in an ESDL-defined energy system comprising of interconnected multi-commodity energy networks. It considers energy system information, data profiles and control strategies configured by the user to simulate dynamics in the energy system over a user-defined time period in user-defined time steps. The simulator generates a dashboard visualising energy mixes in the networks, imbalances and emissions.

5 Procedures to Estimate the impacts: Prioritization of long-term strategies and impact assessment of alternative energy scenarios

This section of the document is directly related to the Phase IV *"Procedures to Estimate the impacts"* of the framework defined in the section 2.

The characterisation of technologies and their related operational models (which include the agents, potential business model, management plans, etc.) is a key aspect to allow cities matching between demand-oriented scenarios and the replication and upscaling of technology projects. The purpose is to provide the appropriate inputs to allow stakeholders analysing through a prioritization tool the replication and upscaling potential of technology solutions and long-term strategies, and their related business models.

In this sense, the long-term solutions and strategies for cities propose a systemic concept that encompasses measures and technologies aligned with the smart city concept, but not only. The establishment of a catalogue of strategies is crucial to understand how deep those measures may modify the city energy system by transforming the way it produces and consumes energy in the decades to come.

Once the solutions and strategies are detailed and selected as the most adequate for the city, it is necessary to deploy strategies to scale up such solutions to cover the entire city. In particular, the use of the prioritization tool approach will serve to assist policymakers and stakeholders in taking decisions aimed at developing city visions with 2050 as time horizon.

This phase of the modelling framework proposed in MAKING-CITY project is focused on the impact assessment of the long-term solutions and strategies, as well as on the analysis of the main implication in the business models when considering the long-term perspective in the deployment of solutions in the city.

In the previous phases the current situation of the cities in terms of the energy consumption and generation, as well as the potential changes that are expected by 2050, and the deployment of solutions that need to be implemented in each of them to achieve the desired low-carbon future are evaluated in detail. After that, this phase proposes the impact assessment of the solutions that will be implemented in the city so that the results of the analysis can serve as extra criteria for the prioritization of actions that will be included in the long-term scenarios of the cities and finally in the city vision to 2050. Since the potential energy and environmental emission reduction can be obtained from the interpretation of the outcomes of the models developed in the previous phases, the current phase is mainly focused on the socioeconomic impact assessment.

As mentioned before, the expected socioeconomic impacts at city and regional scale will provide useful information that municipalities can use during the decision-making stage of the long-term energy planning process. The business models reflexion that will be carried in this phase will also contribute directly, since the economic feasibility of some of the actions to be implemented in the city will depend a lot on the specific business models that are proposed. In that sense, the incorporation of the long-term vision to the definition and analysis of the business models of solutions is a relevant aspect that should be carefully considered.

5.1 State of the art

The prioritisation of solutions to be implemented in a city can be carried out from different points of view. In this case, the aim is to identify those solutions and strategies that are of interest in order to be deployed in different areas of the city over the next few decades. Therefore, on the one hand, it is a matter of evaluating the solutions being implemented in the PED districts of cities from the point of view of their potential for scale-up and deployment throughout the city. On the other hand, solutions that may be of longer-term interest should also be considered.

The PESTEL framework has been used on numerous occasions for this type of problem. Initially, PEST analysis (political, economic, socio-cultural and technological) defined an analytical framework of macro-systemic factors used in the strategic management. It is part of an external analysis when conducting a strategic assessment and gives an indication of the different factors to be taken into consideration. It is a strategic tool for understanding market behaviour, business position, potential and direction for operations. Sometimes referred as PESTEL or PESTLE (PEST plus Environmental and Legal aspects), the conceptualisation of the analysis pursues to detect the importance of multiple factors classified according to the main pillars of the acronym. As the origin of the method is the business management, it is very normal to observe applications in industry since such sector encompasses multiple facets (from technology to produce/consume materials/energy to environmental concerns associated, as well as legal requirements and social awareness related with product, job creation, etc.).

According to this study [48], the characterisation of factors for each pillar are:

Political Factors. Those factors that determine the extent to which government policy may impact on an organisation or a specific industry. For example, political policy and stability as well as trade, fiscal and taxation policies.

Economic Factors. Those factors that impact on the economy and its performance, which in turn directly impacts on the organisation and its profitability. Some examples are interest rates, employment rates, raw material costs or foreign exchange rates.

Social Factors. Those factors that focus on the social situation and identify trends. Social factors include demographics, education levels, cultural tendencies and changes in lifestyles.

Technological Factors. Those factors that consider the rate of technological innovation and development that could affect a market or industry. They could include changes in digital or mobile technology, automation, research and development (improvement in transformation/consumption efficiencies, for instance).

Environmental Factors. Those factors that relate to the influence of the environment and the impact of ecological aspects. For example: climate change metrics, recycling procedures, carbon footprint, waste disposal and sustainability indicators.

Legal Factors. An organisation/body must understand what is legal and allowed within those places they operate in. They also must be aware of any change in legislation and the impact this may have on business operations. Some examples of these factors are employment legislation, consumer law, health and safety regulation, and trade regulation as well.

However, although the PESTEL framework would be an interesting option, taking into account the long-term vision of the current problem and the need of reflecting in a more specific way the scale-up and replication potential of the different solutions, it is observed that the EU Smart Cities Information System (SCIS) has defined a new interesting framework. In this new framework, the factors to be considered to evaluate the potential for scale-up and replication of technologies within a city have been defined. This can be consulted more in detail in the report "The making of a Smart city: replication and scale-up of innovation in Europe" [49]. This document proposes a series of criteria/indicators to be evaluated simultaneously for each of the solutions evaluated. These indicators cover different dimensions in terms of replication potential. At this point, it is of interest to combine the proposed evaluation with the theory of Multiple Criteria Decision Making (MCDM) in order to be able to make a complete comparison between the different solutions and to arrive at a final prioritisation. To this end, MCDA's theory provides a series of methods that can be used to respond to this type of complex problem [50]. Of all these, the interest of evaluating the possible use of the following in the field of prospective energy planning for cities stands out. Elimination and choice translating reality (ELECTRE)[51], Weighted sum method (WSM) [52], [53], Technique for order of preference by similarity to the ideal solution (TOPSIS) [54], Analytical hierarchy process (AHP) [55], Compromise programming (CP) [56], Preference ranking organisation method for enrichment evaluation (PROMETHEE) [57], Weighted product method (WPM) [58].

The combination of the evaluation of the scaling potential through the evaluation and scoring of technologies with the possibility of simultaneously evaluating different criteria that are potentially conflicting with each other and offering the possibility of giving specific weights to each of these criteria according to the specific interests of the cities offers a great opportunity for the configuration of alternative scenarios in the long-term.

Regarding impact assessment on the other hand, it is not as integrated as it should be in the methodologies used for the long-term city energy planning. At least it is not as integrated as in other type of analysis that are usually carried out at a larger scale, such as the regional and the national scale, see [59], [60].

Moreover, the necessity of evaluating city energy planning in an integrated way is not completely covered nowadays [61]. One of the main reasons for this seem to be the difficulties that municipalities face to combine many methods and tools which are very specialized and for which their potential connection is not well defined. This is something that affects especially to the impact assessment.

Impact assessment, as a general concept can be integrated in various phases of the energy planning process. In fact, it can follow different approaches and can have different purposes in each of them. For example, the conventional sustainability analysis can be used to compare the benefits of implementing specific measures in some areas of the city.

Referring only to the socioeconomic impact assessment, there are also many approaches that can be adopted for the project. in this case, the analysis focuses only on the sophisticated methods that are commonly used at a regional and national scale, methods such as the input-output tables, the computable general equilibrium, the hybrid models, and the econometric model-based approaches [59]. These methods are considered robust and detailed and are broadly accepted for the long-term modelling. It needs to be considered that each of these methods are very extensive and that cannot be detailed completely in this section. Besides, the main differences between each method are broadly evaluated and documented and can be consulted in [62] and [63].

The method that will be used in MAKING-CITY project follows the IO approach, as developed by Leontief [64]. These tables describe all the interactions between sectors in a national economy and explicitly reveals supply chain relationships. This methodology is selected for this task considering that the analysis should be flexible enough to evaluate the different solutions included in the PED of each city.

The basic IO model have some limitations such as that they do not consider for example the interactions and the re-spending of household income in the economy [65]. In this project, the models used for the socioeconomic impact assessment are based on the MIOCIM model developed by [66]. This simplified model is adaptable to different countries and overcomes some of the barriers associated to the simple IO models.

The link between the socioeconomic impact assessment model and the solutions adopted in the PED and in the energy scenarios of each city is developed in this project with endogenous demand vectors (shocks). These shocks are the way to generate a change in the economic structure and represent the investments associated to the solutions that will be implemented in the PEDs of MAKING-CITY project.

Here, the supply chain analysis is a useful technique for the characterization of the solutions in a way that can serve as input for the modelling (as a shock). The supply chain analysis can be used for different purposes but in this case, it can be used for the assignation of the costs of the solutions (material costs, labour costs, profit margin for each of the components, etc.) to specific commodities and subsectors according to the commodity classification used in each country of each city. The methodology proposed in the project for the supply chain characterization is a simplification based on the results of a previous research [67],[68].

5.2 Methodology and scope

This section includes a description of the scope and methodology to be followed in the project, for which the following three points are distinguished; solutions and long-term strategies catalogue and how it relates to this phase of the analysis, the prioritization tool and the impact assessment of alternative energy scenarios and business models.

5.2.1 Solutions and long-term strategies catalogue

The idea derived from PEDs as evaluated in detail in WP4 is founded on the potential of the high-performance buildings, the intensive use of renewable energy systems, and the energy connection and integration of several buildings, with similar or different typologies, to take advantage of sharing energy surplus. Though, there is a need to develop one step beyond the current PED concept to scale up the measures at deploy them at the maximum levels.

The current experiences, although limited, show very promising results from a technical point of view. The approach is technically feasible and consists in decreasing radically buildings' energy demand and increasing in parallel the on-site energy production from renewables within the selected area. Thus, the main purpose is to have, in an annual balance, a surplus of energy to share with other urban areas.

Under such a rationale, the MAKING-CITY project will develop strategies to reach real scalability and replicability of the PED solutions. Besides, the project will include social and economic aspects associated to the most appropriate technologies and solutions, thus considering their social impact and associated business models as well.

The technical and non-technical actions that will be implemented in the lighthouse cities (Groningen and Oulu), will be considered here according to the next classification (further details can be consulted in the deliverable D4.1 *"Methodology and Guidelines for PED design"*):

1) Demand side solutions

- Category 1: Low energy consumption
- Category 2: Improve energy efficiency

2) System integration

- Category 3: Integrated infrastructures

3) Supply side solutions

- Category 4: Renewable energy systems alternative urban energy sources

4) Non-technical solutions

- Category 5: Political, social, economic interventions

An important task when looking at the abovementioned measures/solutions is to understand how feasible they are. Some of them are technically easy to implement whereas some others involve non-tangible aspects, with a hard social/human component. From a technical point of view, any intervention involves investing in technologies, materials and salaries. However, social/human-related solutions usually involve paying salaries and investments in educational campaigns, propaganda, etc. While effectiveness in the latter is difficult to measure (e.g. how deep a "collaboration" or a "policy" or a "forum" goes in reaching energy savings or emission reductions?), the massive deployment of technical solutions makes problematic the former (what is considered acceptable/affordable to be invested in transforming technologies?).

To assist urban policymakers in such difficulties is very useful to get tools that allow to prioritise among solutions.

5.2.2 Tool for the prioritization of long-term strategies aimed at the decarbonisation of cities

The proposed methodology consists of two successive steps. In a first step, a series of criteria are established to be used for prioritisation. Each of these criteria will be evaluated simultaneously for each of the solutions and long-term strategies. In addition, a specific weight is assigned to each criterion according to the interests and needs of each of the cities. These are carried out in this case following the Analytic Hierarchical Process (AHP) methodology. In a second step, the evaluation framework defined by the SCIS is used, and the performance of each solution is evaluated for these criteria according to the scoring system proposed therein. Finally, once both parts are combined, the solutions evaluated are prioritised in such a way that interesting information can be obtained in order to shape the alternative scenarios for the decarbonisation of the city.

The first step therefore proposes the selection of evaluation criteria or indicators that will make it possible to prioritise solutions. In this case these indicators can be extracted from the proposals of the SCIS as mentioned above. The figure below shows some of the indicators proposed for the evaluation.

Indicator	*Scoring*				
	1	2	3	4	5
Potential for CO_2 emission reduction	Slight reduction of CO_2 emissions (<10%)	Moderate reduction of CO_2 emissions (10-50%)	Significant reduction of CO_2 emissions (>50%)	Zero CO_2 emissions	Negative CO_2 emissions
Potential for increasing share of renewables	No integration of renewables	Integration of less than 10% of renewables*	Integration of less than 20% of renewables	Integration of less than 50% of renewables	Integration of over 50% of renewables
Increasing energy efficiency	Slight reduction of energy / fuel consumption (<10%)	Moderate reduction of energy / fuel consumption (10-50%)	Significant reduction of energy / fuel consumption (>50%)	Zero energy performance	Excess energy returned to the energy system
Affordability (estimated increasing energy costs for end users)	Significant cost increase (>20%)	Moderate cost increase for end users (10-20%)	Slight cost increase for end users (0-10%)	No increasing costs	Cost reduction
Economic viability (period for return of capital)	Over 20 years	Up to 20 years	Up to 15 years	Up to 10 years	Up to 5 years
Innovative nature/ progress beyond the state-of-the-art	No elements of innovation	Low smartness of: • energy conversion, • materials, • power matching.	Moderate smartness of: • energy conversion, • materials, • power matching.	High smartness of: • energy conversion, • materials, • power matching.	Exceptional smartness of: • energy conversion, • materials, • power matching.
Multidisciplinary/ multi technology approach	Integration aspects not addressed	Low potential for multi-layer integration within and between sectors*	Moderate potential for multi-layer integration within and between sectors*	High potential for multi-layer integration within and between sectors*	Proven record of multi-level integration within and between sectors
Flexibility	Extreme sensitivity to internal and external disturbances	Significant sensitivity to internal and external disturbances	Moderate sensitivity to internal and external disturbances	Low sensitivity to internal and external disturbances	No sensitivity to internal and external disturbances
Integration into the existing urban energy system (facilities and infrastructures)	No possibility to integrate with existing facilities and infrastructures	Significant problems to integrate with existing facilities and infrastructures	Moderate problems to integrate with existing facilities and infrastructures	Some problems to integrate with existing facilities and infrastructures	No problems to integrate with existing facilities and infrastructures

Figure 9 Visualization of some of the criteria (and the scoring process) used for the multi-criteria scoring process. Extracted form SCIS.

The prioritization of dimensions and indicators is carried out via an AHP. The AHP is a structured technique for organizing and analysing complex decisions. This method facilitates the analysis of different criteria (and sub-criteria) through pair-wise comparison. This process of hierarchization is expected to provide additional insights on stakeholder priorities.

These "pair-to-pair comparison" consists of two steps:

- Identification of which dimension or indicator in question is the most important one "A" or "B".
- Evaluation of the intensity of importance considered for this "most important" entity, understanding the intensity of importance (scale from 1 to 9).

Once the municipality completes the corresponding tables according to its interests, a series of figures like the one shown below are obtained for each of the dimensions and the indicators within them.

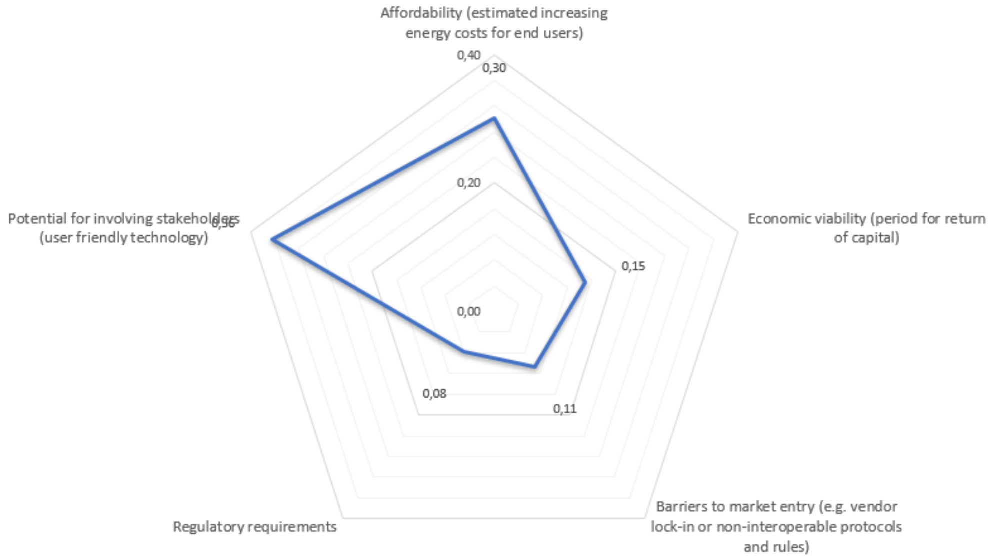


Figure 10: Example of the weighting process of some of the indicators used by the prioritization tool.

Once this process has been completed for each one of the criteria, a final score equivalent to those shown in the following figure will be obtained. It is worth mentioning that this will be different for each evaluated city.

Final indicator weight	
Affordability (estimated increasing energy costs for end users)	0,0334
Economic viability (period for return of capital)	0,0165
Barriers to market entry (e.g. vendor lock-in or non-interoperable	0,0120
Regulatory requirements	0,0087
Potential for involving stakeholders (user friendly technology)	0,0405
Potential for CO2 emission reduction	0,4667
Potential for increasing share of renewables	0,1556
Increasing energy efficiency	0,1556
Innovative nature/ progress beyond the state-of-the-art	0,0067
Multidisciplinary/ multi technology approach	0,0043
Flexibility	0,0226
Integration into the existing urban energy system (facilities and ir	0,0469
Potential for scale-up and replication	0,0307

Figure 11: Example of the final weight of each criterion used for the prioritization.

As mentioned above, in a second step each of the solutions and long-term strategies preselected by each city are evaluated for each indicator by selecting from the tool the option that better fits in each case.

Finally, the information obtained in the two steps is combined and a final prioritization is obtained for the different solutions evaluated in each city. The result would be something like the figure below.

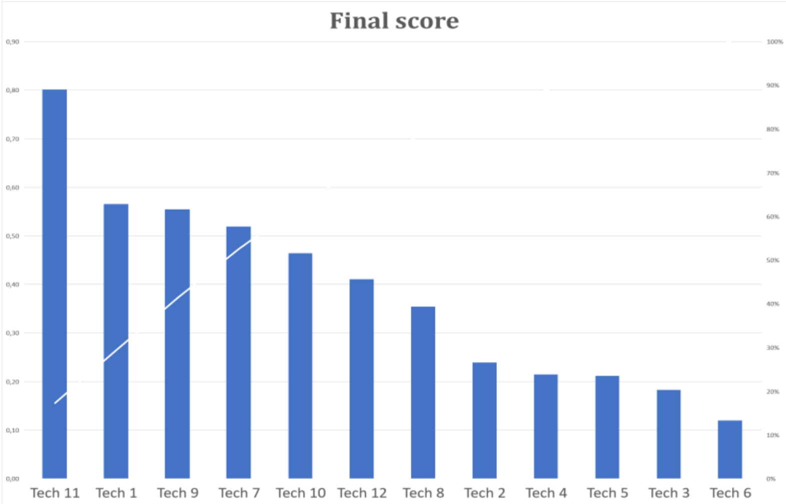


Figure 12: Example of the results obtained from the prioritization tool.

The collection of all this information allows us to carry out a customized analysis for each solution that will be implemented in each city. However, it has a somewhat static character that although it does incorporate a vision of how some issues inherent to the city and the solutions will affect the future, it does not end up offering by itself information that can be easily used for the definition of scenarios. It does not allow to detail for each one of them the potential deployment that it can have in the city, as well as other aspects as the rate of deployment or the period in which they are going to be carried out.

Therefore, in this case, it is proposed to complement the prioritization proposed by SCIS as traditionally used with more quantitative information for each of the solutions that are ultimately capable of being implemented in almost every city.

Therefore, for each intervention and per each city, the analysis should be extended by considering within the analysis the following four aspects:

1. Maximum potential in the city associated to the solution
2. Realistic deployment potential of each solution in the city
3. The rhythm of deployment of each solution across the transition period defined
4. The applicability of the solution in the city (detailing if it is applicable only in residential buildings, or also in industry, etc.)

5.2.3 Impact Assessment of alternative long-term energy scenarios and business models

This section describes on the one hand the proposed method for the evaluation of socio-economic impact and on the other hand provides an idea of the MAKING-CITY context on Business Models applied to the generation of city decarbonisation scenarios.

5.2.3.1 Supply chain characterization and socioeconomic impact assessment of the long-term strategies for the decarbonisation of cities

The methodological approach proposed for the supply chain characterization of the solutions for MAKING-CITY project is described in a visual way in the figure below. It can be observed that based on three big phases the complete process of conformation of the shock that will serve as input for the socioeconomic modelling is carried out.

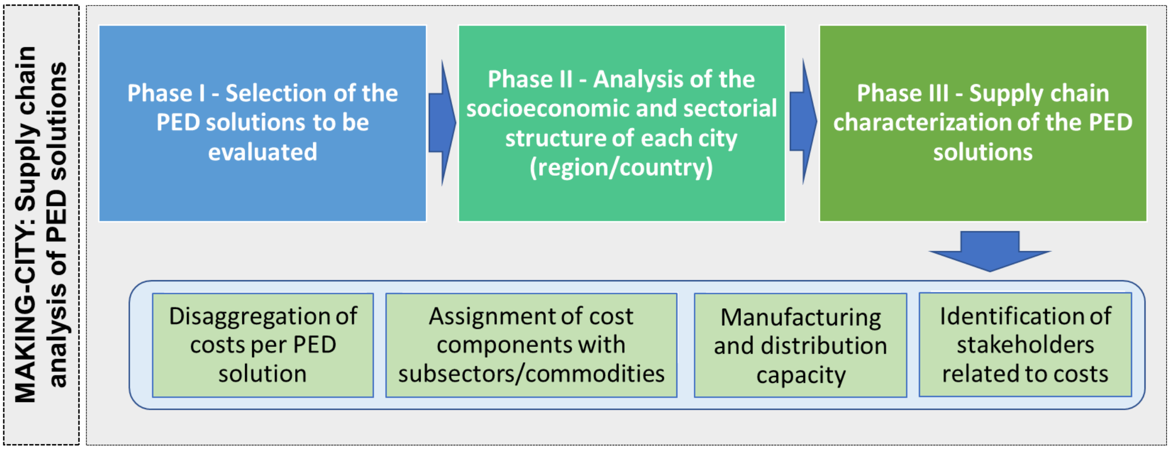


Figure 13: Methodological approach of the supply chain analysis of the long-term strategies for the decarbonisation of cities in MAKING-CITY project

Phase I – Selection of the solutions and strategies to be evaluated

During this phase each city will select and describe the solutions that will be included in the supply chain and socioeconomic impact assessment. This selection will be carried out considering the following criteria; the relevance of each solution for the city evaluated, and the availability of the data required (the data described in the following sections of this deliverable).

Phase II- Analysis of the socioeconomic and sectorial structure of each city

In this second phase the socioeconomic structure of each city (region/country) will be evaluated more in detail. This is a necessary step since the costs that will be disaggregated for each solution need to be assigned in each case study to a specific commodity/sector classification of the city evaluated. In this regard, the focus should be paid in the sectoral structure of both the city and the region/country specially in aspects related to the industrial production, the sectoral value added and the employment.

Here, it needs to be considered that the socioeconomic modelling takes into account as a basis the public available IO tables of the World Input-Output Database (WIOD) [69]. This database serves to evaluate the effects of globalization on trade patterns, environmental pressures and socio-economic development across a wide set of countries. It covers 27 EU countries and 13 other major countries in the world for the period from 1995 to 2009.

Using WIOD as the basis of the assessment is considered a good starting point for the standardization of the analysis in the different cities. In all the countries the same classification of sectors and commodities is followed according to the NACE codes. This classification is precisely the one that will be used for the disaggregation of costs per PED solution in the following steps.

The following table shows the classification of sectors used in the IO tables available in the WIOD database.

Table 9: Classification of sectors in WIOD database

Sector	CODE
Crop and animal production, hunting and related service activities	A01
Forestry and logging	A02
Fishing and aquaculture	A03
Mining and quarrying	B
Manufacture of food products, beverages and tobacco products	C10-C12
Manufacture of textiles, wearing apparel and leather products	C13-C15
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	C16
Manufacture of paper and paper products	C17
Printing and reproduction of recorded media	C18
Manufacture of coke and refined petroleum products	C19
Manufacture of chemicals and chemical products	C20
Manufacture of basic pharmaceutical products and pharmaceutical preparations	C21
Manufacture of rubber and plastic products	C22
Manufacture of other non-metallic mineral products	C23
Manufacture of basic metals	C24
Manufacture of fabricated metal products, except machinery and equipment	C25
Manufacture of computer, electronic and optical products	C26
Manufacture of electrical equipment	C27
Manufacture of machinery and equipment n.e.c.	C28
Manufacture of motor vehicles, trailers and semi-trailers	C29
Manufacture of other transport equipment	C30
Manufacture of furniture; other manufacturing	C31_C32
Repair and installation of machinery and equipment	C33
Electricity, gas, steam and air conditioning supply	D35
Water collection, treatment and supply	E36
Sewerage; waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services	E37-E39
Construction	F
Wholesale and retail trade and repair of motor vehicles and motorcycles	G45
Wholesale trade, except of motor vehicles and motorcycles	G46
Retail trade, except of motor vehicles and motorcycles	G47
Land transport and transport via pipelines	H49
Water transport	H50
Air transport	H51
Warehousing and support activities for transportation	H52
Postal and courier activities	H53
Accommodation and food service activities	I
Publishing activities	J58
Motion picture, video and television programme production, sound recording and music publishing activities; programming and broadcasting activities	J59_J60
Telecommunications	J61
Computer programming, consultancy and related activities; information service activities	J62_J63
Financial service activities, except insurance and pension funding	K64
Insurance, reinsurance and pension funding, except compulsory social security	K65
Activities auxiliary to financial services and insurance activities	K66
Real estate activities	L68
Legal and accounting activities; activities of head offices; management consultancy activities	M69_M70
Architectural and engineering activities; technical testing and analysis	M71
Scientific research and development	M72
Advertising and market research	M73

Other professional, scientific and technical activities; veterinary activities	M74_M75
Rental and leasing activities	N77
Employment activities	N78
Travel agency, tour operator reservation service and related activities	N79
Security and investigation activities; services to buildings and landscape activities; office administrative, office support and other business support activities	N80-N82
Public administration and defense; compulsory social security	O84
Education	P85
Human health activities	Q86
Social work activities	Q87_Q88
Creative, arts and entertainment activities; libraries, archives, museums and other cultural activities; gambling and betting activities	R90-R92
Sports activities and amusement and recreation activities	R93
Activities of membership organizations	S94
Repair of computers and personal and household goods	S95
Other personal service activities	S96
Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use	T
Activities of extra-territorial organizations and bodies	U

Therefore, the main differences between the country commodity and sector classification mentioned above and the city/regional classification need to be evaluated so that the analysis can be specified enough to reflect the singularities of the case studies.

Phase III - Supply chain characterization of the solutions

The main objective of this phase is to make a complete characterization of the supply chain of the interventions that will be evaluated in the study for each of the cities involved. This phase is composed the four steps described in the following paragraphs.

- Step 3.1. The disaggregation of costs per intervention

This step is focused on the definition of the initial cost structure of the interventions evaluated. This cost structure is based on a disaggregation of the main costs of components.

As a rule, the cost components to be included can be divided as showed above in;

- Costs of project planning
- Costs of manufacturing of products
- Costs of transport
- Costs of installation
- Costs of connections
- Costs of operation & maintenance
- Costs of the decommissioning

The most relevant aspect that should be used to determine the level of detail that needs to be achieved in the supply chain characterization is precisely the disaggregation level of the Input Output tables at national level. This is the reason why, although a higher level of detail could be obtained in the supply chain characterization and data gathering stage, this could be lost when this information is used to define the increase of the endogenous demand (shock) in the adapted IO tables.

Therefore, it can be said that the general rule to define the disaggregation level of the PED solution evaluated, from the supply chain point of view should consider as its main detailed disaggregation the classification of commodities considered in WIOD. The following tables show the commodities classification used in the IO tables available in the WIOD.

Table 10: Classification of commodities in WIOD database based on the CPA Statistical Classification of Products by Activity

CODE	Commodity
CPA_A01	Products of agriculture, hunting and related services
CPA_A02	Products of forestry, logging and related services
CPA_A03	Fish and other fishing products; aquaculture products; support services to fishing
CPA_B	Mining and quarrying
CPA_C10-C12	Food products, beverages and tobacco products
CPA_C13-C15	Textiles, wearing apparel and leather products
CPA_C16	Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials
CPA_C17	Paper and paper products
CPA_C18	Printing and recording services
CPA_C19	Coke and refined petroleum products
CPA_C20	Chemicals and chemical products
CPA_C21	Basic pharmaceutical products and pharmaceutical preparations
CPA_C22	Rubber and plastics products
CPA_C23	Other non-metallic mineral products
CPA_C24	Basic metals
CPA_C25	Fabricated metal products, except machinery and equipment
CPA_C26	Computer, electronic and optical products
CPA_C27	Electrical equipment
CPA_C28	Machinery and equipment n.e.c.
CPA_C29	Motor vehicles, trailers and semi-trailers
CPA_C30	Other transport equipment
CPA_C31_C32	Furniture; other manufactured goods
CPA_C33	Repair and installation services of machinery and equipment
CPA_D35	Electricity, gas, steam and air-conditioning
CPA_E36	Natural water; water treatment and supply services
CPA_E37-E39	Sewerage; waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services
CPA_F	Constructions and construction works
CPA_G45	Wholesale and retail trade and repair services of motor vehicles and motorcycles
CPA_G46	Wholesale trade services, except of motor vehicles and motorcycles
CPA_G47	Retail trade services, except of motor vehicles and motorcycles
CPA_H49	Land transport services and transport services via pipelines
CPA_H50	Water transport services
CPA_H51	Air transport services
CPA_H52	Warehousing and support services for transportation
CPA_H53	Postal and courier services
CPA_I	Accommodation and food services
CPA_J58	Publishing services
CPA_J59_J60	Motion picture, video and television programme production services, sound recording and music publishing; programming and broadcasting services
CPA_J61	Telecommunications services
CPA_J62_J63	Computer programming, consultancy and related services; information services
CPA_K64	Financial services, except insurance and pension funding

CPA_K65	Insurance, reinsurance and pension funding services, except compulsory social security
CPA_K66	Services auxiliary to financial services and insurance services
CPA_L68	Real estate services
CPA_M69_M70	Legal and accounting services; services of head offices; management consulting services
CPA_M71	Architectural and engineering services; technical testing and analysis services
CPA_M72	Scientific research and development services
CPA_M73	Advertising and market research services
CPA_M74_M75	Other professional, scientific and technical services; veterinary services
CPA_N77	Rental and leasing services
CPA_N78	Employment services
CPA_N79	Travel agency, tour operator and other reservation services and related services
CPA_N80-N82	Security and investigation services; services to buildings and landscape; office administrative, office support and other business support services
CPA_O84	Public administration and defense services; compulsory social security services
CPA_P85	Education services
CPA_Q86	Human health services
CPA_Q87_Q88	Social work services
CPA_R90-R92	Creative, arts and entertainment services; library, archive, museum and other cultural services; gambling and betting services
CPA_R93	Sporting services and amusement and recreation services
CPA_S94	Services furnished by membership organizations
CPA_S95	Repair services of computers and personal and household goods
CPA_S96	Other personal services
CPA_T	Services of households as employers; undifferentiated goods and services produced by households for own use
CPA_U	Services provided by extraterritorial organizations and bodies

- <u>Step 3.2. Assignment of each cost component with the corresponding subsector or commodity</u>

This step is focused on stablishing a relation between each cost component defined for the solution as defined in the step 3.1 with the commodity which is more like it from the commodity classification of the IO tables of the city or region evaluated as it has been detailed above. This step allows to standardize for all the cities of the project the input information that will be used for the socioeconomic modelling.

- <u>Step 3.3. Manufacturing and distribution capacity</u>

This step on the other hand aims to evaluate the capacities of each city for the local (in the city or in the region) manufacturing and distribution of each cost component of the solutions to be included in the scenario analysis. It can be said that the objective is to provide a better understanding of the imports dependency of each city when providing the technologies and services associated to each solution.

- <u>Step 3.4. Identification of stakeholder related to costs</u>

The last step of the Phase III is intended to respond to the necessity of understanding who is the main actor that makes the investment in each case. Here, part of the investment can be made by private companies and another part by public funding depending on the business model adopted in each case.

5.2.4 MAKING-CITY context on Business Models

Within the framework of the MAKING-CITY project, a few examples of business models (BM) were proposed tentatively in preliminary stages of the work. Those examples will be developed in WP 6 in parallel with the advances of the project.

Thus, the predefined BMs are presented in this section and discussed accordingly. Later, an exploration on the future of BMs is carried out in a generic way.

Alignment with the predefined BM of MAKING-CITY

According to the sketched analysis included within the project proposal and the context of WP 6, the BMs are varied and very dependants on the technology or case studies on which they take place.

- **Energy cooperative**. Within this model, citizens are members of a cooperative which aggregates energy demand and on-site green energy generation. Demand response services can then be offered to grid operators. Some large devices (renewable energy, storage) can be shared by all members of the cooperative. This BM typology is related with Action 45 in Groningen.

- **Shared public-private investment model**. In order to stimulate sustainable energy consumption and production, investments and savings can be shared between public and private partners according to a predefined agreement. Such BM type could be observed in Action 43 taking place in Oulu.

- **Open data business models**. In this model, data collected at building and district level is collected through an urban data platform. It may allow the provision of new services (possibly including non-energy services). This BM is cross-cutting, and it is linked to Action 46 in Oulu and Actions 35 & 46 in Groningen.

- **Energy Performance Contracts / ESCO**. Within this model, an Energy Service Company (ESCO) invests in energy efficiency (EE) measures or in renewable energy (RE) production devices installed in a building. Thanks to the energy savings realised, the building owner reimburse the ESCO with, for instance, monthly payments during a given period. This model allows building owners to implement EE measures and RE generation without making upfront investments (which are often seen as a barrier especially if payback periods are long). The idea behind this BM is expected to be applied through Action 45 in Oulu.

- **Properties certified with green building label (or a to-be-created PED label)**. Within this BM, real estate developers make their buildings certified according to a voluntary certification scheme. This would allow them selling or renting apartments at a higher price compared to conventional buildings. This premium should compensate for the additional costs related to the green features of the building (energy performance, on-site renewable energy generation, etc.). This BM is consequence of implementing EE and RE measures and, as they are perceived like an effort, the positive effect of invest in them is "burdened" by both sides (owners and tenants, for instance), so the BM encompasses all the measures (actions).

- **Creation of a new public service operator by the municipality**. To facilitate energy transition, the municipality may create a heat network in order to replace the gas network (or any device fuelled by gas, coal or oil). Financial incentives must be implemented in order to make it feasible for consumers to switch from gas to heat. This has been done in Groningen (prior to Making-City), the aim of the city being to move away from gas. This might be something interesting to model since the same might happen in other cities. Such BM type, with a great involvement from the public sector might need legal and regulatory support schemes, as well some fiscal developments to facilitate the service released.

• **Vehicle to grid (V2G) services and smart charging**. V2G services, smart charging and/or services provided by batteries installed at charging stations can help manage the grid, avoid bottlenecks and avoid or postpone grid reinforcements. This production-consumption scheme may be understood as a mere deployment but, in fact, it opens the door to a hybrid BM where some of the preceding BM characterisations take place at the same time. For instance, open data platforms may appear, and the data collected could serve other enterprises to develop adjacent service-based businesses. Besides, the energy cooperatives may enter in the play to participate in collaborative efforts in buying and sharing electric vehicles for the community and using those devices as electricity reservoirs that sell electricity to the grid during peak demand hours. The Action 44 in Oulu is aligned with these ideas.

The future of business models or the business models of the future

There are dozens of BM classifications. That fact is based on the different nature and approaches of the products and services behind each BM. If one also considers the multiplicity of agents, relationships, interests and behaviours taking place in each BM, it is possible to get an idea on how difficult is to classify or just characterise BMs attending to their predefined characteristics.

In an study by Gorevaya and Khayrullina [70] it can be seen that there is a simplified characterisation that could serve us as an introduction. The authors established a separation by looking at some concrete attributes. For instance, when observing fundamental business concepts, it is possible to see BM focused on creating new markets, creating new segments or just creating new needs. Attending to the strategic differentiation, there are BM based on offering the same proposal as the current market but adding new types of services while some others are founded on new proposals (reformulation) of old types of services (e.g. electric vehicle), and even some others based on creating new services from scratch (like online payment services). Regarding production schemes there are BMs based on evolving the existing production/products lines increasing quality and capacities, whereas some other BM, are based on creating new developments over older services (online rental apartments, for instance), and some other BMs go from scratch to raise new concepts (like P2P relationships). Some BMs can be differentiated by the distribution channels used, what could make a difference in their profitability while some others are relevant when considering their organisational structures.

Recently, some concepts have appeared to transform entirely the BM realms. One of these concepts is the “for free” BM. Some companies make money from derived services or products, but the primary service is totally free. A good example of this paradigm is the mobile applications uploaded in platforms such as Play Store. Many companies develop their own software for portable devices like smartphones or tablets and they facilitate the acquisition by uploading it in such online platforms. Then, users can access to them and download them for free. The profit comes from the use of metadata -something that previously you agreed- after the installation of the app in your device. The idea is then: you get our app (and the service associated) for free and, in compensation, you allow us to get data from you. Such BM has proved to be extremely useful to personalise propaganda and marketing approaches. However, the access to personal data is a delicate concern and it is always a matter of debate in the public opinion.

The development of IT systems in the last years together with the impact of the social networks in a globalised world is favouring the emergence of new paradigms in terms of BMs. The technological potential associated with data-related technologies (sensors, Internet-of-Things, advanced software, big data, cloud computing, super-computation, deep learning, algorithms, artificial intelligence, robotics) will be the basis for the development of new BMs, mostly based on personalised data coming from the citizens/users.

The transformation observed in many economic sectors is founded on an intensification of the “service” paradigm. A representative case is the transport sector. Regarding transport, problems associated to the higher fuel prices, high prices of the cars as well as the physical problems of living in urban areas (difficulties for parking, municipal taxes, restrictions derived from the pollution, etc.) open the door to new transport services. Under those new BM schemes, a few companies optimise the combination of options (technologies, routes, frequency, traffic…) in order to make benefit from the process of satisfying the need of the citizen (to be transported comfortably at the cheapest cost in the shortest time). While the benefits of those BM (the concept is called 'Mobility-as-a-Service', MaaS) are varied, e.g. reductions in emissions, thus improvements in human and environmental health, there are some drawbacks. The main disadvantage of the MaaS is that the benefit of the citizen discourages users from buying new cars since the device is perceived as a burden in terms of yield.

In 2013, the professor Spring from Lancaster University [71] published a report on the future of the business models in manufacturing industries. It seems relevant to point out that there is a word continuously repeated, 'connect'. Among the list of future BMs -or ideas related with- proposed, one can find: connect products to services, extensively, and in 'upstream' sectors as well as in complex product sectors; connect technologies to potential future application areas and needs, widely drawn; connect products to information, institutions and individuals, to create value; connect – and disconnect, as necessary – firms to one another in collaborative communities; connect the forward and reverse flows of products in a circular economy; connect technological and operational capabilities with entrepreneurial insight and action; connect firms' business models to one another.

In the case of cities, the data gathering process will be the starting point for the future BMs. Thanks to the installation of smart controls (mostly sensors) in buildings, in the streets, as well as within the buildings and the households, a huge compilation of data will bring about new opportunities to personalise and understand the way things happen within the city. In that sense, the city will start to act as a data platform, a new ecosystem of numbers and figures where to extract patterns and undergone optimisations at every level.

An example of this could be the current BM based on car sharing. In such BMs, a company develops an app to optimise future trips by car between predefined (planned) routes. Thanks to the forthcoming massive data compilation, new BMs will go for the instantaneity. Is it possible to take a circulating car that goes to the same destination that you on the fly? Surely, BMs like that will appear in the forthcoming years.

Of course, there are some problems associated to data protection and some legal aspects regarding insurances. Besides, the counterpart is the potential losses may occur in conventional BMs. Taxi and private transport services could suffer decreases in the number of users as much happened with the arrival of platforms such as Uber. In consequence, every advance in the creation of new BMs should be analysed considering the social consequences of such deployment. It seems not acceptable to create a profitable business scheme (for new actors) that, in general terms, causes socioeconomic losses (for existing actors).

[72] published an interesting analysis on the future of BMs related with smart cities. The authors encompassed the BMs for smart cities into 6 groups:

- Internet of Things (IoT).
- Network ownership: utilise smart infrastructure and basically communication network ownership.
- Web-based: address public sector value propositions that can be delivered via e-government practices.
- E-commerce: concern internet-based business, like online selling, advertising etc.
- Business model innovation.
- Ownership business models: address smart city project ownership or management.

According to the study, participants suggested the ownership business model group as the most relevant one, and from its contents preferred the Open Business Model, with the Municipal-Owned-Development as an alternative option. Finally, the authors suggest the expectations associated with the IoT deployment in the years to come as a driving force to arise new BMs paradigms.

Other authors, very associated to IT realms, have explored the innovation of new types of BMs. In that sense, the arrival of faster connectivity systems such as the 5G protocol will favour the IoT deployment. Accordingly, [73] has discussed in depth the concept of BM innovation through the creation of the idea of persuasive business models. We encourage the reader to read the article '*Multi Business Model Innovation in a World of 5G: What Will Persuasive Business Models Look Like in a World of 5G?*' in order to catch the futuristic approach of BMs innovation.

5.3 Required data

One of the key issues before applying the prioritization method proposed is to define which solutions/ technologies/ measures will be passed through the tool. Several initial questions arise:

- What level of the processes of the model should the tool be applied to?
- What is the most useful level?
- Can the prioritization analysis be applied on processes at any level?
- Do all the solutions for the prioritization analysis need to be processes of the same level?
- Is there any restriction regarding the type of process that can be analysed?

A first impression from the point of view of "technological interventions" would suggest that a high level of detail is needed in order to apply a prioritization analysis (e.g. implementing solar PV in residential buildings of a specific district area). It is more difficult to conduct a 'technical' analysis for general high-level processes considering the wide range of options that could help contribute toward this.

However, this is only one purpose of the prioritization tool. The prioritization analysis can be used to both provide a framework for detailed technical analysis, but also to provide a more qualitative analysis of the feasibility of each solution beforehand.

Accordingly, there are some different types of solutions that may be found in the model;

- Implementable general solutions: e.g. New high perform residential buildings
- Implementable technological detailed solutions: e.g. Installing solar PV panels in residential buildings
- Implementable non technological detailed solutions: e.g. Education, co-design and social participation
- Planning process interventions: e.g. Policy Forum on energy transition

Once the solutions to be considered and evaluated have been selected, the necessary information for the analysis is collected. This information is detailed in the following figures and tables.

For the pair-to-pair comparison of the criteria the following table needs to be completed by each municipality. This is requested for each indicator evaluated.

Table 11: Example of the data required in the dimension prioritization matrix

A	B	More important (A/B)	Intensity (1-9)
Affordability (estimated increasing energy costs for end users)	Economic viability (period for return of capital)	A	1
	Barriers to market entry (e.g. vendor lock-in or non-interoperable protocols and rules)	A	1
	Regulatory requirements	B	8
	Potential for involving stakeholders (user friendly technology)	B	6

Besides, for the more technical analysis of the long-term strategies for the decarbonisation of cities, the following figure shows the table that needs to be completed according to the method proposed by the SCIS.

Indicator	S0.3a Foster clean mobility, especially walking and cycling	S1a etc, Building retrofitting
Affordability (estimated increasing energy costs for end users)	Cost reduction	Slight cost increase for end users (0-10%)
Economic viability (period for return of capital)	Significant cost increase (>20%) Moderate cost increase for end users (10-20%) Slight cost increase for end users (0-10%) No increasing cost Cost reduction	Up to 20 years
Barriers to market entry (e.g. vendor lock-in or non-interoperabl	High demand and possibility to apply existing business models	Moderate demand and possibility to apply existing business models
Regulatory requirements	Additional regulation required with slight complexity of implementation	No requirements for additional regulation
Potential for involving stakeholders (user friendly technology)	Interaction with stakeholders requires easy to implement additional measures to improve the acceptability	Interaction with stakeholders requires additional measures with slight complexity of implementation that

Figure 14: Example of the indicator analysis in the prioritization tool for the case of Oulu.

And finally, as described above some extra information is requested to be completed by each municipality for each solution. This extra information aims to provide some new and valuable information to the modeller so that it can be used for the construction of the long-term vision of the city.

This will provide information related to the deployment potential of each solution in the following decades in the case of each city evaluated.

Table 12: Extra information requested in the prioritization tool

Extra information requested in the prioritization tool		Response per each solution
Maximum potential in the city		To be completed
Rhythm of deployment	to 2030	To be completed
	2030-2040	

	2040-250	
Realistic deployment potential in the city		To be completed
Applicability of the solution (per sectors)	Residential (%)	To be completed
	Tertiary (%)	
	Industry (%)	
	Transport (%)	
	Energy generation (%)	
	other (%)	

On the other hand, the following paragraphs describe step by step the entire data gathering process by proposing several data gathering tables and templates developed for the project. The combination of all the templates will allow obtaining from each city of the project the required information for the supply chain characterization of the solutions in the way that it is needed to use it as input for the socioeconomic modelling.

The data gathering process is divided in four different steps as it has been described in the definition of the methodology.

- Step 1. The disaggregation of costs per long-term strategies

This step focuses on obtaining the most accurate disaggregation of the costs of each of the long-term strategy to be considered in the scenarios proposed for each city of the project. Here, the disaggregation needs to be provided per component that conform the solution. Besides, the lifetime of the solution as well as for each component needs to be defined so that the replacement costs can be included in the analysis.

As mentioned, the long-term strategy cost must be disaggregated as much as possible but always considering the following cutting rule;

A higher disaggregation level of components is always desirable as far as it offers a higher level of detail of the shock generated, i.e. if the resulting new subcomponents can be associated to a different code of the classification of commodities described in the previous section.

Therefore, it makes no sense to disaggregate an electric component in smaller subcomponents if all of them will be also electric components or if there are no significative differences regarding the source of financing or the local capabilities for their manufacturing and distribution.

The following table can serve as the main data gathering template for each solution for the step 1 of the supply chain characterization. Note that not only information related to the CAPEX of the solutions are required but also the cost of the OPEX are necessary. An equivalent table needs to be completed for each of the solutions evaluated in the case of each city.

Table 13: Data gathering template (CAPEX and OPEX) for the disaggregation of costs per long-term strategy

Cost breakdown	Costs	Unit	Lifetime of the component (years)
Other project Costs		€	
Cost of the component 1		€	
Cost of the subcomponent 1.1		€	
Cost of the subcomponent 1.2		€	
Cost of the component 2		€	
Cost of the component 2		€	
…		€	
…		€	

O&M Grid electricity price (variable costs)		€/kWh	
O&M Grid electricity base price (fixed costs)		€/kWh	
O&M cost (materials)		€/year	
O&M cost (labour)		€/year	
End of life costs		€	

- Step 2. Assignment of each cost component with the corresponding subsector or commodity

The following table aims to serve as the data gathering template to be used by each city for the assignation of the most related commodity (from the commodity classification used in WIOD) to each of the cost components of the long-term strategies evaluated. This is a relevant step that allows a quick harmonization of the data (from different cities and for different type of measures) to a common format. An equivalent table needs to be completed for each of the solutions evaluated in the case of each city.

Table 14: Assignment of the cost component with the corresponding commodity for the long-term strategy

Component	CODE	Commodity
Other project costs	CPA_K66	Services auxiliary to financial services and insurance services
Cost of the component 1	CPA_C28	Machinery and equipment n.e.c.
Cost of the subcomponent 1.1	CPA_C27	Electrical equipment
Cost of the subcomponent 1.2	CPA_C28	Electrical equipment
Cost of the component 2	CPA_C25	Fabricated metal products, except machinery and equipment
Cost of the component 2	CPA_C28	Electrical equipment
…	..	…
O&M Grid electricity price (variable costs)	CPA_D35	Electricity, gas, steam and air-conditioning
O&M Grid electricity base price (fixed costs)	CPA_D35	Electricity, gas, steam and air-conditioning
O&M cost (materials)	CPA_C28	Electrical equipment
O&M cost (labour)	CPA_C33	Repair and installation services of machinery and equipment
End of life costs	CPA_E37-E39	Sewerage; waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services

- Step 3. Manufacturing and distribution capacity

Table below serves as a template to gather the information per strategy related to the existing capacities both at city level and at regional level for the manufacturing and/or distribution of their main components. Here, the identification of specific companies working on these activities is very interesting. The main objective is to get a better understanding of the necessities of imports associated to each city for the deployment of the strategies. This is an aspect that affect directly to the impact expected in the socioeconomic indicators due to the deployment of solutions. As mentioned for the previous steps, an equivalent table needs to be completed for each of the solutions evaluated in the case of each city.

Table 15: Analysis of the capacities for the manufacturing and distribution of each cost component of the long-term strategy

Cost breakdown	City level producer? (YES/NO)	City level distribution (YES/NO)	Regional level producer? (YES/NO)	Regional level distribution (YES/NO)
Other project Costs	(YES/NO)	(YES/NO)	(YES/NO)	(YES/NO)
Cost of the component 1	(YES/NO)	(YES/NO)	(YES/NO)	(YES/NO)
Cost of the subcomponent 1.1	(YES/NO)	(YES/NO)	(YES/NO)	(YES/NO)
Cost of the subcomponent 1.2	(YES/NO)	(YES/NO)	(YES/NO)	(YES/NO)
Cost of the component 2	(YES/NO)	(YES/NO)	(YES/NO)	(YES/NO)
Cost of the component 2	(YES/NO)	(YES/NO)	(YES/NO)	(YES/NO)
…	(YES/NO)	(YES/NO)	(YES/NO)	(YES/NO)
…	(YES/NO)	(YES/NO)	(YES/NO)	(YES/NO)
O&M Grid electricity price (variable costs)	(YES/NO)	(YES/NO)	(YES/NO)	(YES/NO)
O&M Grid electricity base price (fixed costs)	(YES/NO)	(YES/NO)	(YES/NO)	(YES/NO)
O&M cost (materials)	(YES/NO)	(YES/NO)	(YES/NO)	(YES/NO)
O&M cost (labour)	(YES/NO)	(YES/NO)	(YES/NO)	(YES/NO)
End of life costs	(YES/NO)	(YES/NO)	(YES/NO)	(YES/NO)

- Step 4. Identification of stakeholder related to costs

The main objective of this step is to provide a higher resolution when defining the shock that represents the solution and strategies in terms of the origin of the investments and payments. Here, it is relevant to evaluate which is the share of the costs covered by different stakeholder. A differentiation must be made at least specifying the percentage of the costs covered by public funding, by citizens and be private companies. As mentioned for the previous steps, an equivalent table needs to be completed for each of the PED solutions evaluated in the case of each city.

Table 16: Analysis of the main stakeholders related to each cost component of the long-term strategy in each

Cost breakdown	Costs	Unit	% paid with public funding	% paid by citizens	% paid by private companies
Other project Costs	€				
Cost of the component 1	€				
Cost of the subcomponent 1.1	€				
Cost of the subcomponent 1.2	€				
Cost of the component 2	€				
Cost of the component 2	€				
…	€				
…	€				
O&M Grid electricity price (variable costs)	€/year				

O&M Grid electricity base price (fixed costs)	€/year				
O&M cost (materials)	€/year				
O&M cost (labour)	€/year				
End of life costs	€				

Note that no specific data gathering requirements are defined in this section for the business model analysis step. The main reason is that as mentioned previously the idea behind this activity within the WP1 is not to provide a characterization of the business models proposed for the long-term strategy that will be implemented in the cities of the project. However, focus of this activity is the exploration of the potential aspects that can influence the variations of the business models in the following decades.

5.4 Results and interpretation

The results obtained from the prioritization tool depend to a great extent on the use made of this analysis framework. In the case of the MAKING-CITY project, this framework is applied for the analysis of the solutions of the solution catalogue defined in the WP4 and that will be used for the generation of scenarios oriented to the decarbonization of cities.

The most immediate applicability of these results would be to use them to compare each of the solutions between each other, so that some of them can be prioritized for their incorporation into the final scenarios proposed for the city.

However, as mentioned above, this information can be complemented since through the use of the extended framework, it is possible to obtain a clearer idea not only of which solutions are the most suitable for its potential implementation, but also to determine in greater detail other aspects such as the followings; in which sectors it makes more sense to apply it, which is the limit of the potential installation of each solution (which in many cases can be determined by aspects such as the maximum renewable resource available in the city, etc.), which would be the realistic deployment of each of them (considering specific aspects that may limit or hinder their implementation) and when it is more suitable (during the transition period) that the solution will be implemented depending on aspects such as the evolution of the cost of technology or its level of technological development in general.

Regarding the socioeconomic impact assessment on the other hand, results obtained from the application of the methodology proposed will allow a better understanding of the effects originated from a socioeconomic point of view due to the implementation of the solutions in the cities. This is a relevant aspect to consider in al the urban transformation strategies but not only in the more conventional way in which the impact assessment is proposed as the last step that provides a view of the final impact in terms of increase of the GDP, employment creation or increase of the household disposable income. Here, it is proposed that this step should be part of the core of the analysis since it provides relevant criteria (as ex-ante impact indicators) that can be used for example in the selection of solutions to be implemented in the city and for the comparison and prioritization of scenarios. Here, as mentioned before, data gathering during the supply chain characterization is a key aspect to obtain an accurate input for the socioeconomic modelling. The figure below is an example of the results of the initial phase of supply chain characterization of some solutions.

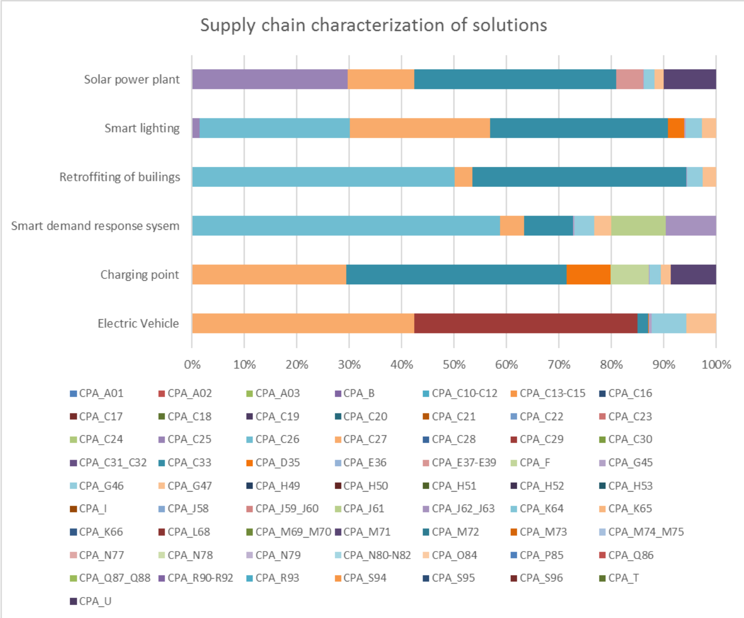


Figure 15: Example of the results of the initial phase of supply chain characterization of some solutions

It can be observed that a partial result such as the one described in the figure above allows interesting analysis of the commodities and sectors associated that are involved when deploying each long-term strategy.

Based on this information and once the socioeconomic impact assessment is carried out several results such as the one showed in the following figure allow a comparison between different long-term strategies so that they can be prioritized for their consideration in the final energy scenario of the city. The figure shows an example of the multiplier values for each long-term strategy that needs to be interpreted as the factor for which needs to be multiplied the initial investment.

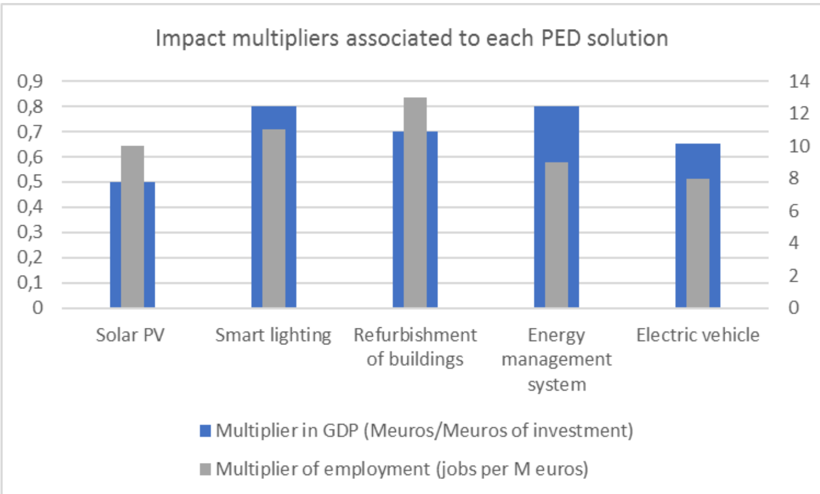


Figure 16: Visual example of the results of the impact assessment. Impact multipliers (GDP and employment) for the comparison of long-term strategies

Results will also allow a higher resolution and interpretation of the impacts as it is showed in the following figure. Here the disaggregated effects generated in each of the subsectors can be better understood.

	difference to "Base" in %			
	direct	indirect	induced	net effects
A01	0,0%	2,9%	3,3%	3,3%
A02	0,0%	16,4%	16,5%	16,5%
A03	0,0%	2,3%	2,8%	2,8%
B	0,0%	0,0%	0,0%	0,0%
C10-C12	0,0%	3,2%	3,6%	3,6%
C13-C15	0,0%	7,0%	7,5%	7,5%
C16	0,0%	16,3%	16,3%	16,3%
C17	0,0%	4,1%	4,2%	4,2%
C18	0,0%	2,7%	2,8%	2,8%
C19	0,0%	6,1%	6,2%	6,2%
C20	5,1%	16,3%	16,4%	16,4%
C21	0,0%	1,7%	1,8%	1,8%
C22	0,0%	7,7%	7,8%	7,8%
C23	125,5%	133,0%	133,1%	133,1%
C24	14,0%	25,3%	25,4%	25,4%
C25	0,0%	22,5%	22,6%	22,6%
C26	0,0%	3,5%	3,5%	3,5%
C27	0,0%	8,1%	8,1%	8,1%
C28	0,0%	21,5%	21,6%	21,6%
C29	10,4%	11,5%	11,6%	11,6%
C30	0,0%	11,2%	11,3%	11,3%
C31_C32	0,0%	3,8%	4,0%	4,0%
C33	311,2%	246,7%	246,8%	246,8%
D35	178,2%	181,8%	182,1%	182,1%
E36	0,0%	3,7%	4,0%	4,0%
E37-E39	0,0%	12,3%	12,4%	12,4%
F	10,2%	14,6%	14,7%	14,7%
G45	0,0%	2,9%	3,2%	3,2%
G46	0,0%	7,1%	7,2%	7,2%
G47	0,0%	1,2%	1,5%	1,5%
H49	0,0%	5,2%	5,4%	5,4%
H50	0,0%	2,3%	2,4%	2,4%
H51	0,0%	2,4%	2,6%	2,6%
H52	0,0%	6,3%	6,4%	6,4%
H53	0,0%	4,4%	4,5%	4,5%
I	0,0%	1,0%	1,3%	1,3%
J58	0,0%	3,4%	3,5%	3,5%
J59_J60	0,0%	11,0%	11,1%	11,1%
J61	0,0%	3,4%	3,4%	3,4%
J62_J63	0,0%	2,7%	2,8%	2,8%
K64	0,0%	4,2%	4,4%	4,4%
K65	0,0%	1,1%	1,3%	1,3%
K66	0,0%	4,6%	4,8%	4,8%
L68	0,0%	1,8%	2,2%	2,2%
M69_M70	0,0%	4,4%	4,5%	4,5%
M71	0,0%	17,1%	17,2%	17,2%
M72	0,0%	0,8%	0,8%	0,8%
M73	0,0%	6,4%	6,5%	6,5%
M74_M75	0,0%	5,5%	5,7%	5,7%
N77	0,0%	7,1%	7,2%	7,2%
N78	0,0%	9,1%	9,2%	9,2%
N79	0,0%	0,1%	0,7%	0,7%
N80-N82	0,0%	6,9%	7,1%	7,1%
O84	0,0%	2,6%	2,6%	2,6%
P85	0,0%	0,2%	0,3%	0,3%
Q86	0,0%	0,1%	0,2%	0,2%
Q87_Q88	0,0%	0,0%	0,1%	0,1%
R90-R92	0,0%	0,1%	0,4%	0,4%
R93	0,0%	0,6%	0,8%	0,8%
S94	0,0%	0,8%	1,1%	1,1%
S95	0,0%	5,6%	5,8%	5,8%
S96	0,0%	0,4%	0,7%	0,7%
T	0,0%	0,0%	0,4%	0,4%
U	0,0%	0,0%	0,0%	0,0%

Figure 17: Visual example of the results of the impact generated in the increase (in % respect to the VA of the sector) of the sectoral VA due to the implementation of an energy transition scenario (composed by long-term strategy)

6 Application to the cities of the project and results

Regarding the application of the modelling approach in each of the cities of the project, this section describes the main results of the first two phases of the proposed methodology (see Section 2). It needs to be taken into account that phases of prioritisation of the long-term strategies, the definition and evaluation of the decarbonisation scenarios of the cities, and the impact assessment, will be carried out in the following steps of the project and therefore they are not included in this section. All those analysis and results will be included in detail in the Long-term city plan (city vision 2050) of each city and in the new/updated SECAPs of each city that will be reported later in the project (D1.5 – D1.12 and D1.13-D1.20).

According to the abovementioned methods, the energy performance of the cities has been evaluated. In that sense, it is necessary to point out at the differences between the two types of modelling developments carried out:

a) **The Building Stock Modelling (BSM)** of each city pursues to establish the energy characterisation of the buildings. Such characterisation is required to understand how the city behaves and thus facilitating the process of designing PED solutions and implementing measures oriented to create long-term plans (City Visions). Broadly speaking this configurates a bottom-up approach since micro-level (buildings) sets the analysis at the macro-level (city).

b) **The Energy Systems Modelling (ESM)** of each city tries to develop the energy-based model of the entire city, meaning economic activity sectors in the demand side and in the supply side too. Those energy balances are considered for a reference year and, subsequently, projections to the future are established as a combination of assumptions, binding commitments and historical trends. The resulting analysis is based on the concept of 'scenarios', i.e. different configurations of those evolutions on which different types of measures are implemented. Such approach is considered in here as top-down since macro-considerations for the entire city are assumed to understand the ESM of the city.

While the first modelling (a) is static, the second approach (b) is dynamic -in the sense that it expresses the evolution in time of different entities such as demands, technology mixes, etc. Besides, the joint of both approaches is a matter of scale since there is conflict between bottom-up (BSM) and top-down (ESM). The extract of aggregated results from city's BSM will be used as input of the city's ESM created afterwards.

The **application of these two types of modelling for each city allows to establish a basis for developing energy evaluations, thus facilitating the later scenario assessment on which the City Vision** is founded. Such analytical foundation is the so-called Business as Usual (BaU) scenario.

This entire section shows an **extract of results for the BaU scenario only**. In the case of the BSM developed for the cities (see Appendix III), as they are static (based on historical/existing data or adjusted estimates), it is clear that every result is conceived under the BaU narrative (in other words, there are no parametrical evolution into the future of the BSM figures). In the case of ESM, the construction of the BaU narrative acts as the baseline case on which the future alternative narratives will be compared with (see Appendix IV). Accordingly, **it is highly remarkable that the present report will include a set of results only for the BaU scenario narratives of each city**.

In the following, especially during Task 1.5 focused on developing alternative scenario narratives, different solutions/interventions considered within the long-term strategy will be implemented in the

ESM. Such implementation will dive into the comparison of those alternative scenarios '*against*' the BaU scenario.

In order to underpin the creation of the alternative scenario narratives, Task 1.4, focused on Capacity Building, will contextualise the required work regarding collaboration among city responsible persons and technical managers from WP 1. Indeed, a set of meetings were held, one-to-one meetings with each of the 8 cities, to explain and validate the models developed so far and ask few questions regarding the procedures developed in T1.3. With these questions the goal was to understand the available LT modelling capacities or needs of the cities, identify their understanding and familiarity with these or similar tools and look for the potential application of the developed models and tools now or in the future in their organizations (see Deliverable 1.23).

In addition, within the creation of the alternative scenarios the citizen engagement strategies must be considered (T1.5.3). In order to assure that this is tackled by the cities, the process and aspects to be considered to put in place a citizen engagement strategy has been defined (Appendix V). Some cities, mainly LHCs already have their strategies in place, unlike the FWCs. The defined process can be used to check the strategies already in place (D2.11 and D3.11) and applied to different domains (City, PED, neighbourhood, etc.) as well.

As mentioned in previous sections of the document, the main objective of the methodological developments, as well as of the analysis that can be carried out in cities based on the application of them, is to generate useful information to provide input criteria for the different stages of the long-term city energy planning.

More specifically, these developments will serve for the city diagnosis stage, for exploring the potential energy needs of cities during the following decades, for comparing alternative PED solutions between each other, for exploring alternative scenarios for the decarbonization of cities, and for evaluating the impact that these scenarios will have in a wide sense.

Hence, **this section, that will be further developed in the following stages of the project will evaluate and propose how to use all the different outcomes of the phases defined for the methodologies for supporting the definition of the long-term city energy plans**. These plans will be reported D1.5-D1.12 "*Long-term city plans of each city*".

In a similar way, as explained in the previous section for the development of long-term city energy plans, the information generated through modelling will serve as a relevant input for the definition or updating of the SECAP of the different cities of the project.

It is evident that there must be a clear connection between both strategies which, although they may have a different time horizon, must follow the same criteria in terms of defining future objectives and proposing improvement actions for the city. In addition, the methodologies and models proposed in this deliverable connect very well with the data reporting and strategy definition requirements of the SECAPs.

In any case, this analysis should be enriched when it corresponds with the section not only of mitigation but of adaptation for each city of the project. In any case this analysis will support the definition of the SECAP that will be developed within the Task 1.6 "*Medium term planning SEAP/SECAP updating*" and that will be reported in the deliverables D1.13-D1.20 "*New/Updated SECAP*".

This section that will be further developed in alignment with Task 1.5 for alternative scenarios, will focus of defining how to consider the outcomes of the works carried out in Task 1.3 for the updating of the SECAP of the cities of the project.

6.1 Bottom-up approach for energy characterization of the building stock

This section anticipates the main results obtained per lighthouse and follower city regarding the bottom-up energy characterization of the building stock. It needs to be mentioned that the main results of the subtask are not the figures included in this deliverable. In this section a summary of the work carried out as well as the main visual results are included. Apart of the content included in the following sections of this deliverable (see Appendix III) a specific document has been provided to each city describing more in detail the main assumptions and considerations related to the modelling. Besides, the main results of this work are provided to each city via several attachments. More precisely, the main results provided to each city include the following;

- The CityGML file generated with both the input data and the energy modelling results for the entire city
- The shape files with the energy characterization of the building stock of the city
- Several excel files with all the results obtained
- An online visualization of the energy modelling results of the building stock of the city

The process followed for the energy modelling of the cities' building stock is broadly common and the methodology followed has been detailed in section 3 of this deliverable.

In any case, the main steps followed are the following;

- Collection of necessary data from the cities (cadastral information, etc.)
- Pre-processing of the information contained in the forms provided by the city.
- Energy modelling of the city: at this point, the work is done on an initial adjustment process by modifying the Enerkad tool database with specific data for the city, followed by a process of contrasting the results obtained with real data on the city's energy consumption (depending on availability) or with different sources of information available.

On this last point, it should be noted that the initial adjustment of the simulation tool database is similar (although with different data) for all cities. This is why it is described below instead of being included in the specific section for each city.

Among the input data for model generation is the adjustment of the followings;

- Building physical characteristics, Thermal transmittance of the building envelope elements
    - European Building Stock observatory [74] (Groningen, Lublin, Oulu, Trenčín, Vidin)
    - Tabula Webtool [75] (Bassano)
    - Previous experiences with Finnish and Turkish cities [76], [77] (For the case of Oulu and Kadiköy)
    - Spanish CTE [78] for the case of Leon
- The **construction periods** are defined according to the source from which the U-values were obtained in each case
- The **air infiltration** in buildings is adapted for the construction periods considered for each city based on the “Average EU building heat load for HVAC equipment” report [79] and adapted to the city's regulations if necessary.

- **Window to wall ratio** (WWR) for each building use based on literature review [80][81][82][83][84][85]
- The **internal gains** of equipment, lighting and occupancy are also taken from various sources
    - Design Builder simulation tool [86]
    - Previous experiences [76], [77]
    - Literature review [87][88][89][90]
    - Calculated values based on literature review and Design Builder
- The **outdoor temperature** used in the simulations is the Dry Bulb Temperature taken from the Energy plus weather database [23]
- The **Heating and Cooling seasons** are calculated based on the outdoor temperature and on the methodology defined in Eurostat for the calculation of the Heating and Cooling degree days [91]
- The **schedules for heating, cooling, DHW, equipment, lighting and occupancy** are also taken from Design Builder and adapted to the specific characteristics of the city if necessary, according to the data provided by each city.

6.2 City energy system modelling for long-term planning

As explained before, the development of the Energy Systems Model (ESM) for each city has been carried out founded on two steps. First, with the information required to the cities the energy balance was established for a reference year. Second, the construction of the BaU scenario was developed by establishing a set of assumptions on socioeconomic drivers, historical trends of demands, and technology data disaggregation, among others. During this process, cities' feedback has been considered in order to enrich the BaU narrative, thus strengthening the baseline storyline of the cities. After closing such discussion periods on data validation and assumptions with the cities, current report has been carried out including an excerpt of some of the most representative results for each of the BaU scenarios of the cities. Those results on BaU scenarios for each city are included in Appendix IV.

It should be remarked that according to the expectations of the cities and the analytical robustness of ESMs performed, extra results and potential adjustments (due to COVID-19 effects in terms of volatility, for instance) could be incorporated during Task 1.5 development.

7 Conclusions

The urban energy planning process is an increasingly complex problem. Cities must respond to a growing population, which is concentrated within their municipal / jurisdictional limits, at the same time than investing and deploying in better infrastructures and services associated with ever-increasing demands from citizens. All of them also accompanied by a greater need to address an integrated energy system where there are both consumers and prosumers that affect various sectors such as housing, services and transport. This is a relevant aspect that cities need to get involved in order to design the best strategy possible for meeting the emission reduction targets in the long term, achieve energy savings, and dealing with sustainable growth concerns (pollution, waste, air quality, noise, etc.).

Within the framework of the MAKING-CITY project, a Methodological framework for the Advanced Long-Term Planning has been defined. This framework is provided as a global approach to all the modelling that must accompany the long-term urban energy planning process. This framework is made up of four major phases that lay the foundations for identifying the specific methodologies to be considered and, if necessary, adapting them to the problem addressed. These methodologies are precisely those that have been developed in detail throughout the document, each of them with a state of the art, with a methodological proposal, with a characterization of the required data, and with a description of the type of results obtained as well as their applicability for long term planning.

One of the key aspects identified throughout the process is that the connection between the different methodologies and tools proposed is one of the greatest difficulties, since the problem requires the use of methods that *a priori* may seem to come from very diverse fields.

Another difficulty is that, defining the methodologies mentioned in a sufficiently generic way so that they can be applied to the cities of the project, which in principle are very different. In this sense the efforts made for harmonization are essential to try to optimize the modelling efforts, which are very intense in each of the phases of the methodology.

On the other hand, another aspect that has been identified as critical is all that has to do with the process of collecting input information for each of the methodologies. It should be noted that depending on the quality of the data and their level of disaggregation, both the modelling options and the reliability of the results obtained will be strongly influenced.

For this reason, the need for the active participation and involvement of the project cities in the whole process is highlighted, especially in those cases in which specific hypothesis and considerations are required for the construction of the data when they are not available with the required level of detail. This will also make it possible to move forward in a more efficient way, since through the involvement of the city, the usability of works and models that each of them has used and is using throughout their planning processes are identified with greater efficiency. The combination of these existing models with those proposed in the project will allow to particularize the studies to each city so that the results obtained become relevant for them.

Regarding the application of the modelling to each of the cities involved, this deliverable contains a summary of the main results obtained for each city evaluated for the first two phases of the proposed methodology. It should be noted that both the prioritisation of the PED solutions and the definition and evaluation of the decarbonisation scenarios of the cities are carried out in the following phases of the project, as well as the impact assessment results. Therefore, it is not included in this deliverable but will be included in detail in the Long-term city plan (city vision 2050) of each city and in the new/updated SECAPs of each city.

The bottom-up approach for the energy characterisation of the building stock has been carried out by using the ENERKAD® tool, co-created by Tecnalia. The results obtained allow a quick energy diagnosis of the building sector in the cities of the project through a visualization of the energy demands, energy consumption and environmental emissions where appropriate. These results and the models themselves will provide relevant information that can feed into the definition of long-term scenarios that are carried out in the next phase of the proposed methodology. In addition, they will be able to feed into WP4 regarding the identification and selection of PEDs in the different cities, as well as the energy characterisation of the buildings included in them during the design phase.

Once created the energy picture of the city buildings, a set of Energy Systems Models (ESM) for each of the cities has been developed using the LEAP tool. Those urban ESM represent the energy balance of the cities in a reference year (2016 to 2018, depending on the available data from each city) in addition to the Business as Usual (BaU) scenario. Thus, the base year figures should give us an idea as diagnosis of the energy picture for each city in the present whereas the BaU scenario would mean the expected evolution of the system if no extra measures are applied from now to 2050. The storyline behind BaU scenarios does not represent a forecast but the undesired expectations of not doing anything. Accordingly, the figures in most of the cities show a growing behaviour in final energy demands and GHG emissions as well. In most cases such behaviour is very linked to the historical trends observed from transport, a sector very dependent on fossil fuels. Regarding emissions reductions, solutions such as electrification in demands will make a difference, but measures founded on energy efficiency and savings are crucial too.

Appendix I - Inventory of Models - description

Table 17: Inventory of Models

	Model Name	Description	Type	Owner
thermal	CHESS	Heat network design		TNO
	Warmte Transitie Atlas (WTA)	Geo-mapping to visualise facts and opportunities	commercial	Over Morgen
	VESTA MAIS	Spatial energy model for the urban environment with technical and economic analysis	open	PBL
	PLANHEAT	Heat network design	open	h2020
	THERMOS	Heat network design	open	H2020
electricity	CEGRID	Translates future scenarios for the energy supply and its impact on the electricity grid	commercial	CE Delft
	COMPETES	Modelling the optimization of the centralised electricity dispatch		TNO
	International Test and Simulation Facility (ITSF)	Used to stimulate local electricity peaks as result of increasing renewables		DNV-GL
	MKBINS	Simulation of cost and benefits of flexibility options for the grid relative to capacity increase		Stedin-CE Delft
	POWERFYS		commercial	Ecofys
	PV+OPSLAG	Simulate potential of solar generation, use, storage and delivery to grid		Alliander
	WINDPLANNER	Online software tool for planning van visualization of wind and solar projects	open	The Imagineers
mixed sources	CEGOIA	Chain-wide cost calculation of sustainable thermal solutions	commercial	CE Delft
	DIDO	Energy Transition Simulation Environment that model stakeholder investment decisions to simulate the evolving energy transition based on policy measures from governments	commercial	TNO
	DNV-GL Smart Grid Scenatio Model (DSSM)	Insights on impact energy transition on the Dutch electricity supply	commercial	DNV-GL
	Analysekaarten NP RES	(Geo) Visualisation of energy production, demand and infrastructure	open	RES
	Energy Transition Model	Scenario simulation towards carbon neutral futures	open	Quintel
	GEBIEDSMODEL			

Model Name	Description	Type	Owner
HET DUURZAAM DATAPLATFORM	Data platform which links energy label data for an enriched estimation of the sustainability opportunities for dwellings	open(conditional)	BackHoom
LEAP	Simulation of scenarios for energy transition roadmaps of neighborhoods or industrial parks	commercial	Energy Transition Group (ETG)
OMONS	Platform to simulate the impact of individual and collective decisions on the system	commercial	OMONS
OPERA	Integral system analysis of NL with optimization on the mix of technologies resulting in the lowest system costs	available at cost	TNO
PICO	Geo-mapping of current energy situation on different scales plus outlook regarding opportunities for sustainability solutions	Open	Geodan/TNO/Ecofys
TRANSFORM	Simulation based platform to support decision makers in analyzing (opportunities in) the energy system, with the possibly to conduct scenario simulation and optimization studies	To be made open	Accenture, AIT, Macomi
WARMTEVRAAGPROFIELEN	Simulation of thermal demand scenarios per dwelling based on a variety of thermal installation	Expert tool	TNO
Simulation and Analysis model for Dwelling Energy use (SAWEC)	Simulation model for households that calculates the building-related energy use of houses, based on a stock database, and the effects of measures.		TNO
SAVE-Production	Simulation model that calculates the (future) energy demand of industry and agricultural sectors and the sectoral implementation of combined heat and power generation		TNO
SAVE-Services	Simulation model for the services sector. Based on the economic growth per subsector and the measures taken, the model calculates the future gas and electricity demand.		TNO
EVA (households)	uses a detailed stock database to calculate the national electricity use of household appliances, yielding prognoses up to 2020, with insights on the impact of efficiency measures		TNO
RESolve-E	Provide data about the total renewable energy production (excluding biofuels)		
ESSIM	simulates integrated network balancing in an ESDL-defined energy system comprising of interconnected multi-commodity energy networks		
WOONCONNECT	Online platform with dynamic BIM-models to configure new built dwellings, visualize renovation scenarios and test energy solutions	commercial	De Twee Snoeken

Appendix II - Inventory of Models - characterization

Table 18: Inventory of Models -characterization

		Geographic scope					Phase of transition targeted					Functionality			
		National	Regional	City	District/ neighbourhood/ Street	Dwelling	Vision	Pathways	urban (spatial) planning	Execution	O&M	Energetic	Market	Policy	Spatial visualisation
thermal	CHESS		x	x	x	X			x			x			x
	Warmte Transitie Atlas (WTA)		x	x	x		x	x	x			x			x
	VESTA MAIS	x	x	x	x		x	x				x		x	x
	PLANHEAT														
	THERMOS														
electricity	CEGRID	x	x	x	x		x	x				x			
	COMPETES						x						x		
	International Test and Simulation Facility (ITSF)		x	x	x		x	x	x			x	x		x
	MKBINS		x	x	x		x	x				x			
	POWERFYS	x	x				x						x		
	PV+OPSLAG					X	x					x			
	WINDPLANNER	x	x	x	x		x	x	x			x			x
mixed sources	CEGOIA	x	x	x	x		x	x				x			x
	DIDO		x	x			x	x				x	x	x	
	DNV-GL Smart Grid Scenatio Model (DSSM)	x	x	x	x		x					x	x		
	Analysekaarten NP RES	x	x	x	x		x	x				x			x

	Geographic scope						Phase of transition targeted						Functionality			
	National	Regional	City	District/ neighbourhood/ Street	Dwelling		Vision	Pathways	urban (spatial) planning	Execution	O&M		Energetic	Market	Policy	Spatial visualisation
Energy Transition Model	x	x	x	x			x	x	x				x	x	x	
GEBIEDSMODEL		x	x	x				x					x			
HET DUURZAAM DATAPLATFORM		x	x	x	X		x	x	x				x			x
LEAP				x	X		x	x					x			
OMONS				x	X								x			x
OPERA	x						x						x			
PICO	x	x	x	x	X		x	x	x				x			x
TRANSFORM		x	x	x			x	x					x			x
WARMTEVRAAGPROFIELEN				x			x	x	x				x			
Simulation and Analysis model for Dwelling Energy use (SAWEC)	x	x	x				x	x					x			
SAVE-Production	x	x	x				x	x								
SAVE-Services	x	x	x				x	x								
EVA (households)	x	x	x				x	x								
RESolve-E	x	x	x				x	x							x	
ESSIM		x	x	x	X		x	x					x		x	
WOONCONNECT				x	X								x			x
	15	23	22	20	8	0	26	22	8	0	0	0	24	6	5	12
32 models	National	Regional	City	District/ neighbourhood/ Street	Dwelling		Vision	Pathways	urban (spatial) planning	Execution	O&M		Energetic	Market	Policy	Spatial visualisation

Appendix III - Bottom-up approach for energy characterization of the building stock

This section includes the main results obtained per lighthouse and follower city regarding the bottom-up energy characterization of the building stock. It needs to be mentioned that the main results of the subtask are not the figures included in this deliverable. In this section a summary of the work carried out as well as the main visual results are included. Apart of the content included in the following sections of this deliverable a specific document has been provided to each city describing more in detail the main assumptions and considerations related to the modelling. Besides, the main results of this work are provided to each city via several attachments.

Oulu

As described in the introductory section, the results obtained and provided to the city contain a series of files among which are the resulting shapes, databases, the CityGML and the online visualization of the results obtained from the energy modelling of the building stock of the city. This section of the deliverable (and the following ones that correspond to the rest of the cities of the project) is focused on describing in the most simple and visual way possible some of the results obtained from all these attached files.

As a first step in the process of energy modelling of the city's buildings, a process of collecting and processing the basic information necessary both geometrically and semantically to establish the basic parameters of the case study is carried out. In the case of Oulu, the following information has been provided by the municipality in various shape files.

Table 19: Origin of the data for the city of Oulu

Content	File name	Description
Buildings	Oulu buildings 20190408_am_region.shp	Includes all the needed basic information + information related to the energy system type and configuration.
Parcels	kiinteistot19052020_area.shp	Includes the information related to the parcels
Ownership	Rakennukset25052020.shp	Includes the ownership of the residential buildings
DH network	OuluDistrictHeat.shp	Details of the DH network
Buildings	OuluBuildings18062020.shp	Includes additional information related to the ownership and the modification in the buildings

On the basis of this data, Tecnalia has carried out a process of pre-processing and refining the data so that it can be used for energy modelling in Enerkad.

The processing of the data required to obtain an input file with the necessary characteristics has been based solely on the adaptation of the parameters included in the layers sent by the city to the required formats. It has not been necessary to combine information from additional layers since both the basic information required and the additional equipment information were included from the beginning.

At a geometric level, geometries with a floor area of less than 30m^2 have been removed from the shape and it has been checked that there are no overlaps between geometries or duplicated geometries or IDs.

Finally, information about ownership and refurbishments has been included for informative purposes since it has not been used in this preliminary analysis. Additionally, the layer with the geometry of the district heating network has been included in the closed project.

The following figure shows an example of the resulting layer for a specific area of the city of Oulu. However, this process has been carried out for the entire city.

Figure 18: Example of the uses of the buildings for an area of the city of Oulu

Once all the input basic information is available, the modelling is done in Enerkad. For this purpose, all the necessary input parameters (described above) for the energy characterization of each building of the city is assigned. From this, modelling results are obtained which are contrasted (and some modelling input parameters are adjusted if necessary) with the energy information available in the city. In the case of Oulu, this adjustment process has been carried out taking into account the following information sources:

- Data source 1: Calculation method and tool for assessing energy consumption in the building stock [92]. This has been used mainly in the case of residential and office buildings.
- Data source 2: Values from previews experiences in Finland: Helsinki 3D model [93]. This has been used mainly in the case of residential and office buildings.
- Data source 3: Energy planning of low carbon urban areas - Examples from Finland [94]. This has been used mainly in the case of residential and office buildings.
- Data source 4: Europe’s buildings under the microscope – BPIE [95](used for office buildings). This has been used mainly in the case of residential and office buildings.
- Data source 5: Energy consumption of Finnish schools and daycare centers and the correlation to regulatory building permit values [96]. This has been used mainly in the case of education and health care buildings.
- Data source 6: Measured energy consumption of educational buildings in a Finnish city [97]. This has been used mainly in the case of education buildings.
- Data source 7: Comparison with real data provided by Oulu for residential and office buildings, for education buildings and for health care buildings

The following figure serves as an example of the results obtained in the adjustment process. In this case, the results obtained with the energy modelling of the project (in Enerkad software) are compared with the real heating energy consumption data provided by the municipality of Oulu for the case of the residential buildings.

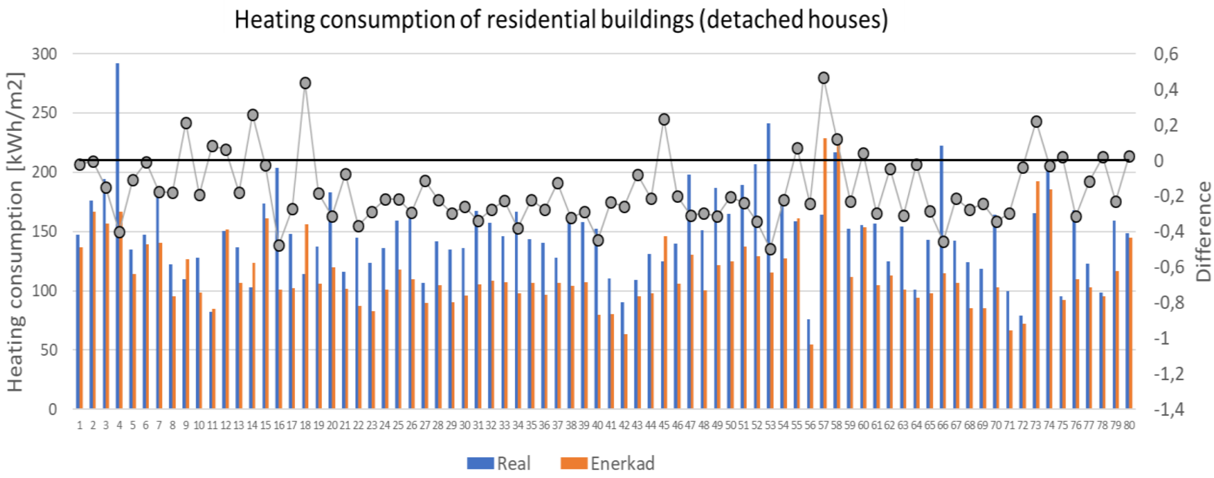


Figure 19: Heating consumption of 80 representative detached residential houses. Enerkad modelling results vs real data provided by the municipality of Oulu (Data source 7).

It should be noted that an equivalent analysis has been carried out for all the buildings of the city and with the rest of the data sources mentioned. The results obtained show a good correlation of the results. It should also be taken into account when interpreting the results that the simulated modelling of all the city's buildings is being carried out. Furthermore, it should be mentioned that in many cases the different sources of information (from literature) contrasted provide values that have relevant deviations between each other. As a conclusion of the analysis, the model is capable of considering the differences in energy consumption between the different types of buildings in the city, both in terms of use, age and geometry.

The following figure shows in a visual way the heat consumption of the buildings in the city of Oulu. In this case the modelling results are shown as energy consumption density in kWh/m^2 via a colour scale. As mentioned above, the modelling allows an equivalent visualisation of the rest of the energy demands and consumptions (electrical such as lighting, equipment, etc.) of the buildings.

Figure 20: Modelling results, electricity consumption[3] of the buildings of the city of Oulu (kWh/m²).

This type of visualization allows to easily identify those buildings with the worst energy performance and therefore allows to propose alternative scenarios for the city in a simple way through the identification of areas with potential for building rehabilitation or integration of renewable energy sources.

In the case of the city of Oulu, information on the type of energy systems and fuels consumed in each of the buildings was available. Therefore, it has also been possible to evaluate the environmental impact and the primary energy consumption associated with the total energy consumption of each building. This is shown in the following figures where the impact in kg of CO_2equi.

[3] The electricity consumption includes also the electricity for heating + DHW

Figure 21: Modelling results, environmental impact associated to the total energy consumption of the buildings in Oulu (kg of CO_2 equi.).

Figure 22: Modelling results, Primary Energy consumption associated to the total energy consumption of the buildings in Oulu (kWh/m²).

In addition, all the results have been grouped into 250x250m cells, showing the results for the whole city in a more aggregated way. The heating demand per cell for the whole city in kWh/m² is shown below.

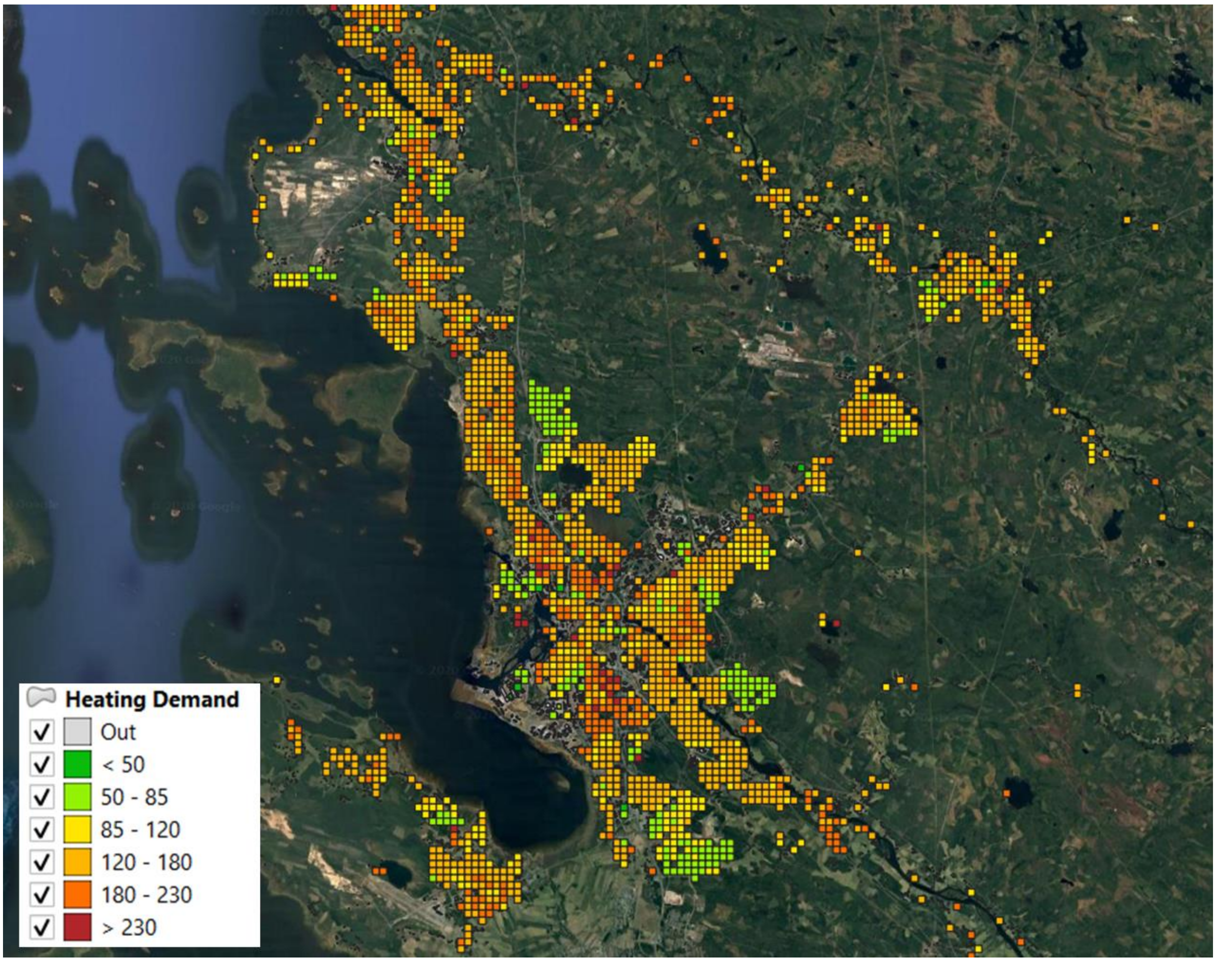


Figure 23: Modelling results grouped in 250x250m cells, energy demand for heating of the buildings in the city of Oulu (kWh/m^2).

Groningen

In the case of the city of Groningen, the following paragraphs are focused on describing in the most simple and visual way possible the main results obtained from the energy modelling of the building stock of the city, which have been provided to the municipality in the form of several files (equivalent to the case of Oulu) attached to the deliverable.

Data collection and processing of the basic information necessary to establish the basic parameters of the case of Groningen has include the treatment of the following information sources provided by the municipality.

Table 20: Origin of the data for the city of Groningen

Content	File name	Description
Buildings	bag3d_2019-03-23.gpkg	Information of buildings for the Netherlands
Buildings	Groningen.shp	Includes de height of the buildings. Obtained from the bag3d_2019-03-23.gpkg, limited to the boundaries of Groningen
Buidings	Groningen_GeometryInfo.shp	Final Geometry after treatment. Includes use, construction year, postcode and IDPAND
Points	Groningen_PointInfo.shp	Information of each geometry in Groningen_GeometryInfo.shp

Addresses (points)	BAG_adres_punt.shp	Addresses per buildings. Used for the definition of the number of dwellings

Based on this information, Tecnalia has carried out a process of pre-processing and refining the data so that it can be used for energy modelling in Enerkad.

In the Groningen_GeometryInfo.shp layer, the duplicated geometries and IDs have been removed. By removing the duplicate geometries, we go from 137049 to 70485 buildings.

For each geometry obtained, the predominant use is calculated from the Groningen_PointInfo.shp layer, as the overlapping geometries indicate different uses in the same building. The year of construction, PC and IDPAND are also obtained from this layer.

Finally, the height of the buildings in the layer Groningen.shp and the number of dwellings in BAG_adres_punt.shp are obtained and included in the layer generated in the previous step.

Once the final geometry to be used in the model has been obtained, the geometries with a floor area of less than 25m^2 have been removed, and the use and height for nearby buildings for which no information is available has been completed.

Subsequently, the information on ownership and student housing has been included for informative purposes and the name of the district to which each building belongs for the validation of the results.

The following figure shows an example of the resulting layer used for the city of Groningen.

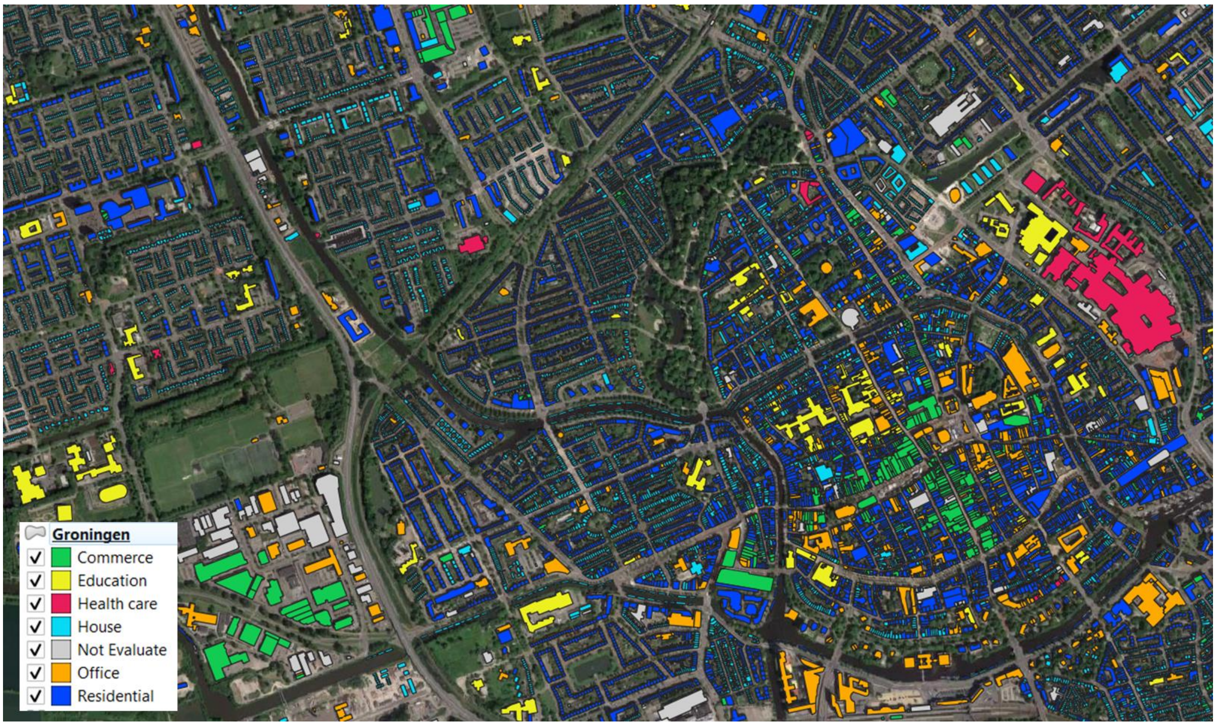


Figure 24: Example of the uses of the buildings for an area of the city of Groningen

In a following step, the energy modelling of the city is carried out in Enerkad. With this aim, all the necessary input parameters for the energy characterization of each building of the city are assigned. Modelling results are then contrasted and adjusted with the energy information available in the city. In the case of Groningen, this adjustment process has been carried out taking into account the following information sources:

- Comparison with data from literature: TABULA webtool [75]
- Comparison with real data provided by Municipality

- [Energy_data_Groningen_2018_Gas] → In this case the average gas consumption per dwelling was available. However, as the information is referred to each dwelling and the results of the modeling in Enerkad are obtained by blocks, to be able to compare them an estimation of the number of dwellings contained in each block was necessary. It needs to be noted that this is a source of possible deviation in some cases, since the data of both the number of floors and heights and the number of connections were somewhat confusing in some specific cases. In any case, this information has been very valuable in the adjustment of the main parameters of the Groningen model.
- [City Level KPIs] → The total average natural gas use per district has been compared with the energy demand for heating+DHW obtained from Enerkad. Enerkad gives the results in kWh and the information related to the districts is given in gas m^3 and it has been converted into kWh. The following figure is an example of the results obtained during the adjustment process of the model. Energy modelling results obtained in the project are compared with the real gas consumption data provided by the municipality of Groningen.

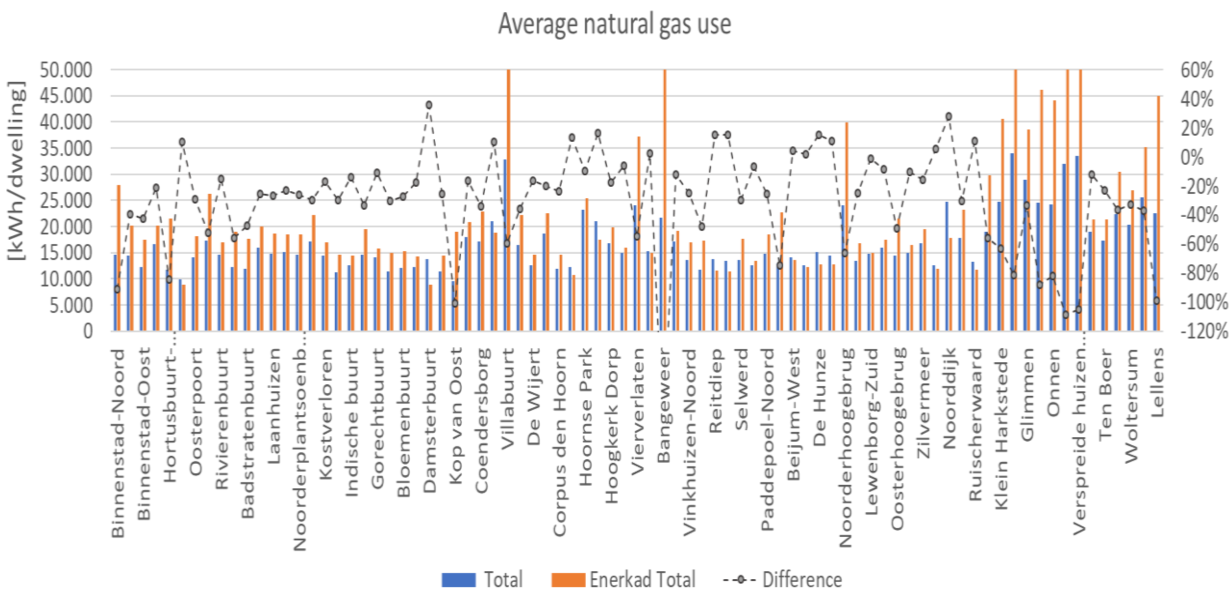


Figure 25: Average natural gas use per district in Groningen. Enerkad modelling results vs real data provided by the municipality.

The results obtained show a good correlation of the modelling results with the real energy consumptions available. As can be seen in the figure, there are specific cases in which there is a relevant variation (over 60% in some specific cases). A more detailed analysis of the results corresponding to these particular cases shows the great influence they have on them, the uncertainty which exists in terms of the number of connections and the number of dwellings per block, which makes difficult to make a reasonable comparison of data. The weight of the discrepancy in the geometry of these particular buildings in the layer available in the city has also a great influence. In any case, these are specific cases, and the general results for the city as a whole are positively evaluated.

The following figure shows in a visual way the heat demand of the buildings in the city of Groningen. In this case the modelling results are shown as energy demand density in kWh/m^2. As mentioned above, the modelling allows an equivalent visualisation of the rest of the energy demands (and including the electricity use for lighting, equipment, etc.). In this case for heating only the energy demands are evaluated since there is no specific information about the energy system and fuel used by each building of the city.

Figure 26: Modelling results, heat demand of the buildings in the city of Groningen (kWh/m^2).

Figure 27: Modelling results, electricity consumption of the buildings in the city of Groningen (kWh/m^2).

Bassano del Grappa

As in the previous cases, this section describes the main results obtained from all these files (resulting shapes, databases, the CityGML and the online visualization) that have been provided to the city of Bassano with the results of the modelling.

In the case of Bassano, the following information sources have been provided by the municipality. All these files have been taken into account in the initial step of the modelling, data collection and pre-processing (geometric and semantic data of the buildings of the city).

Table 21: Origin of the data for the city of Bassano Del Grappa

Content	File name	Description
Buildings	fabbricati.shp	Includes de ID
Parcels	particelle.shp	Considered as the city limit
Buildings	UN_VOL_Bassano.shp	Final geometry calculated from this layer. Includes the height of the building
Buildings	EDIFIC_Bassano.shp	Includes the building use
Buildings	EDI_MIN_Bassano.shp	Geometries of buildings out of the scope of the analysis.

On the basis of this data, Tecnalia has carried out a process of pre-processing and refining the data so that it can be used for energy modelling in Enerkad. In this case, each of the basic parameters required come from several layers with different geometries, so intense processing has been necessary, resulting in some loss of information.

In the UN_VOL layer the area of each geometry has been calculated and the records with uses that are not evaluated have been eliminated. The geometries of UN_VOL_Bassano.shp that appear in EDI_MIN_Bassano.shp have also been eliminated. Subsequently, each geometry is associated with the ID of fabbricati.shp (PK_FABBRIC). All geometries outside the study area have been removed, considering as study area the one defined particelle.shp.

For the calculation of the height the information of UN_VOL_ Bassano.shp has been used. The weighted average height has been calculated for each of the geometries defined in the previous step. Finally, the use of the layer EDIFIC_Bassano.shp and in year of construction are associated.

The complexity of the process has made that some geometries have disappeared due to incorrect data or a lack of information in some of the steps. These mistakes have been detected and corrected by the municipality, adding the missing buildings and modifying manually the wrong uses or ages.

The following figure shows an example of the resulting layer for a specific area of the city of Bassano. However, this process has been carried out for the entire city.

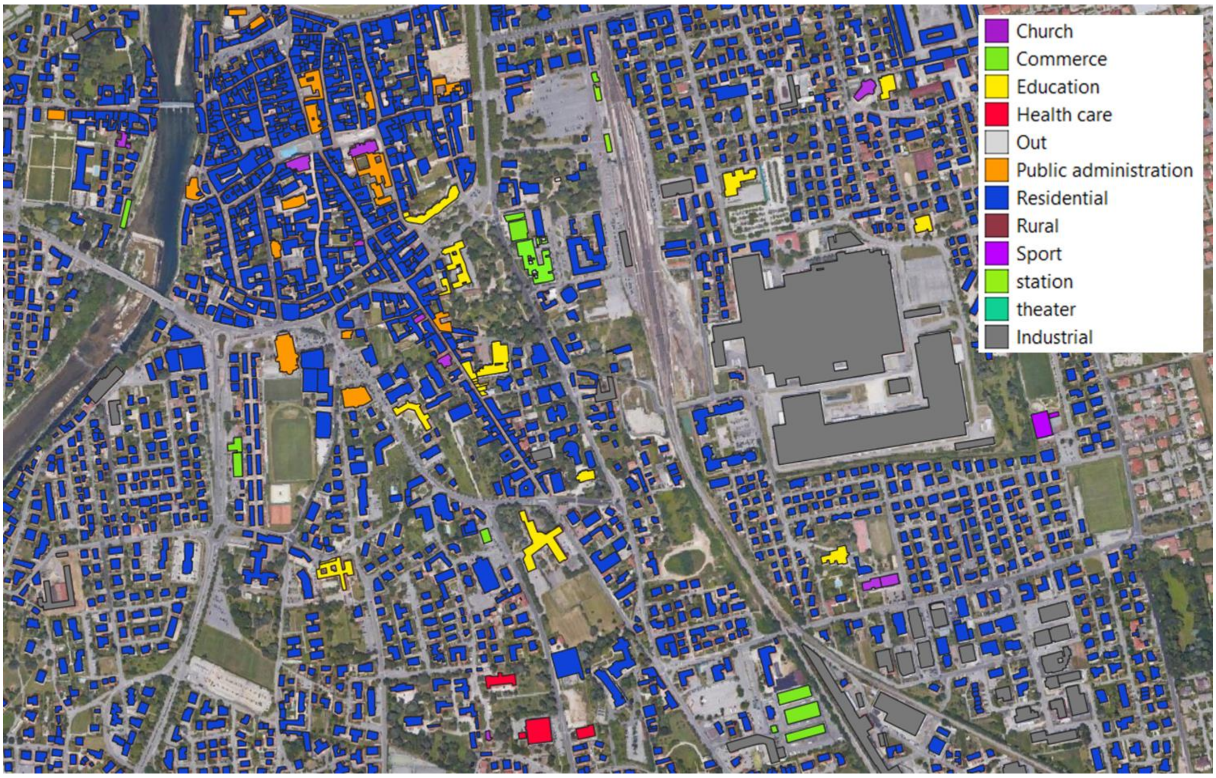
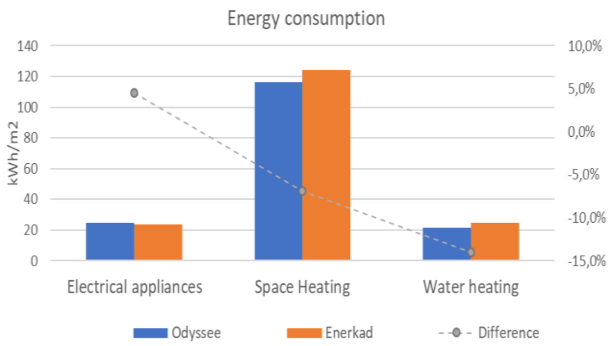


Figure 28: Example of the uses of the buildings for an area of the city of Bassano

Obtained modelling results have been contrasted and adjusted with the energy information available in the city. In the case of Bassano, this adjustment process has been carried out taking into account the following information sources:

- Data source 1: Tabula Webtool [75]. Used for residential buildings.
- Data source 2: Odyssee [98]. Used for residential buildings.
- Data source 3: Italian Energy Efficiency Action Plan (EEAP) [99]. Used for residential and tertiary buildings.
- Data source 4: EU Buildings Observatory [100]. Used for residential buildings.

The following figure is an example of the results obtained during the adjustment process of the model. In this case, there has been no real data on buildings in the city to make the contrast, so the process has focused on the data available in the literature.



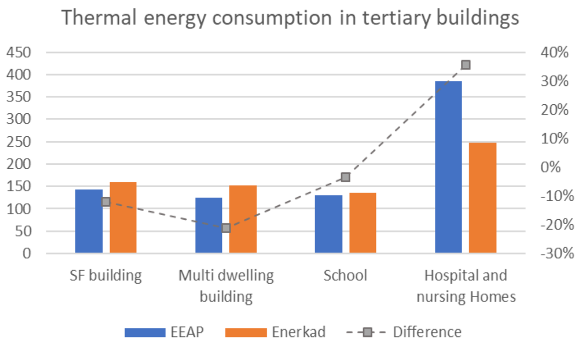


Figure 29: Energy consumption in residential buildings, modelling results vs Odysee (left). Thermal energy consumption in tertiary buildings, modelling results vs data from the Italian Energy Efficiency Action Plan (right).

The figure above shows the results of the comparison with two of the five cases mentioned. In these two cases the results observed in the modelling are aligned with the data available. In the rest of the analysis similar results have been observed, although with a better correlation with the data provided in the EU Buildings Observatory (differences of up to 1.5%) than in the case of the data provided by Tabula for example. In the latter case, differences of between 10% and 50% are seen in some cases. The largest differences correspond to residential buildings built after 2006.

The following figures shows the energy demand results for the buildings of the city of Bassano. Results are shown as energy demand density in kWh/m^2. In this case for heating only the energy demands are evaluated since there is no specific information about the energy system and fuel used by each building of the city.

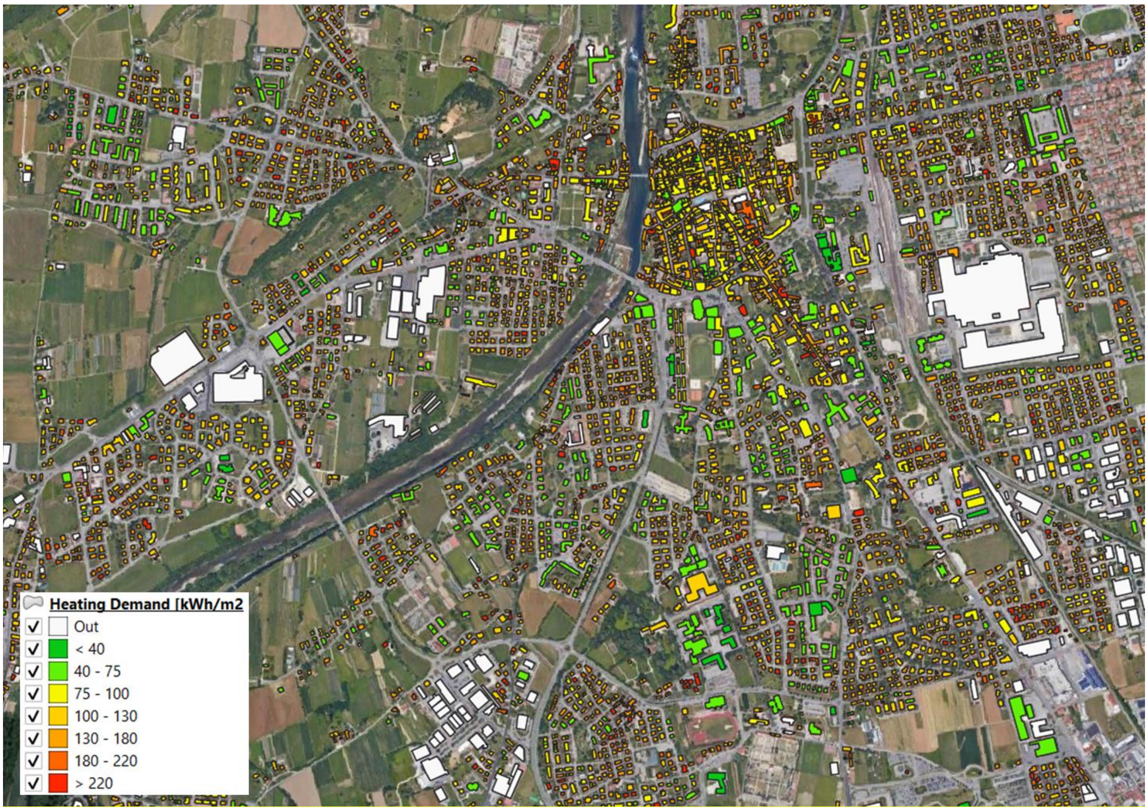


Figure 30: Modelling results, heat demand of the buildings in the city of Bassano (kWh/m^2).

Figure 31: Modelling results, electricity consumption[4] of the buildings in the city of Bassano (kWh/m²).

Kadiköy

This section describes the main results obtained from the energy of the city of Kadiköy. This can serve as a summary and as a visual representation of the type of results provided to the city (resulting shapes, databases, the CityGML and the online visualization).

The following information sources have been provided by the municipality. All this data has been evaluated and treated so that it can be used as input data for the energy modelling.

As a first step in the process of energy modelling of the city's buildings, a process of collecting and processing the basic information necessary both geometrically and semantically to establish the basic parameters of the case study is carried out. In the case of Oulu, the following information has been provided by the municipality in various shape files.

Table 22: Origin of the data for the city of Kadiköy

Content	File name	Description
Buildings	yapi_making_city.shp	Oudated shape file with all the buildings
Area	yeni_sinir_Kadiköy.shp	Limit of the not renovated area
Buildings	yapi_making_city_fikirtepe_05052020.shp	It includes now the use and the height of the buildings
Buildings	fikirtepe.shp	Information of construction years for the fikirtepe area
Buildings	yapi_making_city.shp	Oudated shape file with all the buildings

[4] Electricity consumption for lighting and appliances

On the basis of this data, Tecnalia has carried out a process of pre-processing and refining the data so that it can be used for energy modelling in Enerkad.

In the case of the city of Kadiköy, it has been necessary to combine different files to include the newly developed area in the analysis. The first of the layers yapi_making_city.shp is outdated, so buildings that have currently been demolished appear and recently constructed buildings do not. The buildings in this area have been removed using the boundaries defined in yeni_sinir_Kadiköy.shp.

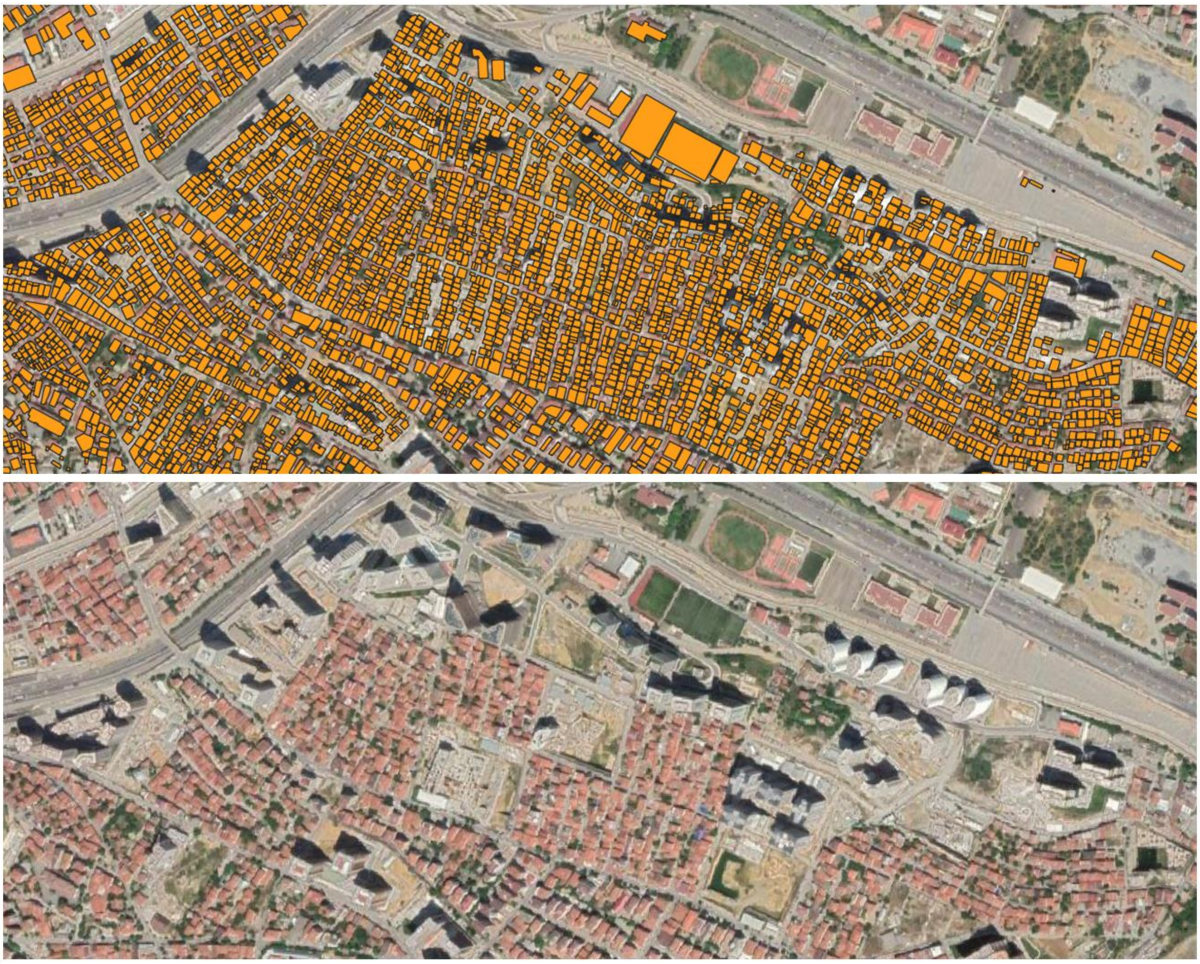


Figure 32: Example of the information contained in yapi_making_city.shp (top) VS the new developed area (down)

Later, the information of the renovated area has been treated, first in yapi_making_city_fikirtepe_05052020.shp and later it has been updated with the years of construction defined in fikirtepe.shp for the same area.

Once the information is processed, both layers are combined, and the use and age information are completed for the buildings that have not defined it from the information of the nearby buildings. Finally, some construction years have been modified taking into account the suggestions of the city.

The following figure shows an example of the resulting layer for a specific area of the city of Kadiköy. However, as mentioned in the previous cases this process has been carried out for the entire city.

Figure 33: Example of the uses of the buildings for an area of the city of Kadiköy

Modelling results obtained with Enerkad, have been compared with the information available in the city. In the case of Kadiköy, some real data has been sought through energy bills as not many references have been found in the literature. The main data sources evaluated are the followings;

- Data source 1: Typical residential use in Kadiköy – data from bills provided by the municipality.
- Data source 2: Data from the Sustainable Energy Action Plan (SEAP) document of the city combined with the surface area of the buildings obtained from the GIS DATA-Shp. Data provided by the municipality.

As an example, the following figure shows a comparison of the energy end-use distribution between a typical residential building and the modelling results obtained in the project. A good correspondence of consumptions can be seen in all end uses except for home appliances. In this last case, the data provided by the municipality are much lower than the modelling results. This may be due both to discrepancies with real user behaviour and to possible inaccuracies when breaking down final electricity consumption from total bill data.

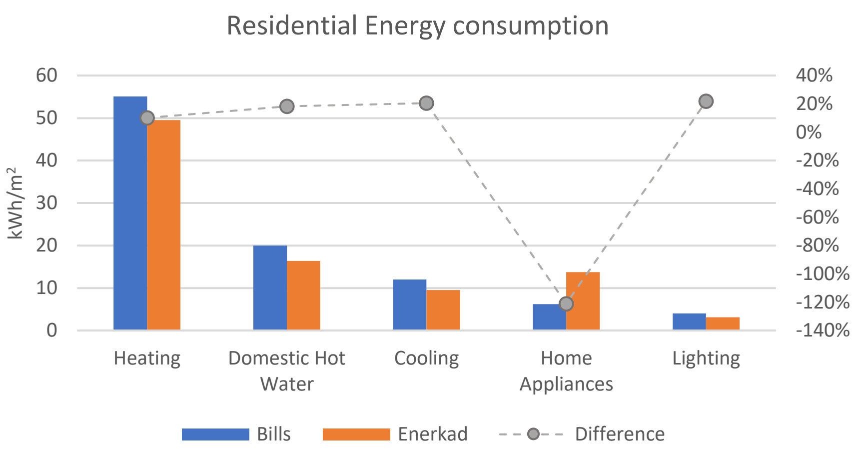


Figure 34: Energy consumption in typical residential buildings of Kadiköy (energy bills) vs modelling results (Enerkad)

The following figures shows the energy demand results for the buildings of the city of Kadiköy. In the case of heating, only the energy demands are evaluated since there is no specific information about the energy system and fuel used by each building of the city.

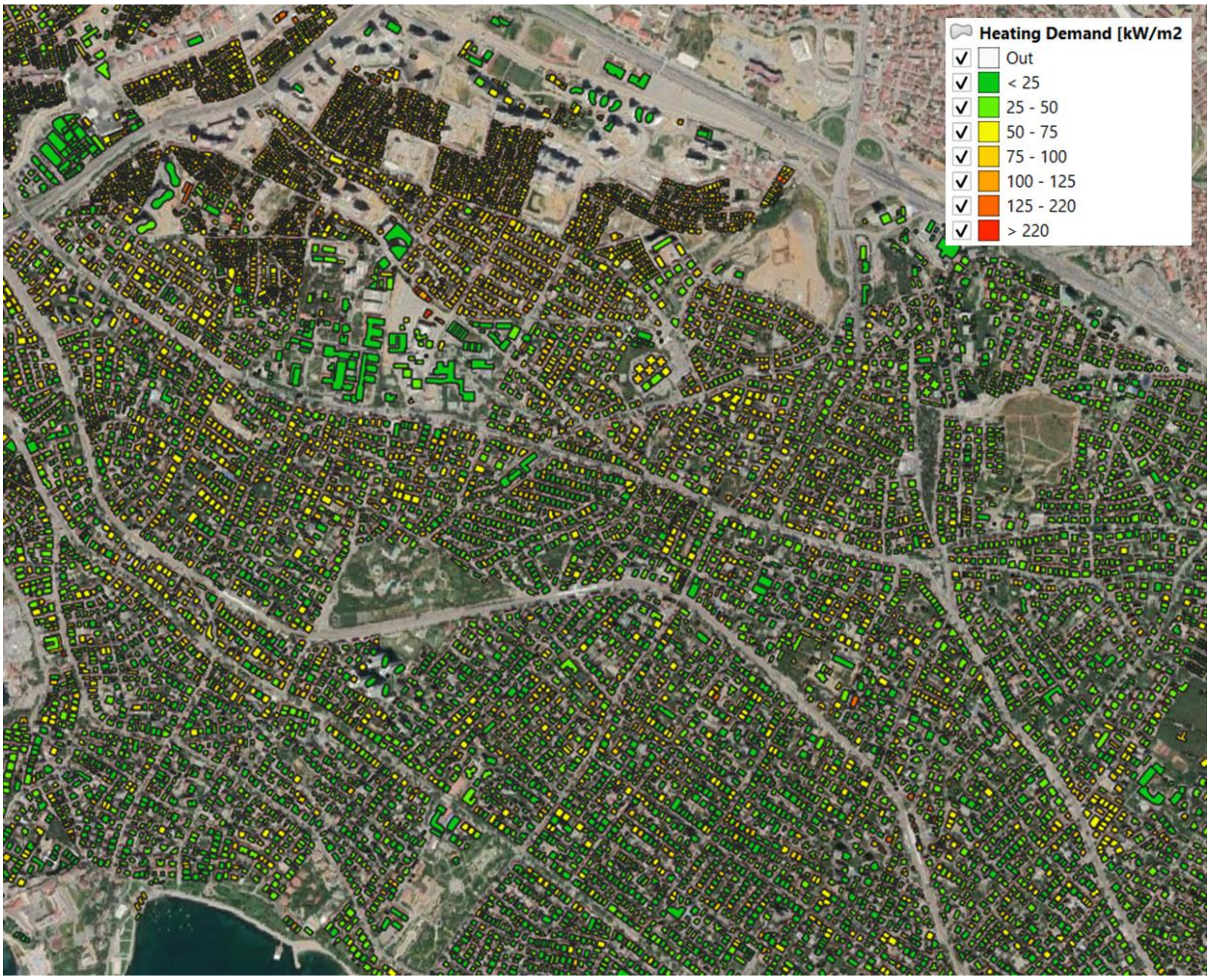


Figure 35: Modelling results, heat demand of the buildings in the city of Kadiköy (kWh/m²).

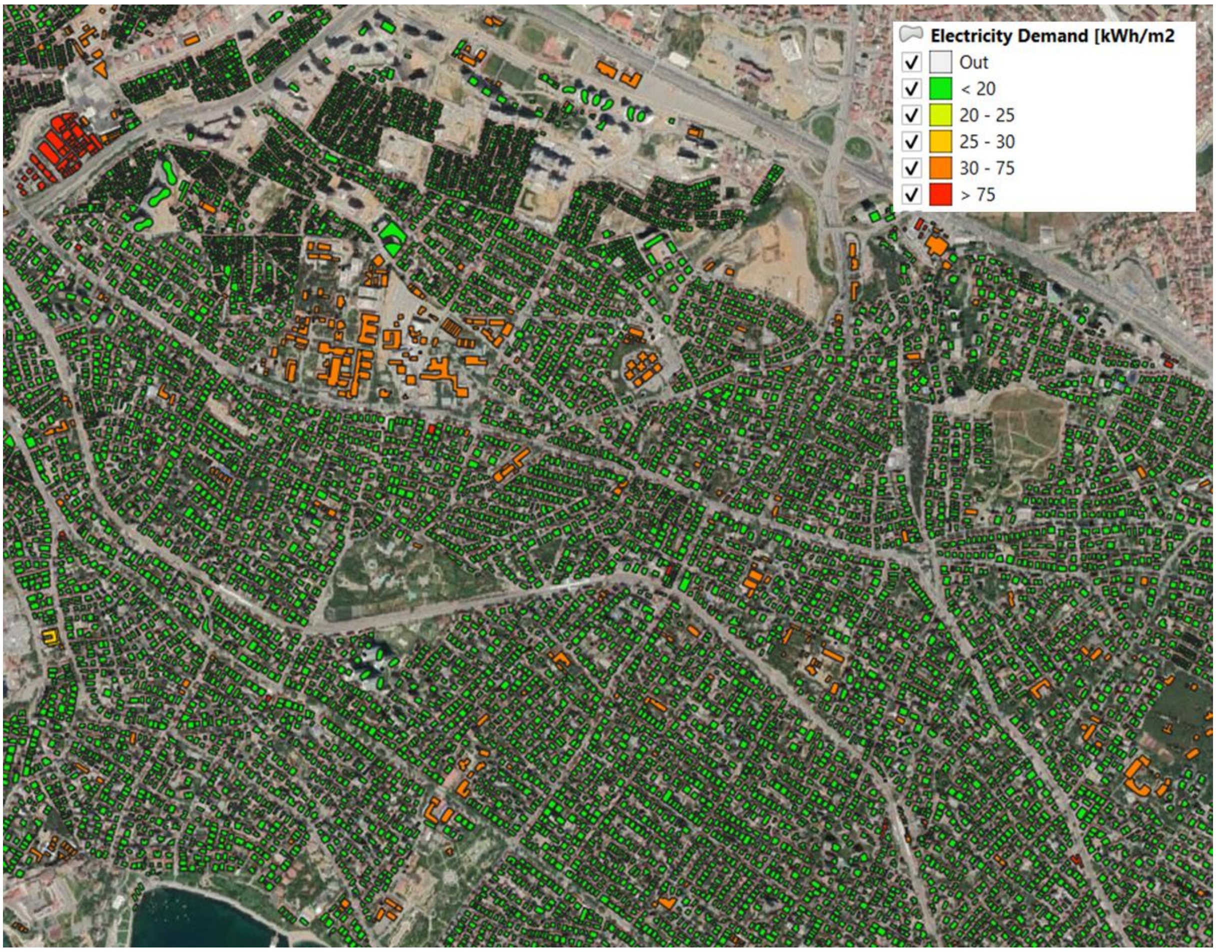


Figure 36: Modelling results, electricity consumption of the buildings in the city of Kadiköy (kWh/m^2).

León

The main results obtained from the bottom-up energy modelling of the city of León are described here. As mentioned in the previous cases, the resulting shapes, databases, the CityGML and the online visualization have been provided to the city of León.

The following information sources have been provided by the municipality. All this data has been evaluated to obtain the basic information of the buildings of the city.

Table 23: Origin of the data for the city of Leon

Content	File name	Description
Buildings	BuildingParts.shp	Obtained from the spanish cadastre
Data	Formato_CAT_tipo15_20071.xlsx	Information to be combined with the building parts
EPC	19_10-09_datos leon-eren_Coord.csv	EPCs - transformed into GIS using the coordinates

On the basis of this data, Tecnalia has carried out the pre-processing and refining of the data so that it can be used for energy modelling in Enerkad. In the case of the city of Leon, the input data has required very complex and time-consuming processing, as the necessary data came from different data sources and in different formats.

The geometry of the buildings is obtained from the electronic site of the Spanish cadastre [101]. However, this geometry, BuildingParts.shp, does not have the necessary level of disaggregation (a single geometry per building) and does not include some of the required data (use and year of construction), so it will be necessary to obtain them from the CAT file, a flat ASCII text file that can be imported into an Excel file, also obtained from the electronic site of the Spanish cadastre using the cadastral reference level, which is also the parameter through which the new geometry will be generated.

For the construction year, the average construction year of all the building parts of each cadastral reference is calculated, while for the building use, the predominant use in each cadastral reference is selected. Once these parameters have been obtained, they are transferred to the shape file.

The next step is to obtain a valid geometry, unifying all the building parts, for which it is necessary to eliminate small geometries, patios or other elements that may distort the final geometry. The selection is made by establishing a series of exclusions based on the number of floors and the percentage of adjoining facade surface, which is obtained by means of a java process. Once these small geometries have been eliminated, the number of floors weighted by the surface area of each building part is calculated for each cadastral reference. All the parameters required for the simulation are then obtained and all the building parts are dissolved according to the cadastral reference, so that a single geometry is generated for each building.

Figure 37: Example of the buildings before (pink) and after (green) the cleaning process

This process is performed simultaneously for all the buildings in the city and results in a geometry of considerable quality for the downtown area. However, in some types of buildings, such as single-family homes in locations that are far from the downtown area, the geometries obtained are not so adequate.

Figure 38: Poor definition of the Single Family house geometries

With the information obtained in this processing, a basic simulation can be carried out in Enerkad, in which the energy demand for each building is calculated. However, in the case of Leon, the energy certificates are available, allowing the energy systems and fuel used to be included, and therefore the consumption and associated emissions to be calculated.

The information in the energy certificates also has been adapted for the inclusion as in this case the information is given at the dwelling level and, as well as the geometry, has to be defined at the building level. The EPCs are not available for all the buildings within the city, and so that, the information is extrapolated from the available ones to the rest of the buildings.

The following figure shows an example of the resulting layer for a specific area of the city of León. This process has been carried out for the entire city.

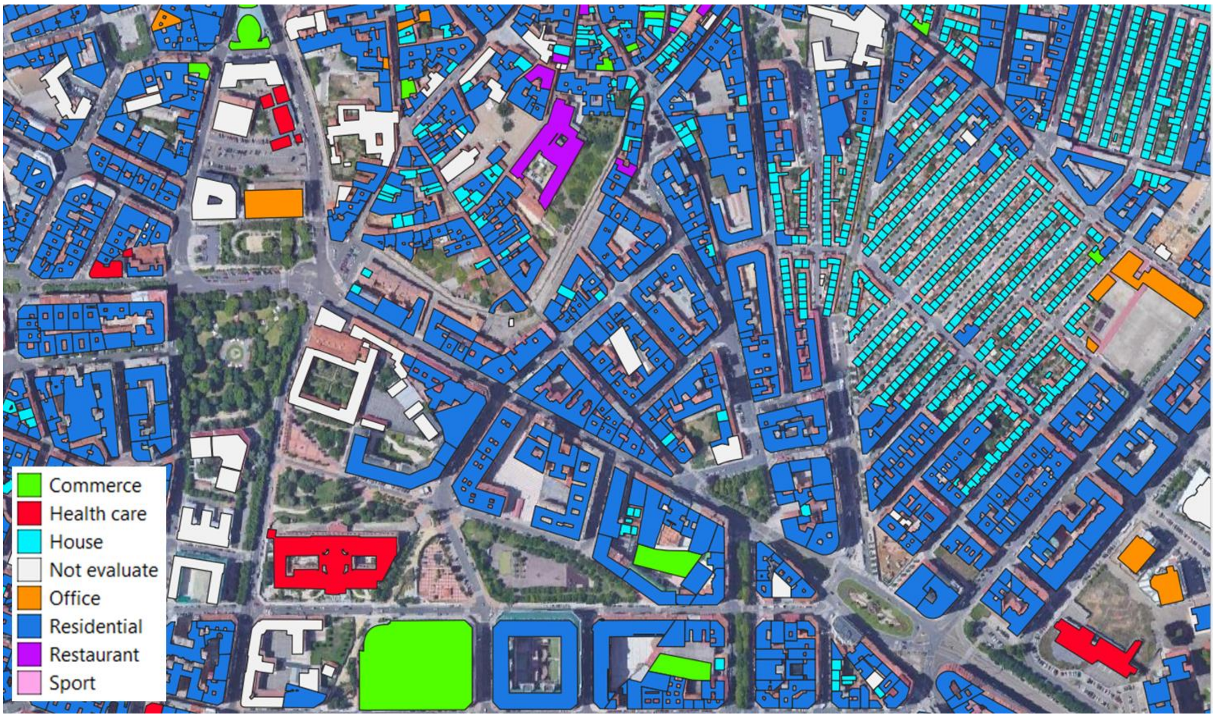


Figure 39: Example of the uses of the buildings for an area of the city of Leon

Once the tool's database has been adapted to the characteristics of the city, the results are compared with other models or data sources, and with data related to the energy certificates of buildings when available. The adjustment process has been carried out taking into account the following information sources:

- Data source 1: Energy performance certificates as tools for energy planning in the residential sector. The case of La Rioja (Spain) [102].
- Data source 2: Estudio de la distribución del consumo energético residencial para calefacción en España [103].
- Data source 3: Energy certificates of buildings in the city of León provided by the municipality.

The figure below, shows the primary energy consumption per construction period in the E1 climatic zone for apartment blocks. More precisely, the comparison between modelling results respect to the data available in literature (data source 1) can be appreciated. It can be seen how the tendency of the average values of the modelling correspond well by periods with respect to this reference. Differences of between 5% and 22% are obtained. In the case of single-family houses, the discrepancies between the input data geometry and the reality are higher and therefore specific cases of buildings have been observed in which the differences with respect to this data source are somewhat greater. Other sources of inaccuracy observed in this case are related to the low accuracy on the height of the buildings in some cases (some assumptions were made in the data pre-process step) and the lack of data related to the buildings that have already been refurbished.

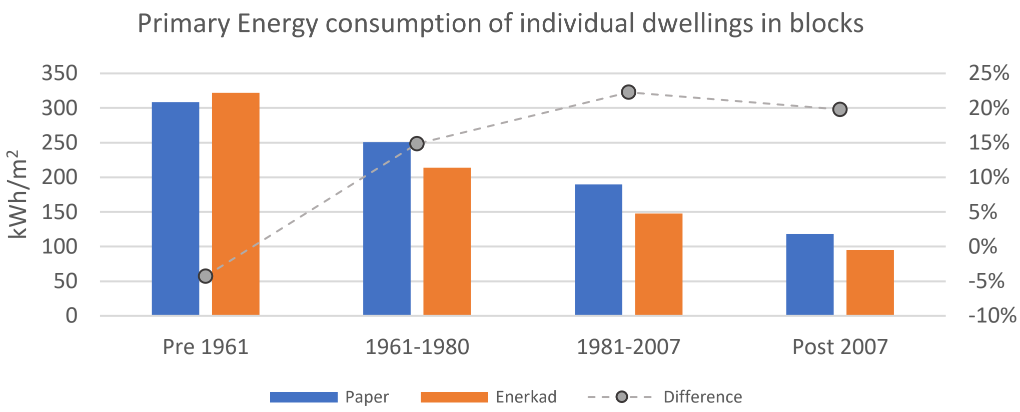


Figure 40: Primary energy consumption per construction period modelling results vs data source 1 [102].

The simulation results have also been compared with the values available in the energy certificates. In this case, as in the first comparisons, the correspondence of the results is better in the case of building blocks than in the case of single-family houses. In the case of single-family houses, the form factor is a parameter with a great impact on the results. The quality of the geometry for this type of building is lower in the city, so the accuracy of the results obtained will also be lower in this case.

It is important to take into account also other factors such as the accuracy of the input data and the comparability of the information against which the results are compared. In the case of energy certificates, the information they provide may be in many cases very specific (dwelling scale of the energy certificates vs the building block scale of the modelling) and inaccurate in some cases [104]. There are several analyses [105], [106], [107] which show that actual energy consumptions can differ greatly from the data provided in energy certificates, especially in limit cases such as the A certificate, where the actual consumption is usually higher than the theoretical one, or in the cases of F and G, where actual consumption may be even half of the estimated one.

In fact, the results obtained from modelling in the project are more in line with this than the values of the energy certificate. This can be seen in the following figure where in the right part it can be seen a flatter curve between the different degrees of certificate in the case of energy modelling with Enerkad that in the case of the energy certificates.

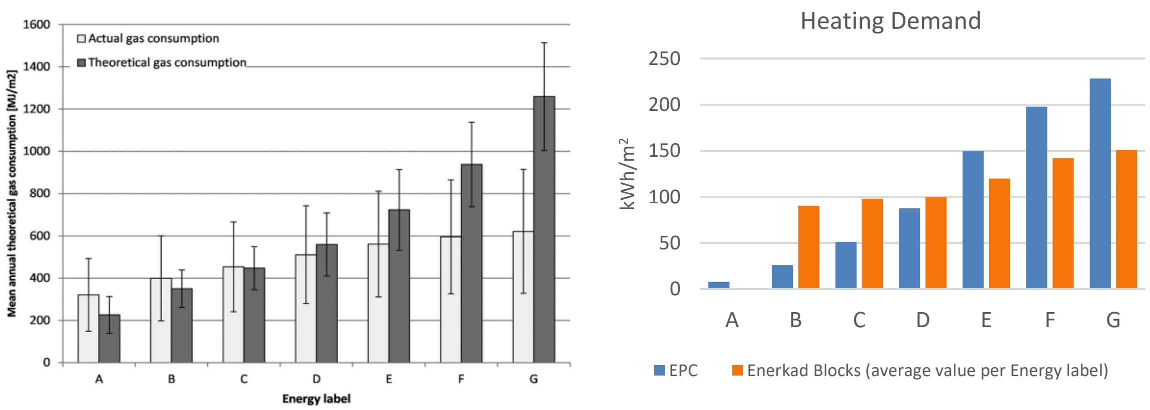


Figure 41: Actual gas consumption vs theoretical gas consumption from [105] **(left). Heating demand in residential buildings, modelling results vs energy certificate values (right).**

The following figure shows the modelling results for the buildings of the city of León. Results are shown as energy consumption density in kWh/m².

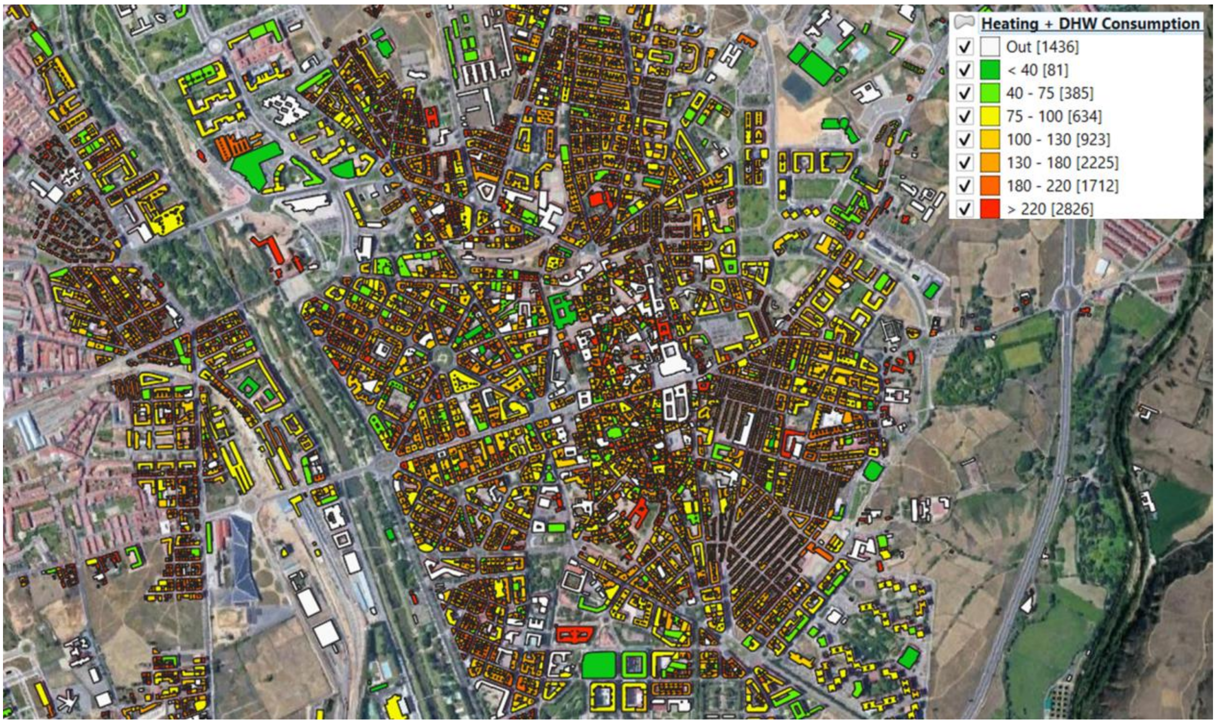


Figure 42: Modelling results, energy consumption for heating + DHW in the city of León (kWh/m²).

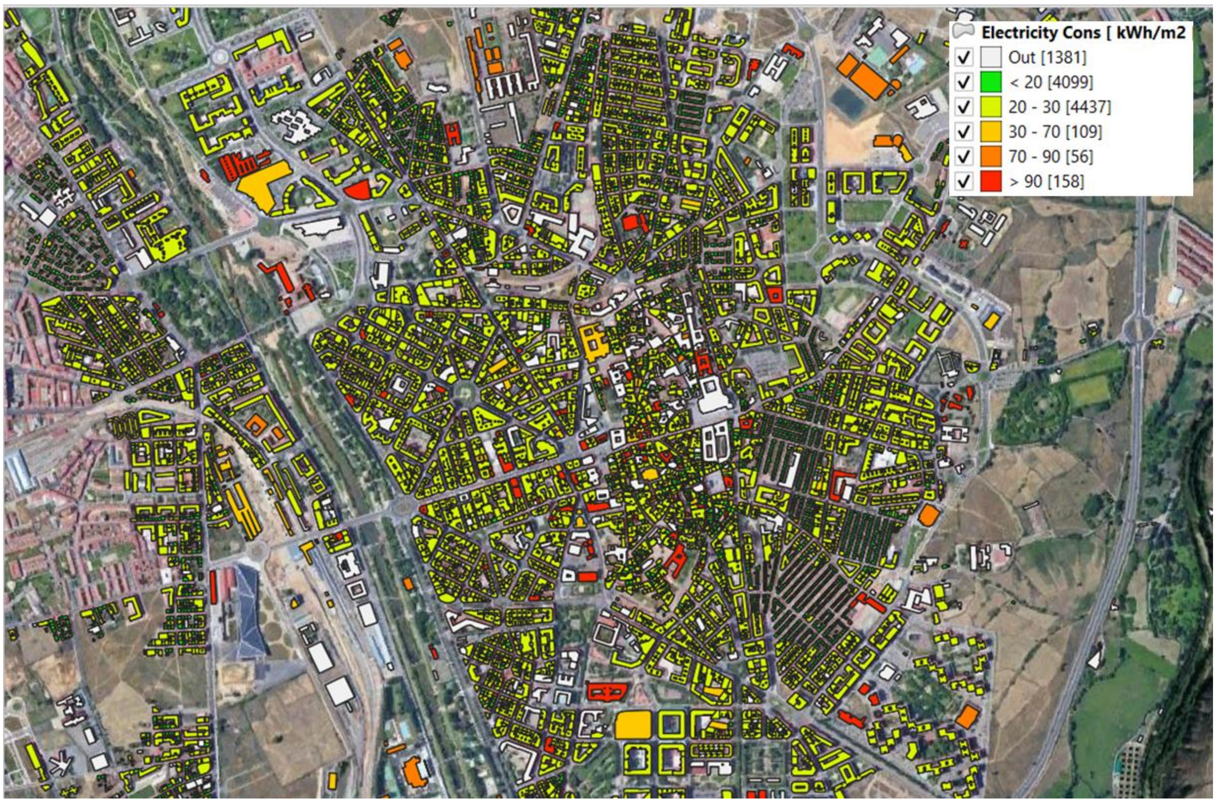


Figure 43: Modelling results, electricity consumption[5] of the buildings in the city of León (kWh/m²).

[5] Electricity consumption for lighting and equipment

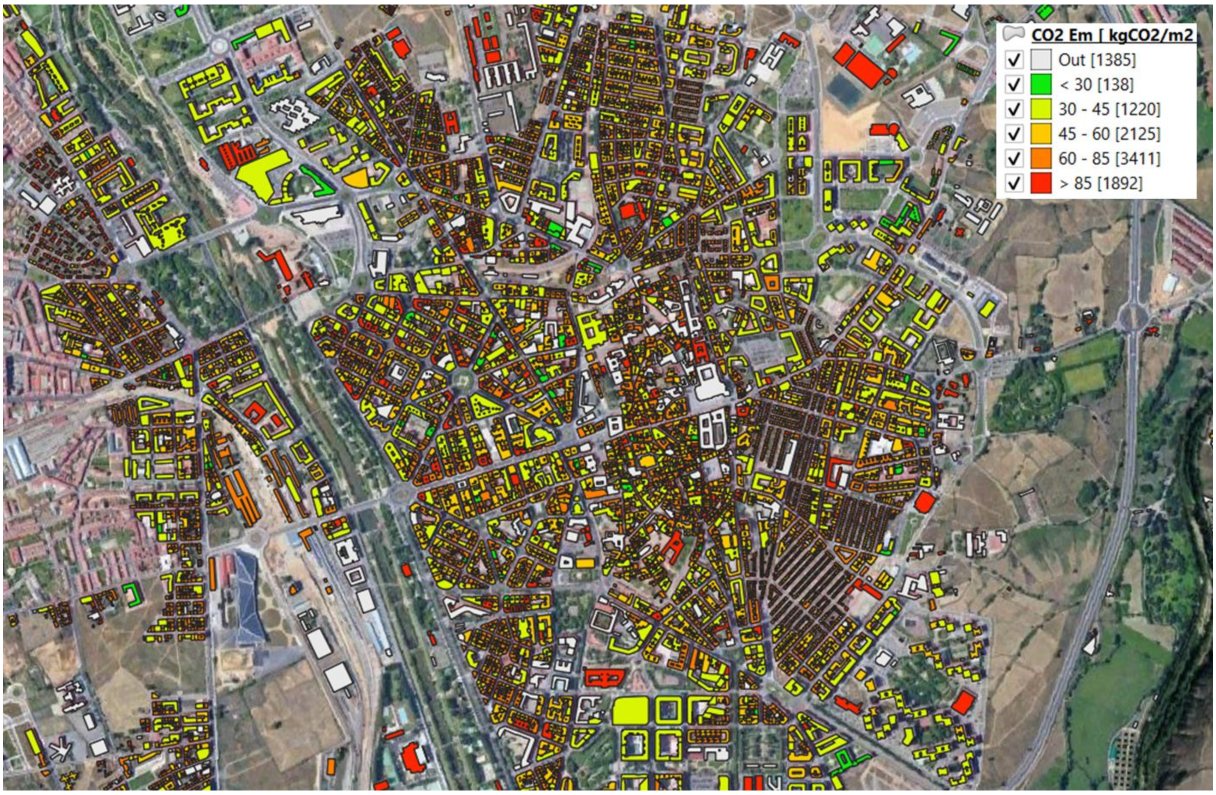


Figure 44: Modelling results, environmental impact associated to the total energy consumption of the buildings in León (kg of CO_2 equi.).

Lublin

This section includes a description of the main results obtained from the bottom-up energy modelling of the city of Lublin (the resulting shapes, databases, the CityGML and the online visualization have been provided to the municipality).

The basic data provided by the municipality for the construction of the geometry of the buildings in the model is the following:

Table 24: Origin of the data for the city of Lublin

Content	File name	Description
Buildings	eg_budynki_polyg.shp	Complete information for the whole city

On the basis of this data, Tecnalia has carried out the pre-processing and refining of the data so that it can be used for energy modelling in Enerkad. In this case, no intense treatment or combination of various layers was necessary, instead a single input file containing all the necessary information was used.

The uses have been translated into English, and the years of construction have been completed from the values of the nearby buildings for those buildings that did not have information.

Finally, the overlaps between geometries have been removed, the area has been calculated and those geometries with an area under 30m^2 have been excluded.

The following figure shows an example of the resulting layer for the city of Lublin.

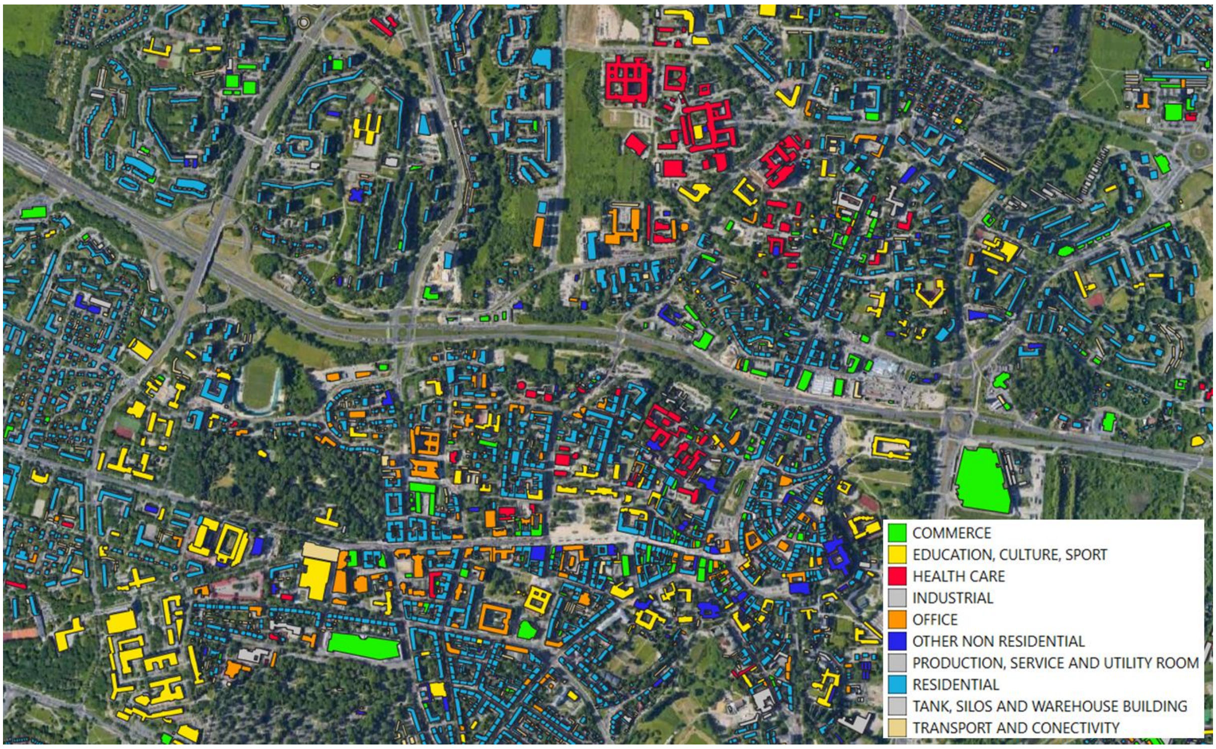


Figure 45: Example of the uses of the buildings for an area of the city of Lublin

The database of the Enerkad tool was adapted to the specific characteristics of the city. Then, results are compared with other data sources available, which in this case include data from literature with extra data provided by the municipality. The following information sources have been considered for the adjustment process:

- Data source 1: Energy Efficiency trends and policies in Poland in years 2006-2016 prepared in framework of ODYSSEE- MURE project [108]. Data used for residential buildings.
- Data source 2: NEEAP Poland [109]. Data used for residential buildings.
- Data source 3: BPIE [95]. Data used for residential and tertiary buildings.
- Data source 4: TABULA Web tool [75]. Data used for residential buildings.
- Data source 5: Energy related data provided by the municipality
- Data source 6: Odyssee Mure [110]. Data used mainly for residential buildings.

On the left of the figure below, the energy consumption of residential buildings per final use is showed. More precisely, the comparison between modelling results respect to the data available in literature (data source 1) can be appreciated. It can be appreciated how the modelling results correspond well with this data. Differences of between 0,5% and 13% are obtained. On the right side of the figure below on the other hand, the comparison between the data provided by the municipality respect to the modelling result is shown. The analysis show differences between less than 5% and 15% depending on the year of construction period evaluated.

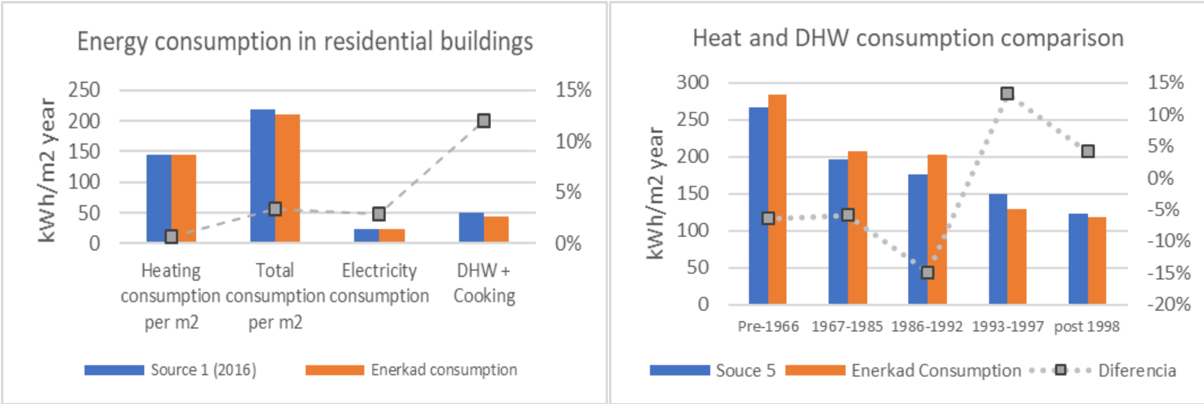


Figure 46: Energy consumption (data source 1) vs modelling results (left). Heating and DHW energy consumption in residential buildings, modelling results vs data provided by the municipality (right).

Apart of these two examples, the rest of the analysis show a great correspondence of the results respect to the data available in the literature. Differences between 7% and 9% in the case of the data source 2 evaluated, differences between 1% and 25% for the data source 3, differences between 1,3% and 17% for the data source 4, and differences between 2% and 10% for the data source 6.

The following figures shows the modelling results for the buildings of the city of Lublin. Results are shown as energy demand density in kWh/m^2.

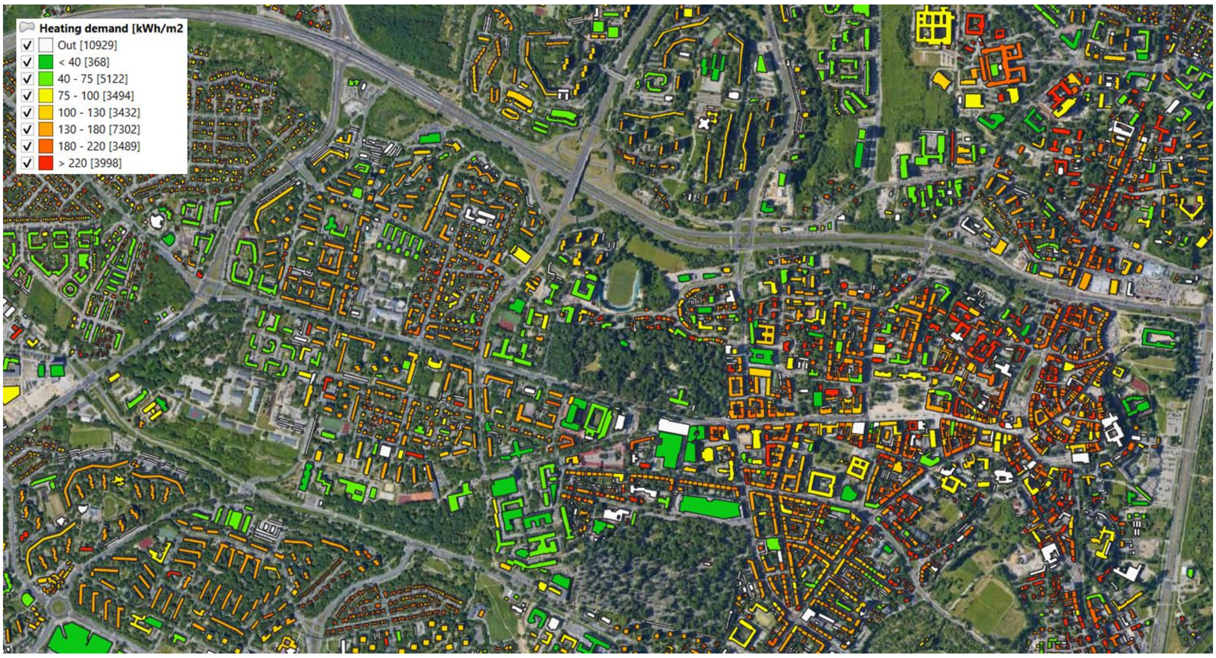


Figure 47: Modelling results, heat demand of the buildings in the city of Lublin (kWh/m^2).

Figure 48: Modelling results, electricity consumption of the buildings in the city of Lublin (kWh/m²).

Trenčín

In the case of the city of Trenčín, energy modelling has been carried out, as in the previous cases, for all the city's buildings (excluding industrial and singular buildings). Among the results obtained and provided to the municipality, both thermal and electrical energy demands stand out. These results are provided for each of the buildings, taking into account their specific features such as geometry, use, date of construction, etc. All these results are provided as attachments to this deliverable. Among these files are, as for the rest of the cities, the shape files, the CityGML, the databases and the web viewer.

For the construction of the basic characteristics of the model, the city has provided the following information;

Table 25: Origin of the data for the city of Trenčín

Content	File name	Description
Buildings	BudovaMurovana_Plg.shp	Geometry without semantic
Buildings	TN_budovy.shp	Includes Use and height

On the basis of this data, Tecnalia has carried out a process of pre-processing and refining the data so that it can be used for energy modelling in Enerkad. In this case the information is defined in 2 layers. From the Budova Murovana layer, the geometry is used, and the use and predominant height for each of the defined geometries is assigned.

The information of the year of construction of the buildings has been defined by zones by the municipality and subsequently assigned to all the buildings.

Finally, the information has been completed for the buildings that did not have any of the parameters according to the values of these parameters of the nearby buildings.

The following figure shows an example of the resulting layer for the city of Trenčín.

Figure 49: Example of the uses of the buildings for an area of the city of Trenčín

This basic modelling includes the most relevant information regarding the geometry of the buildings, as well as some semantic information regarding the use or number of houses, among others.

This initial basic modelling is completed for each of the buildings from the Enerkad database which has been adjusted with specific information for the city of Trenčín (climate data, characteristics of the envelope of buildings depending on the use and the age, etc.) as described in the introductory part of this section.

Once the model has been built in its entirety, the simulations that provide the hourly energy characterisation of each building for the base year under evaluation are carried out. These results are compared with the reference information available for the city.

In this case, the available data sources are the following:

- Data source 1: EU Buildings Factsheets – Slovakia [111]
- Data source 2: ODYSSEE [110]
- Data source 4: Data provided by the municipality of Trenčín. Data related to the electricity consumption in households and the distribution of this consumption per final use.
- Data source 5: EU building database. European Commission [100]

The following figure shows the results of the comparison of some of the energy results obtained from the project modelling with the different data sources mentioned. Although the degree of detail of the literature data is not very high (lack of values for different building uses and different construction periods), a good correlation is observed in general terms.

Table 26: Energy characterization comparison (different data sources vs modelling results)

Reference from the literature	Parameter evaluated	Value from literature	Modelling result (Enerkad)
EU Building Factsheet	Residential energy consumption (kWh/m^2)	170	194

ODYSSEE	Total consumption per dwelling (kWh/m^2)	163	194
	Electricity consumption (kWh/m^2)	27	27
	Heating consumption (kWh/m^2)	104	132
Data from municipality	Energy consumption of lighting (kWh/m^2)	6	5
	Energy consumption of appliances (kWh/m^2)	19	19
EU building database	Heating (kWh/m^2)	102	132
	Total consumption (kWh/m^2)	150	194

The following figures serve as examples of the type of results obtained in the energy characterisation of the city. In this case, as far as the thermal needs are concerned, it has only been possible to model in detail the energy demands of the buildings (not final energy consumption). This is due to the fact that no information on the energy systems and fuels used for the buildings of the city is available for Trenčín.

Figure 50: Modelling results, heat demand of the buildings in the city of Trenčín (kWh/m^2).

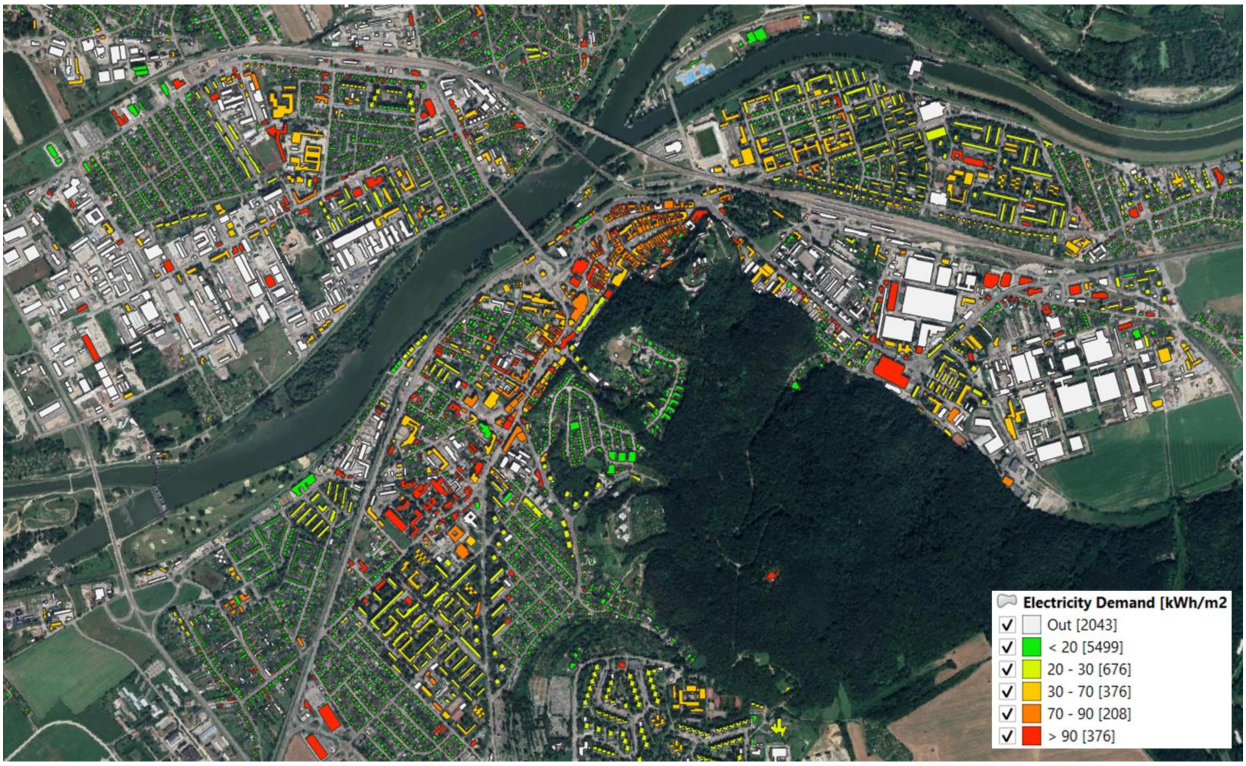


Figure 51: Modelling results, electricity consumption of the buildings in the city of Trenčín (kWh/m²).

Vidin

Finally, in the case of the city of Vidin, the energy characterisation of the city's buildings has been carried out following a process equivalent to that of the other cities described above. In the same way, the municipality has been provided with a series of files attached to the deliverable. This section focuses on describing the main aspects of the work carried out by showing the main results in a visual way.

For the construction of the basic characteristics of the model, the city has provided the following information;

Table 27: Origin of the data for the city of Vidin

Content	File name	Description
Buildings	10971_BUILDING.shp	Geometry with use and height

On the basis of this data, Tecnalia has carried out a process of pre-processing and refining the data so that it can be used for energy modelling in Enerkad. In this case the information is defined in a unique layer which contains almost all the needed information, only the information related to the construction year was missing. This data has been provided by the municipality in an image divided by zones and has been transferred to each building in the shape file.

After the information was completed, the corresponding spatial reference has been assigned and all geometries with an area of less than 20m^2 have been removed.

The following figure shows an example of the resulting layer for the city of Vidin.

Figure 52: Example of the uses of the buildings for an area of the city of Vidin

This basic characterisation is completed in the following case with a more specific characterisation of all the characteristics of each of the buildings evaluated that influence the energy analysis.

Once the model generated for the city has been simulated, the results obtained are compared with the energy consumption data available for the city. In this case, the following data is available;

- Data source 1: TABULA Webtool [75]
- Data source 2: Building stock characteristics and energy performance of residential buildings in Eastern-European countries [112]
- Data source 3: NEEAP Bulgaria [113]
- Data source 4: EU Buildings Factsheets [114]
- Data source 5: ODYSSEE [110]

The following figure shows, by way of example, the results of the comparison carried out for two of the sources evaluated. In both cases the differences observed are less than 15%.

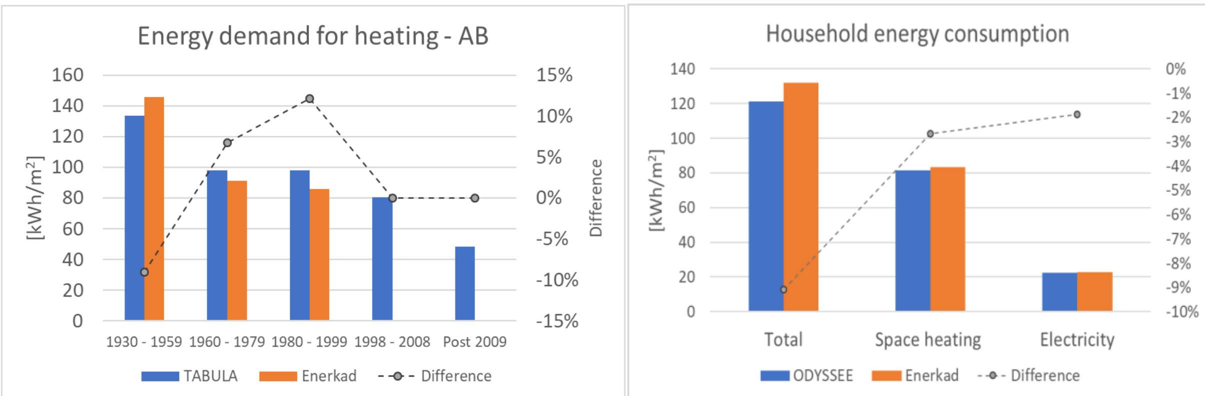


Figure 53: Energy demand comparison for apartment blocks (data source 1: Tabula) vs modelling results (left). Energy consumption comparison (data source 5: ODYSEE) vs modelling results (right).

Something relevant to consider in this case is that the energy consumption in the residential sector in Vidin is relatively low, because of the fact that many people are unable to maintain optimal comfort in their home because of the low incomes and energy poverty (this is distinctive feature for big part of the population - about 45% of the district's population lives below the national poverty line). This is an aspect that is difficult to reflect in the model at the level of individual buildings since there is no specific information on which buildings or even dwellings are in such a situation.

This is something to take into account when aggregating the energy consumption of houses in the city, especially if large areas are considered. What happens in this case is that the difference between the energy demand of homes, understood as their energy needs according to their use and specific characteristics, may differ more significantly than in other cities from their actual energy consumption. In any case, as no specific information is available on energy systems or the fuel consumed by each of the buildings, energy modelling has focused on the analysis of energy demands.

The following figures serve as examples of the type of results obtained in the energy characterisation of the city.

Figure 54: Modelling results, heat demand of the buildings in the city of Vidin (kWh/m²).

Figure 55: Modelling results, electricity consumption of the buildings in the city of Vidin (kWh/m²).

Appendix IV - City energy system modelling for long-term planning

As explained before, the development of the Energy Systems Model (ESM) for each city has been carried out founded on two steps. First, with the information required to the cities the energy balance was established for a reference year. Second, the construction of the BaU scenario was developed by establishing a set of assumptions on socioeconomic drivers, historical trends of demands, and technology data disaggregation, among others. During this process, cities' feedback has been considered in order to enrich the BaU narrative, thus strengthening the baseline storyline of the cities. After closing such discussion periods on data validation and assumptions with the cities, current report has been carried out including an excerpt of some of the most representative results for each of the BaU scenarios of the cities.

It should be remarked that according to the expectations of the cities and the analytical robustness of ESMs performed, extra results and potential adjustments (due to COVID-19 effects in terms of volatility, for instance) could be incorporated during Task 1.5 development.

Oulu

The ESM of the city of Oulu (Finland) has been created for the purpose of Making City project. The **reference year selected is 2017**, last year with enough data. Deviation between such reference year and present time has been adjusted using available data from the municipality. Potential mismatches between energy outcomes for in between years (2018, 2019, 2020) are accepted since they do not entail substantial changes in long-term trends.

As explained previously, to develop the ESM it is necessary to establish the most detailed energy picture of the city for the reference year and subsequently taking projections of the demands to 'evolve' that energy system into the future. To do so it is required to base some hypotheses on the expected behaviour of some socioeconomic drivers such as population, Gross Domestic Product (GDP), households' number, etc. (see Table 28).

Table 28: Hypotheses on key drivers assumed for the city of Oulu

Driver	2017	2018-2050
Population	201,810	Values assumed by the municipality (*). A slow decline has been considered since 2040. 2018: 203,567 2019: 205,179 2020: 206,857* 2025: 213,424* 2030: 218,464* 2035: 221,466* 2040: 222,167* 2050: 221,627
GDP	8,003.5 M€	2020: -6.90% 2021: +3% 2022: +2.90% 2023: +2.55% 2024: +2.20% 2025: +1.85% 2026-2050: +1.50%

		Source: https://www.bofbulletin.fi/en/2020/3/finland-s-economy-will-gradually-recover-from-the-sudden-shutdown/
GDP per capita	37,410€	Values assumed by the municipality. Derived from the relationship GDP/Population
Households	97,284	Housing blocks stock growth: 1,72% annually Single Family Houses stock growth: 0,94% annually

Besides, it is required to declare some assumptions about the specific behaviour of the economic sectors, sub-sectors, technologies and/or fuels. These assumptions are founded on establishing a realistic Business as Usual (BaU) scenario and they mix historical trends, binding commitments, and some constraints, but they should not include expectations. Those expectations will be modelled through alternative scenarios in terms of technology penetration, extra enforcement of emission limits, changes in fuels use, etc. The following Table 29 shows the main assumptions taken in the case of Oulu to perform the energy demand projections.

Table 29: Hypotheses on assumptions to make demand projections for the city of Oulu

SECTOR	ASSUMPTION
Residential	Residential sector is divided into housing blocks and houses. Stock of "housing blocks" grows 1,72% per year due to the entrance of new buildings (both for pre-2030 and post-2030 buildings). Stock of "houses" grows 0,94% per year due to the penetration of new buildings (both for pre-2030 and post-2030 buildings). Refurbished buildings (both houses and housing blocks) replace old buildings from the initial stock and apply energy efficiency measures. Considered refurbishment rates with respect to the initial stock are: 0.5% refurbished buildings per year until 2030, and 1% afterwards (https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/renovation-wave_en). New and refurbished buildings have their own energy needs and energy systems and specific details are included within the LEAP model
Tertiary	Every private and public end-use energy service (heating, cooking, DHW, lighting and appliances) is based on historical trends. Public services related with space heating and district hot water are assumed to grow 1.6% per year up to 2030 and 1% per year afterwards. Lighting and appliances grow 1.32% per year during the entire modelling horizon. Private services related with space heating and district hot water are assumed to grow like GDP does. Lighting and appliances grow 1.32% per year during the entire modelling horizon.
Outdoor lighting	Outdoor lighting is modelled as a separate sector. The energy consumption evolves according to the installation of new devices and renovation of the old ones. New devices will be LED and their installation rate is assumed to follow the population behaviour until 2040, when new devices are not added (according to the slow decline in population). The renovation of the old devices to LED is assumed to be completed by 2030.
Industry	The entire industry sector (in here means chemical and pulp & paper plants) behaves according to the GDP behaviour until 2025. After this date the energy consumption growth is assumed to slowly decline due to increases in efficiency: 2018-2025: growth as GDP; 2025-2030: 1%/yr; 2030-2040: 0,5%/yr; 2040-2050: 0%/yr (based on experts estimates and EU trends for countries). No extra measures are considered herein.
Transport	Transport by rail is assumed to evolve like population does. Transport by road – public – is assumed to evolve like population. Transport by road – private – cars – is assumed an annual 1.7% based on historical trends (within cars, it is assumed a conservative share of 14% EV in 2050) Transport by road – private – motorcycles & mopeds – is assumed to decrease up to 5,000 units by 2050 based on historical trends (with a 23% electric in 2050) Transport by road – private – vans – is assumed to increase up to 15,000 units by 2050 based on historical trends (with a 14% electric in 2050) Transport by road – private – trucks – is assumed to increase up to 3,250 units by 2050 based on historical trends (with a 17% electric in 2050) Transport by water – is assumed to evolve like population.

	Transport by air – is assumed to evolve like population.

Regarding the assumption from Table 29 it is necessary to add some extra details on the residential sector. Thus, by using the data provided by the municipality besides Enerkad tool (see previous Section) to make some validations, Table 30 has been included with specific assumptions by building type (housing blocks and single family houses) and by conceptualisation (current buildings, refurbished, or new buildings), considering the disaggregation of energy services (space heating, water heating) per technology.

Table 30: Assumptions on energy services for Oulu residential buildings in the BaU scenario

HOUSING BLOCKS						
		Current	Refurbished pre 2030	New pre 2030	Refurbished post 2030	New post 2030
	Energy systems/devices	Share	Share	Share	Share	Share
Space Heating	DH	90%	90%	90%	90%	90%
	Light heating oil boilers	3%	0%	0%	0%	0%
	Ground source heat pumps	0,25%	1%	3%	3%	5%
	Biomass boilers	2,75%	2%	1%	1%	1%
	Electric heaters and heat pumps *	4%	7%	6%	6%	4%
Water Heating	DH	90%	90%	90%	90%	90%
	Light heating oil boilers	3%	0%	0%	0%	0%
	Ground source heat pumps	0,25%	1%	3%	3%	5%
	Biomass boilers	2,75%	2%	1%	1%	1%
	Electric heaters and heat pumps *	4%	7%	6%	6%	4%
SINGLE FAMILY HOUSES						
		Current	Refurbished pre 2030	New pre 2030	Refurbished post 2030	New post 2030
	Energy systems/devices	Share	Share	Share	Share	Share
Space Heating	DH	26%	26%	30%	30%	30%
	Light heating oil boilers	9%	0%	0%	0%	0%
	Ground source heat pumps	2%	4%	5%	5%	10%
	Biomass boilers	30%	33%	30%	30%	25%
	Electric heaters and heat pumps *	34%	37%	35%	35%	35%
Water Heating	DH	72%	72%	75%	75%	75%
	Light heating oil boilers	8%	0%	0%	0%	0%
	Ground source heat pumps	1%	3%	5%	5%	10%

	Biomass boilers	3%	5%	5%	5%	5%
	Electric heaters and heat pumps *	15%	20%	15%	15%	10%

Note that (*) encompasses electric heaters and heat pumps other than ground source heat pumps.

With the data provided by the municipality, that will be polished and calibrated during the following Task 1.5 for the creation of the alternative scenarios –basis of the City Vision–, a set of results for the city of Oulu has been obtained. Those results are just an extract of the potential amount of results that will be exploited by the city in the preparation of its long-term energy plans. The reason for that is founded on readability concerning the present deliverable and has been agreed with the city previously. The results showed in here are those concerned on final energy demands (by sectors, and by fuels) as well as the GHG emissions. In all cases the results are plotted by the BaU scenario only according to the project schedule and commitments. Comparison with alternative scenarios (implementing measures/actions) will be performed in Task 1.5.

Figure 56 shows the evolution of the final energy demand of Oulu from 2017 to 2050 in the BaU scenario.

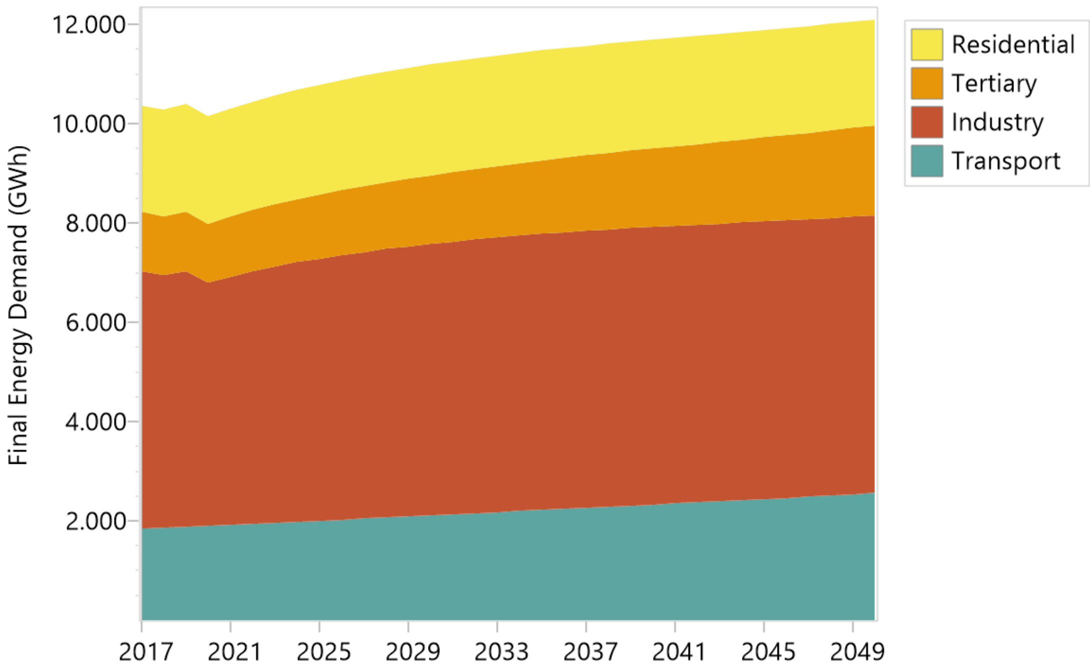


Figure 56: Oulu's final energy demand by sectors in the scenario BaU (GWh)

Results from Figure 56 show a growing trend in the long-term pushed mostly by the historical behaviour of transport. Other sectors behave stable with a flattening process occurring in the long-term 2030-2050 whereas transport energy demand is expected to grow pointing out the need to renovate this sector (e.g. phasing out fossil fuels). Figure 57 expresses the same final energy demand for Oulu but disaggregated by fuels.

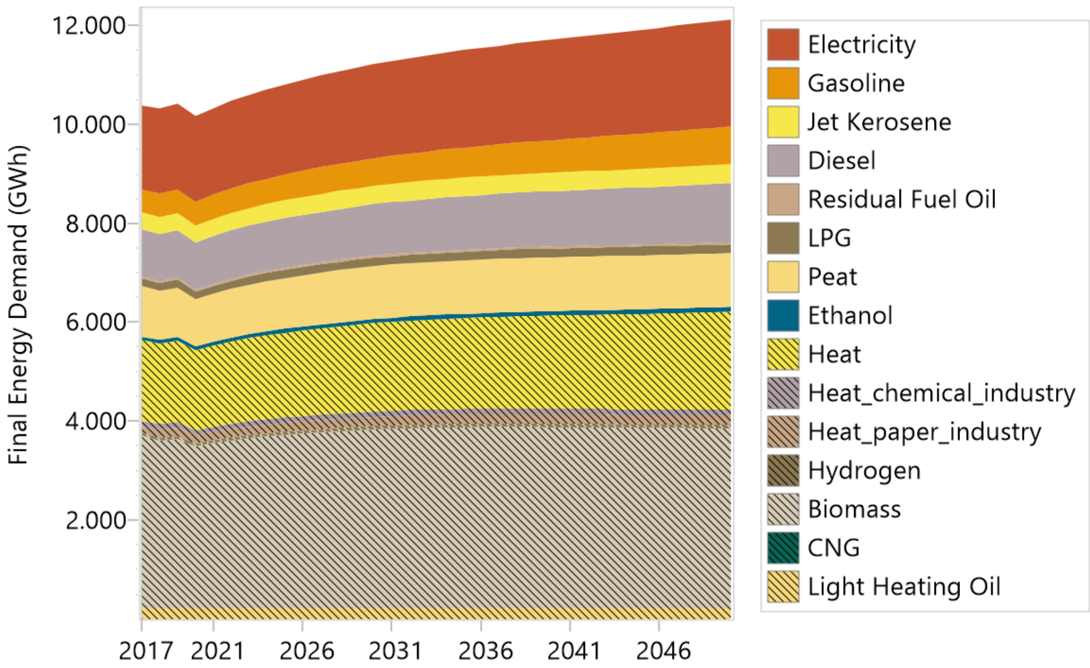


Figure 57: Oulu's final energy demand by fuel in the scenario BaU (GWh)

From a look at Figure 57 one can see the great importance of biomass in Oulu. The consideration of biomass is good from a preliminary approach regarding decarbonisation (when biomass is considered carbon neutral), however associated concerns should be considered in future analyses: other emissions, considerations about carbon neutrality shares, biodiversity issues, land use, etc.

Figure 58 shows the global warming potential (GWP) as the characterisation of GHG emissions released from the demand sectors of Oulu in the BaU scenario.

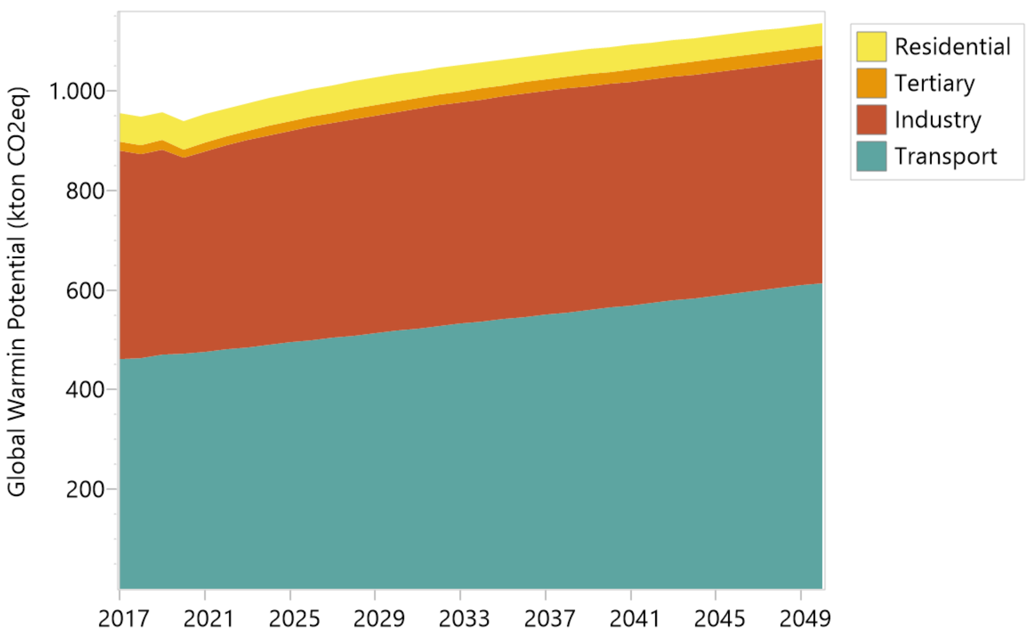


Figure 58: Oulu's global warming potential (kt CO2eq) by demand sector in the scenario BaU

Results from Figure 58 show the growing behaviour observed in Figure 57. It can be seen the growth in emissions coming from transport since this sector -in the BaU scenario- is mostly based on fossil fuels (gasoline and diesel) combustion. It is also significant the emissions coming from industry since Oulu has two large factories.

Finally, a Sankey diagram on the energy system for the reference year of the city has been included (see Figure 59).

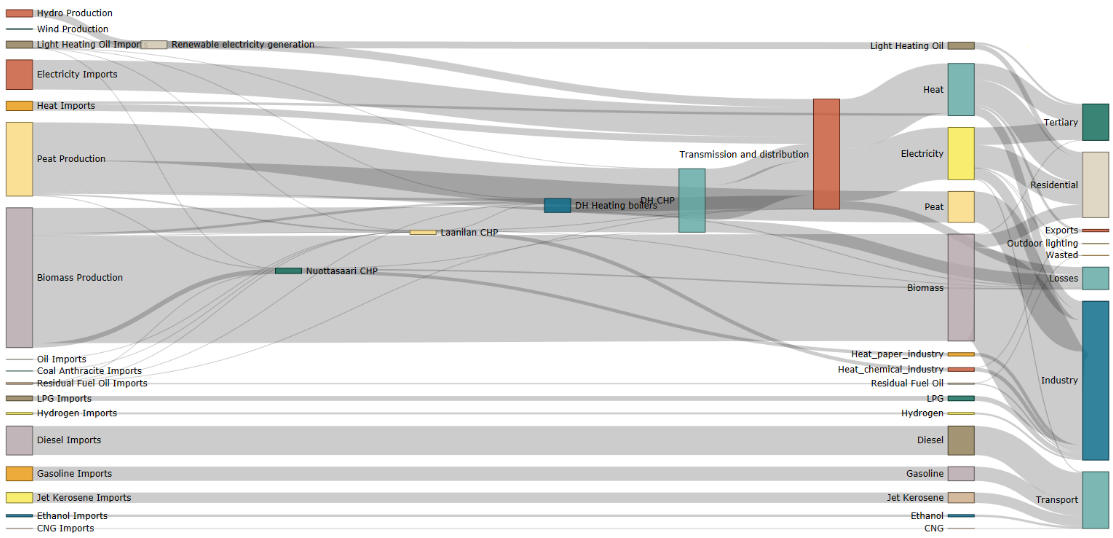


Figure 59: Sankey diagram of Oulu's energy flows in BaU scenario (2017)

Figure 59 shows the energy balance of Oulu in 2017. It is highly remarkable the amount of biomass and peat produced within the area. Those quantities are significant due to their relevance for industry as well as direct use of peat to produce electricity and heat.

Groningen

The ESM of the city of Groningen (The Netherlands) has been created for the purpose of Making City project. The **reference year selected is 2016**, earliest year with enough data. Deviation between such reference year and present time has been adjusted using available data from the municipality. Potential mismatches between energy outcomes for in between years (2017, 2018, 2019, 2020) are accepted since they do not entail substantial changes in long-term trends.

As explained previously, to develop the ESM it is necessary to establish the most detailed energy picture of the city for the reference year and subsequently taking projections of the demands to 'evolve' that energy system into the future. To do so it is required to base some hypotheses on the expected behaviour of some socioeconomic drivers such as population, Gross Domestic Product (GDP), households' number, etc. (see Table 31).

Table 31: Hypotheses on key drivers assumed for the city of Groningen

DRIVER	2016	2017-2050
Population	201,270 (growth between base year and 2020 is explained by the inclusion of Haren and Ten Boer in 2019)	Values assumed by the municipality (*); 2040, 2045 and 2050 are estimated as linear extrapolations. 2020: 233,903* 2025: 244,978* 2030: 253,594* 2035: 261,381* 2040: 268,711 2045: 276,176 2050: 283,641

GDP	23,460 M€ (NUTS 2)	Assumed annual growth rates from historical Eurostat data: 2017: 2,45% 2018: 3,86% 2019: 3% 2020: -5,7% 2021: 2,9% 2022-2030: 1,77% 2031-2050: 1,93%
GDP per capita	52,727 €	Assumed values from historical World Bank data: 2020: 56,299 2025: 59,176 2030: 62,054 2035: 64,932 2040: 67,809 2050: 73,565
Passenger-km	1863,76 Mpkm	Assumed to evolve as the population. 2020: 2173,24 2025: 2276,14 2030: 2356,19 2035: 2428,54 2040: 2496,65 2050: 2635,36
Tonne-km	945,31 Mtkm	Assumed to evolve as the regional GDP. 2020: 976,99 2025: 1078,41 2030: 1177,29 2035: 1295,37 2040: 1425,59 2050: 1725,54

Besides, it is required to declare some assumptions about the specific behaviour of the economic sectors, sub-sectors, technologies and/or fuels. These assumptions are founded on establishing a realistic Business as Usual (BaU) scenario and they mix historical trends, binding commitments, and some constraints, but they should not include expectations. Those expectations will be modelled through alternative scenarios in terms of technology penetration, extra enforcement of emission limits, changes in fuels use, etc. The following Table 32 shows the main assumptions taken in the case of Groningen to perform the energy demand projections.

Table 32: Hypotheses on assumptions to make demand projections for the city of Groningen

SECTOR	ASSUMPTION
Residential	-Every end-use energy service (heating, DHW, cooling, cooking, lighting and appliances) is based on population's behaviour affected by an elasticity of 0,35.
Tertiary	-Energy demand in tertiary buildings is assumed to evolve following the same trend as the national GDPP. -Energy demand in public outdoor lighting is assumed to evolve following the same trend as the population.
Industry	-Energy demand in every industry subsector (chemical, food, paper, central ICT, other) is assumed to evolve following the same trend as the regional GDP.
Agriculture	-Energy demand is assumed to evolve following the same trend as the regional GDP.
Transport	-Energy demand in passenger transport is assumed to evolve following the same trend as the passenger-kms. -Energy demand in freight transport is assumed to evolve following the same trend as the tonne-kms.

With the data provided by the municipality and data obtained from ETModel repository (https://github.com/quintel/etmodel), that will be polished and calibrated during the following Task 1.5 for the creation of the alternative scenarios –foundations of the City Vision–, a set of results for the city of Groningen has been obtained. Those results are just an extract of the potential amount of results that will be exploited by the city in the preparation of its long-term energy plans. The reason for that is founded on readability concerning the present deliverable and has been agreed with the city previously. The results showed in here are those concerned on final energy demands (by sectors, and by fuels) as well as the GHG emissions. In all cases the results are plotted by the BaU scenario only according to the project schedule and commitments. Comparison with alternative scenarios (implementing measures/actions) will be performed in Task 1.5.

Figure 60 shows the evolution of the final energy demand of Groningen from 2017 to 2050 in the BaU scenario.

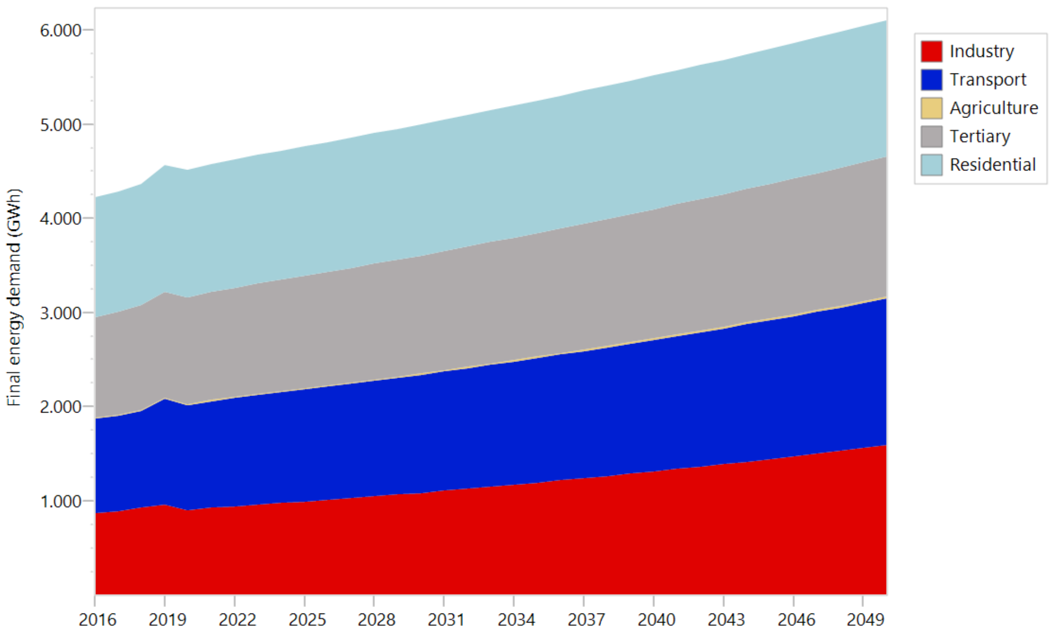


Figure 60: Groningen's final energy demand by sectors in the scenario BaU (GWh)

Final energy demand shown in Figure 60 grows in the BaU scenario narrative. This is due to the push of the transport, tertiary and industry sectors (mostly) of the city. Thus, residential sector will go from 1,281 GWh up to 1,450 GWh by 2050, while transport will vary from 999 to 1,561 GWh; tertiary sector from 1,067 to 1,488 GWh, and industry from 868 to 1,584 GWh by 2050. Accordingly, the BaU scenario evolution point out the need to implement measures in order to avoid energy consumption growth.

Additionally, Figure 61 includes the final energy demand disaggregated by fuel as an extra analysis regarding demands.

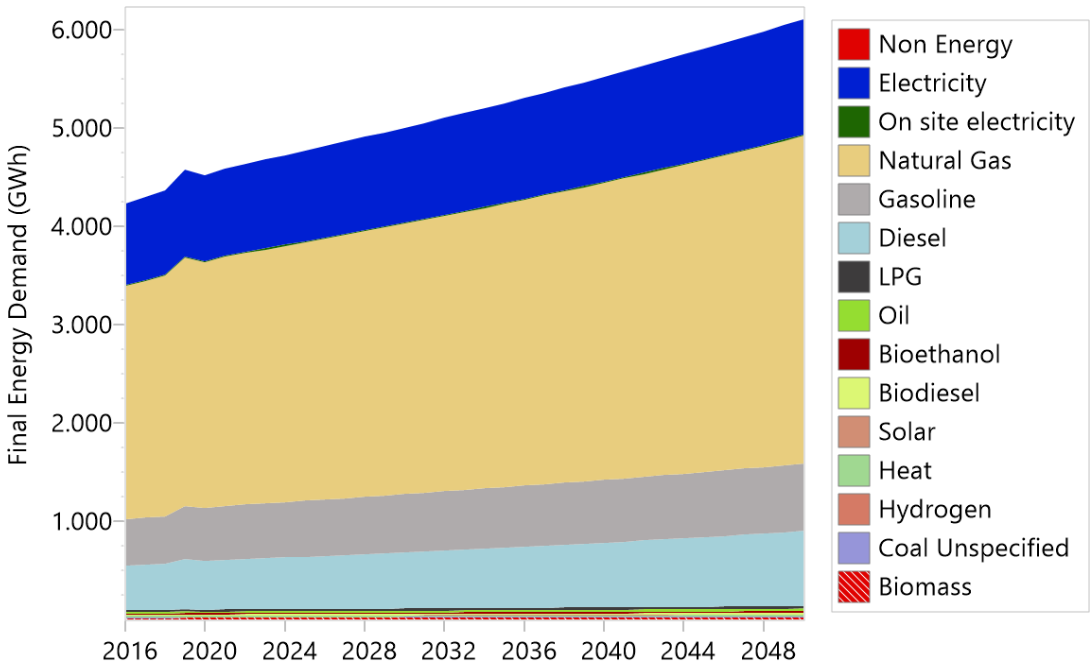


Figure 61: Groningen's final energy demand by fuel in the scenario BaU (GWh)

Figure 61 shows the evolution of fuels in the final energy demand of Groningen in the BaU scenario. Such narrative is growing and shows the huge share of natural gas within the mix (2,375 GWh). In a second term, electricity meant 825 GWh by 2016, while gasoline 472 GWh and diesel 455 GWh. If no extra measures are applied, the BaU scenario will result in a continuous increase of natural gas reaching 3,332 GWh by 2050.

Accordingly, the following Figure 62 expresses the evolution of GWP of Groningen for the BaU scenario from 2016 until 2050.

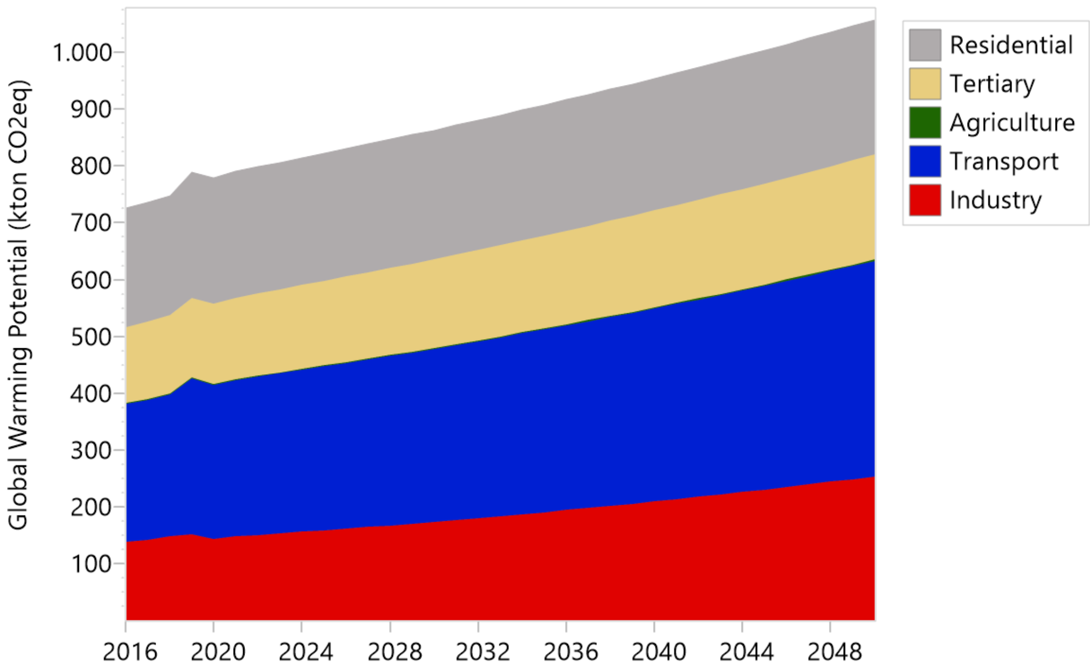


Figure 62: Groningen's global warming potential (kt CO_2eq) in the scenario BaU

The BaU scenario shows a growing trend in energy consumption with a continuous increase in the use of natural gas, diesel and gasoline. In consequence, those increases cause an increase in the GHG emissions. The transport sector is the principal emitter of Groningen (243 kt CO_2 in 2016) and if no measures are implemented to avoid it, sectoral emissions will reach up to 380 kt CO_2 by 2050 (+56%). In other sectors increases by 2050 will mean: +13% in residential; +39% in tertiary; +82% in industry. Consequently, it seems necessary to deploy measures to decarbonise Groningen attending to this undesired BaU expectations -as will be performed throughout Task 1.5 within the Making City project.

Additionally, when considering indirect emissions associated with the electricity production from the national grid, results vary significantly (see Figure 63).

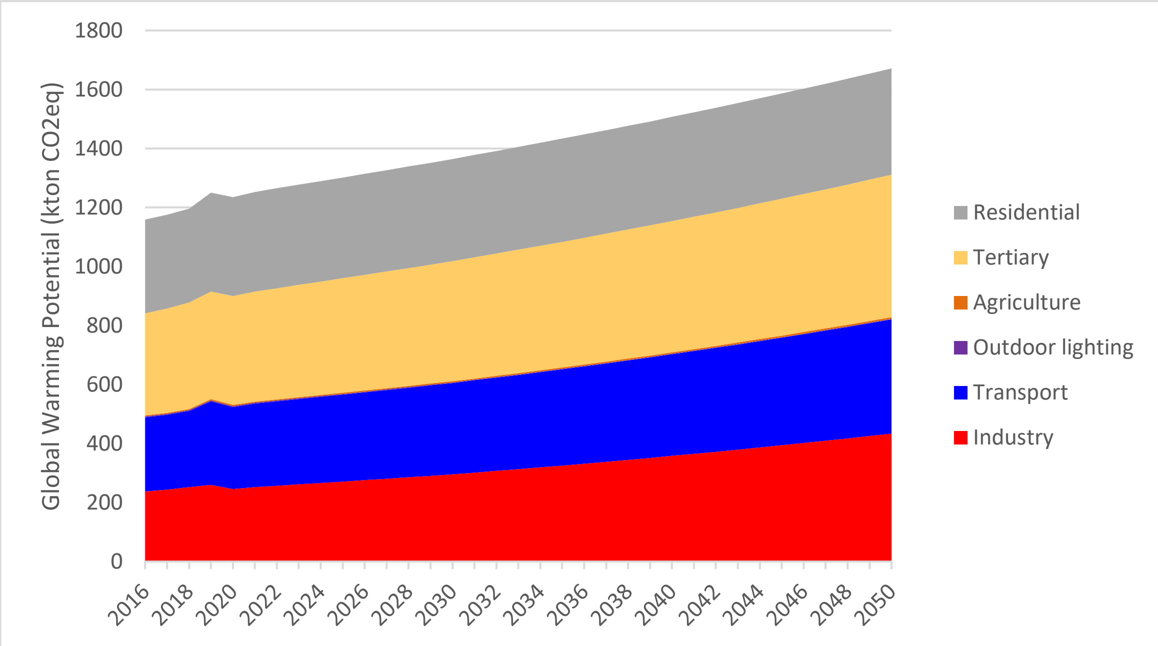


Figure 63: Groningen's global warming potential (kt CO_2eq) by sector in the scenario BaU when including indirect emissions from electricity

Looking at Figure 62 and Figure 63 it is possible to observe differences depending options to allocate emissions (725 kt CO_2 *vs* 1,159 kt CO_2 in 2016). This aspect should be taken into consideration when analysing the objectives of the city since ambiguous definitions of how emissions are allocated could discourage investments in many sectors and services. It is required to avoid a biased decarbonisation through indirect electrification by taking 'renewability' from the national grid (once assuming such electricity goes more and more renewable).

Finally, a Sankey diagram on the energy system for the reference year of the city has been included (see Figure 64).

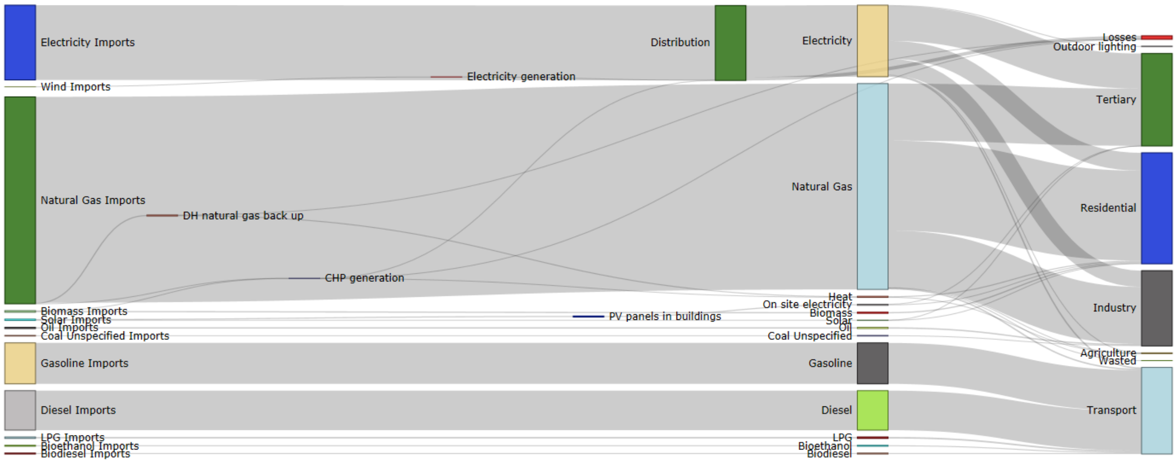


Figure 64: Sankey diagram of Groningen's energy flows in BaU scenario (2016)

Figure 64 shows the energy balance of Groningen in 2016. It is highly remarkable the amount of natural gas imports consumed mostly in residential, tertiary and industry. Transport is very dependent on gasoline and diesel imports, and electricity comes from the national grid mostly with a timid local production. Besides, there is still a little contribution from coal in industry.

León

The ESM of the city of León (Spain) has been created for the purpose of Making City project. The **reference year selected is 2017**, last year with enough data. Deviation between such reference year and present time has been adjusted using available data from the municipality. Potential mismatches between energy outcomes for in between years (2018, 2019, 2020) are accepted since they do not entail substantial changes in long-term trends.

As explained previously, to develop the ESM it is necessary to establish the most detailed energy picture of the city for the reference year and subsequently taking projections of the demands to 'evolve' that energy system into the future. To do so it is required to base some hypotheses on the expected behaviour of some socioeconomic drivers such as population, Gross Domestic Product (GDP), households' number, etc. (see Table 33).

Table 33: Hypotheses on key drivers assumed for the city of León

DRIVER	2017	2018-2050
Population	125,817	Projection based on historical data given by the municipality (validated with INE). 2020: 124,193 2025: 121,213 2030: 117,625 2050: 103,277
GDP	9,575,557 k€ (province)	GDP values taken at the province level. Evolution assumed based on historical trends Real values up to 2019 around 2%/year 2020-2021: -10,6% & +6% (according to BBVA estimates (22/09/2020) to consider COVID-19) 2022-2025: +2,38% (own estimate based on long-term trends) 2025-2030: +2% (own estimate based on long-term trends) 2030-2040: +1,5% (own estimate based on long-term trends) 2040-2050: +1% (own estimate based on long-term trends)
Households	64,098*	Based on 10-years households census, it has been assumed the last growth (+1,83%) for the entire decade 2011-2020.

	(*) estimate based on 2011 data with 10-years trend	From 2020 to 2029: 1% per year From 2030 to 2050: 0,5% per year

Besides, it is required to declare some assumptions about the specific behaviour of the economic sectors, sub-sectors, technologies and/or fuels. These assumptions are founded on establishing a realistic Business as Usual (BaU) scenario and they mix historical trends, binding commitments, and some constraints, but they should not include expectations. Those expectations will be modelled through alternative scenarios in terms of technology penetration, extra enforcement of emission limits, changes in fuels use, etc. The following Table 34 shows the main assumptions taken in the case of León to perform the energy demand projections.

Table 34: Hypotheses on assumptions to make demand projections for the city of León

SECTOR	ASSUMPTION
Residential	-New buildings 2018-2030: 0,2% annual growth (with respect to the base year stock). 50% equipped with natural gas boilers; 50% equipped with heat pump -New buildings 2031-2050: 0,1% annual growth (with respect to the base year stock). 100% equipped with heat pump. - Refurbished buildings (envelope and appliances) 2018-2030: 1% annual with respect to the base year stock. It is assumed to affect buildings up to 2007 category. Coal disappears and is moved to natural gas. - Refurbished buildings (envelope and appliances) 2031-2050: 1,5% annual with respect to the base year stock. It is assumed to affect buildings up to 2007 category.
Tertiary	-Public lighting based on households (driver)' behaviour -Local tertiary buildings based on historical data. Diesel is completely substituted by biomass by 2030. -Regional tertiary buildings: consumption and fuel shares remain constant according to historical trends. -Private tertiary buildings: activity is based on GDP's behaviour. No fuel changes have been considered.
Industry	The whole activity is based on GDP's behaviour. No fuel changes have been considered
Transport	No fuel shares changes nor efficiency improvements have been considered in BaU. Only the historical trends of the different vehicles' stocks have been considered. -Municipal fleet and public transport: from historical consumption data -Private fleet: from historical stock data

With the data provided by the municipality as well as the assumptions from Table 33 and Table 34, a set of results for the city of León has been obtained. Those results are just an excerpt of the potential amount of results that will be exploited by the city in the preparation of its long-term energy plans. The reason for that is founded on readability concerning the present deliverable and has been agreed with the city previously. The results showed in here are those concerned on final energy demands (by sectors, and by fuels) as well as the GHG emissions. In all cases the results are plotted by the BaU scenario only according to the project schedule and commitments. A comparison with alternative scenarios (implementing measures/actions) will be performed in Task 1.5.

Figure 65 shows the evolution of the final energy demand of León from 2017 to 2050 in the BaU scenario.

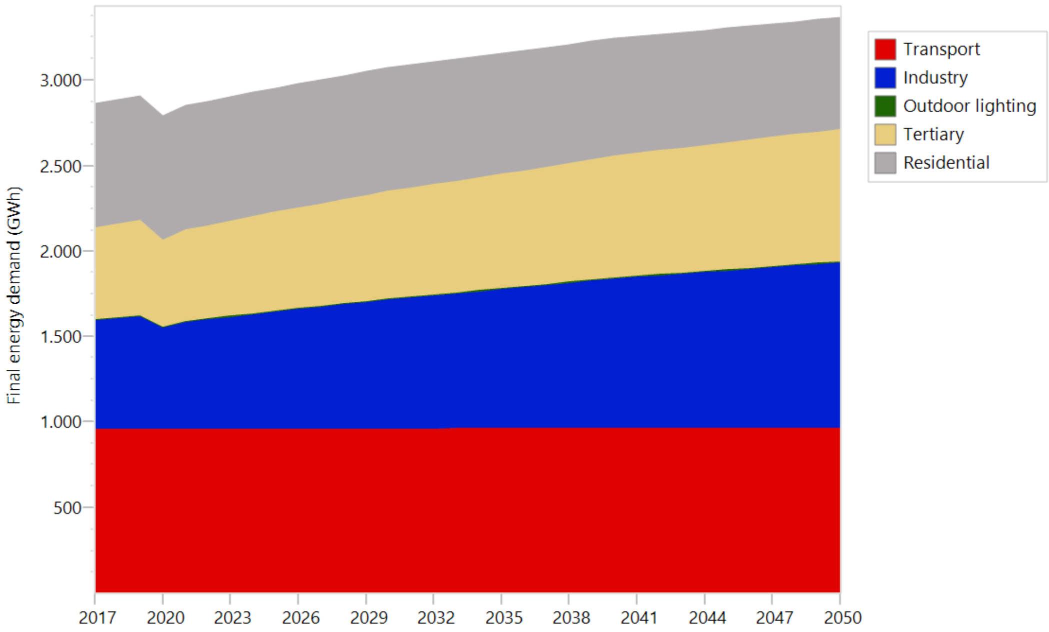


Figure 65: León's final energy demand by sectors in the scenario BaU (GWh)

Final energy demand shown in Figure 65 grows in the BaU scenario narrative. This is due to the expectations from industry mostly. In this sense, transport sector is expected to behave almost flat in the long-term according to historical trends on vehicle fleet, the effect of negative growth of population, besides the countereffect of traffic increases (as discussed in depth with the municipality).

Additionally, Figure 66 includes the final energy demand disaggregated by fuel as an extra analysis regarding demands.

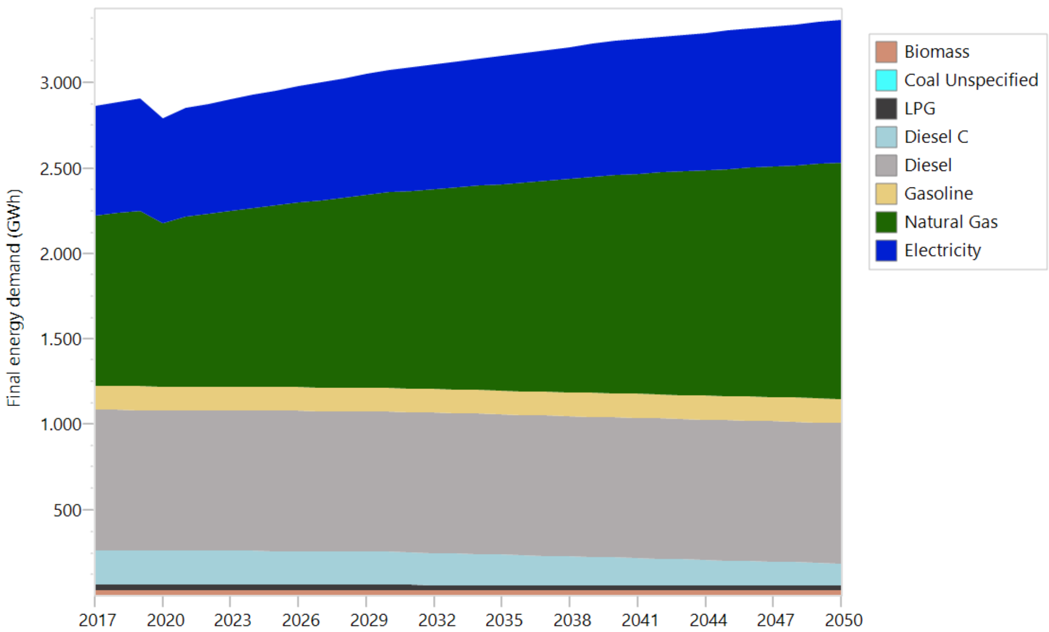


Figure 66: León's final energy demand by fuel in the scenario BaU (GWh)

Results from Figure 66 show a clear growth in natural gas derived from the growth in industry mostly and the inertial trends in tertiary and residential uses.

As expected, such evolution of the BaU scenario can be analysed from the GHG point of view (see Figure 67 next).

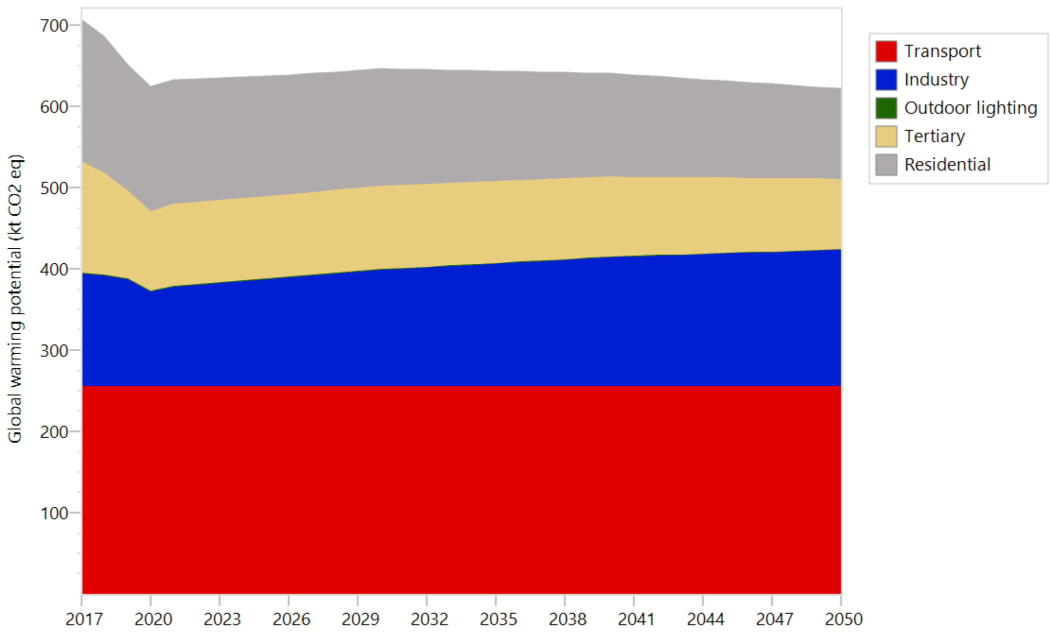


Figure 67: León's global warming potential (kt CO_2eq) in the supply side for the scenario BaU

Results from Figure 67 show the behaviour of GHG emissions in the long term. The observed decrease between 2017-2019 is a calibration with present year statistics. Thus, it is possible to see the importance of economy when assuming a post-COVID recovering by 2021 in GDP, occurring a sort of rebound effect by then. At a first glance, one could say emissions from transport are high and measures should be carried out to decarbonise that sector in León. Besides, industrial processes which make use of natural gas should be evaluated in order to propose solutions for the long term. And finally, extra measures beyond electrification should be implemented both in residential and tertiary where possible.

Finally, a Sankey diagram on the energy system for the reference year of the city has been included (see Figure 68).

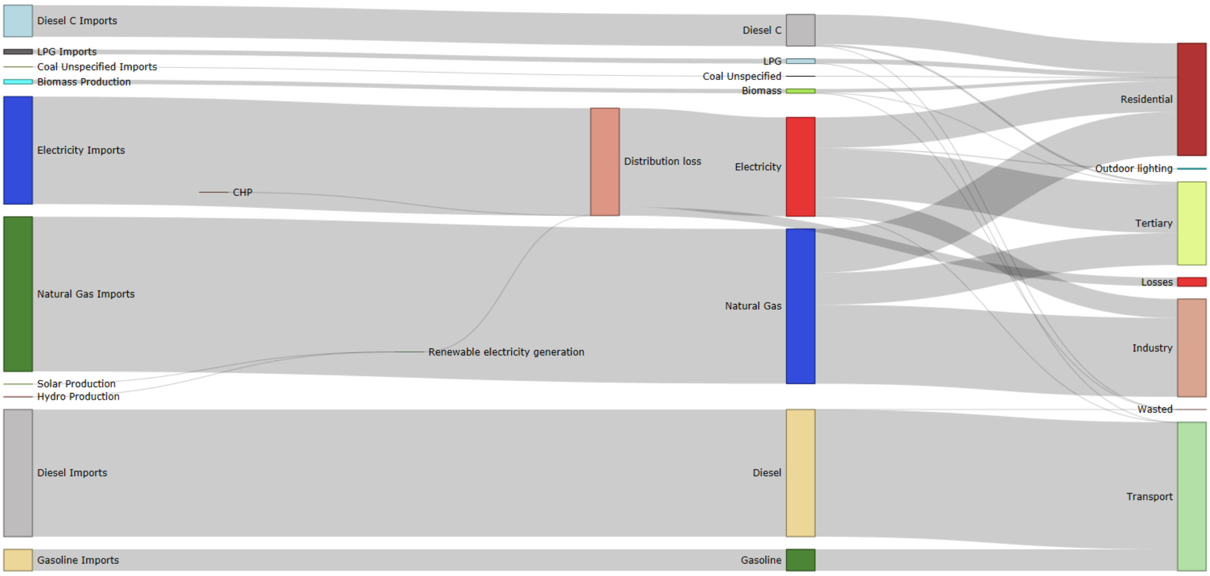


Figure 68: Sankey diagram of León's energy flows in BaU scenario (2017)

Figure 68 shows the energy balance of León in 2017. It is highly remarkable the amount of natural gas imports consumed mostly in industry as well as diesel imports for transport. Most of the electricity is imported from the national grid. Thus, there are a lot of measures to be deployed to increase the energy self-sufficiency of the city at the same time than implementing renewable solutions (in the supply side) and efficiency measures (in the demand side).

Bassano del Grappa

The ESM of the city of Bassano del Grappa (Italy) has been created for the purpose of Making City project. The **reference year selected is 2018**, last year with enough data. Deviation between such reference year and present time has been adjusted using available data from the municipality. Potential mismatches between energy outcomes for in between years (2019, 2020) are accepted since they do not entail substantial changes in long-term trends.

As explained previously, to develop the ESM it is necessary to establish the most detailed energy picture of the city for the reference year and subsequently taking projections of the demands to 'evolve' that energy system into the future. To do so it is required to base some hypotheses on the expected behaviour of some socioeconomic drivers such as population, Gross Domestic Product (GDP), households' number, etc. (see Table 35).

Table 35: Hypotheses on key drivers assumed for the city of Bassano del Grappa

DRIVER	2018	2019-2050
Population	43,412	Values assumed by the municipality: 2020: 43,412 2050: 49,000 (assuming an annual growth rate of 0.4% (equivalent to the average annual growth of the last 20 years))
GDP	732,636,965€	Values assumed by the municipality: 2020 adjustment: -9% due to COVID-19 (Italy forecast) 2021 adjustment: +5% due to COVID-19 (Italy forecast) 2025: 793,880,541€ 2030: 837,626,111€ 2035: 881,371,681€ 2040: 925,117,251€ 2045: 968,862,821€

		2050: 1,012,608,391€
GDP per capita	16,876€	Resulting from GDP divided by Population
Households	19,196	Annual growth: 0,64% – based on the historical trends

Besides, it is required to declare some assumptions about the specific behaviour of the economic sectors, sub-sectors, technologies and/or fuels. These assumptions are founded on establishing a realistic Business as Usual (BaU) scenario and they mix historical trends, binding commitments, and some constraints, but they should not include expectations. Those expectations will be modelled through alternative scenarios in terms of technology penetration, extra enforcement of emission limits, changes in fuels use, etc. The following Table 36 shows the main assumptions taken in the case of Bassano del Grappa to perform the energy demand projections.

Table 36: Hypotheses on assumptions to make demand projections for the city of Bassano del Grappa

SECTOR	ASSUMPTION
Residential	Every end-use energy service (heating, cooking, DHW, lighting and appliances) is based on Households' behaviour.
Tertiary	Every public service (here divided into education, public administration, sports leisure and culture, and other sectors) behave like population does. Public lighting behaves differently, like Households' behaviour. Private services are assumed to evolve like GDP per capita's behaviour.
Industry	The whole activity is based on GDP's behaviour, both for machinery and lighting, as well as heating processes.
Transport	Private vehicles – annual growth rates are assumed by type of vehicles attending to historical trends in fleets: cars 1.38%; light utility vehicles 0.28%; motorcycles 1.92%; others 1.38%. Public vehicles are assumed to grow like population does.
Agriculture	Electricity reported within Agriculture sector is assumed to evolve like GDP does.

With the data provided by the municipality as well as the assumptions from Table 35 and Table 36, a set of results for the city of Bassano del Grappa has been obtained. Those results are just an excerpt of the potential amount of results that will be exploited by the city in the preparation of its long-term energy plans. The reason for that is founded on readability concerning the present deliverable and has been agreed with the city previously. The results showed in here are those concerned on final energy demands (by sectors, and by fuels) as well as the GHG emissions. In all cases the results are plotted by the BaU scenario only according to the project schedule and commitments. A comparison with alternative scenarios (implementing measures/actions) will be performed in Task 1.5.

Figure 69 shows the evolution of the final energy demand of Bassano del Grappa from 2018 to 2050 in the BaU scenario.

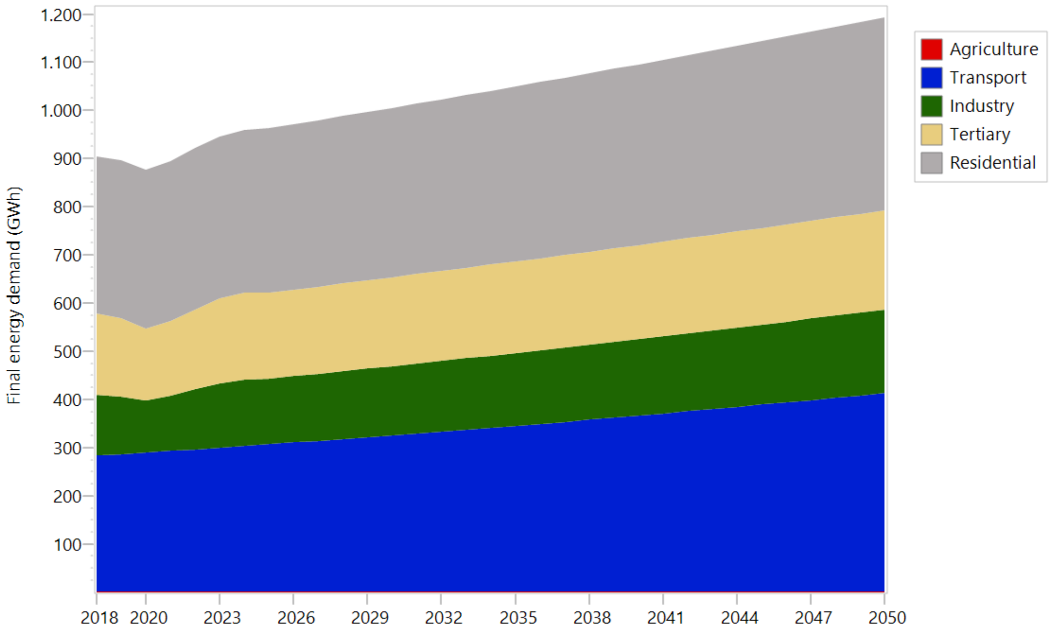


Figure 69: Bassano del Grappa's final energy demand by sectors in the scenario BaU (GWh)

Final energy demand shown in Figure 69 grows in the BaU scenario narrative. This is due to the expectations from transport mostly. In this sense, transport sector is expected to grow -depending on vehicle types- from 1-2% per year in terms of fleet. Accordingly, if no changes are assumed in the sector, that behaviour will target the transportation as the most difficult sector to deal with (in terms of GHG emissions since transport is very fossil-based). Share of residential and tertiary sectors in terms of energy demand are also considerable.

Additionally, Figure 70 includes the final energy demand disaggregated by fuel as an extra analysis regarding demands.

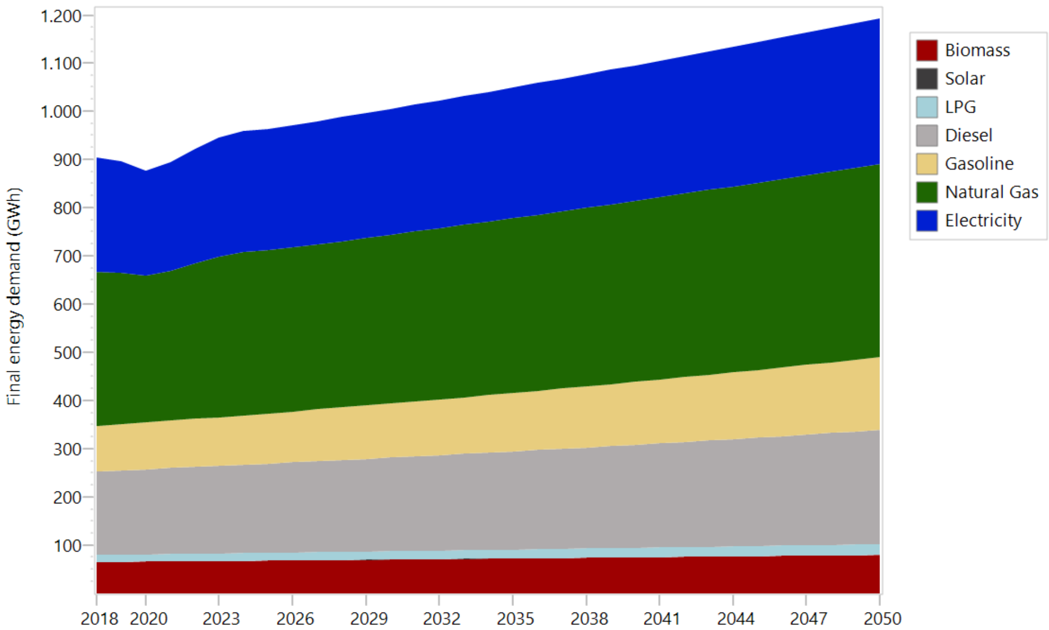


Figure 70: Bassano del Grappa's final energy demand by fuel in the scenario BaU (GWh)

In Figure 70 it is possible to see the large contribution of natural gas and electricity in the final energy demand of Bassano. The long-term behaviour in the BaU scenario is monotonic and growth is not high. Besides, contribution from diesel is significant and tends to grow. It is remarkable that decarbonisation of the city would mean to reduce or change the natural gas and diesel where possible.

Additionally, Figure 71 is plotted next to depict the behaviour of GHG emissions associated with the preceding consumptions.

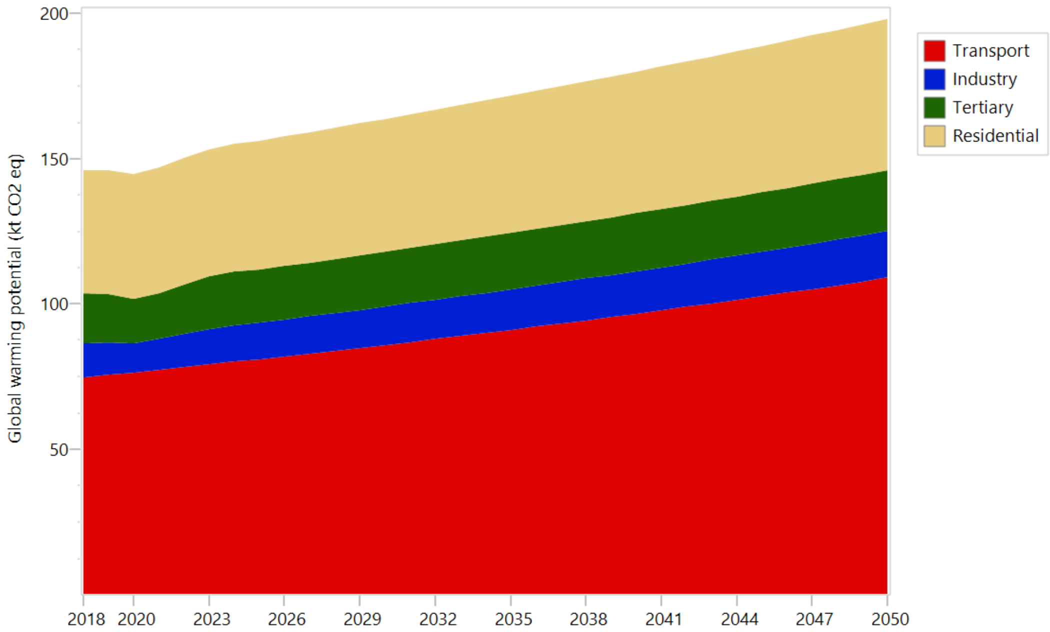


Figure 71: Bassano del Grappa's global warming potential (kt CO_2eq) in the supply side for the scenario BaU

Emissions' evolution of the BaU scenario of Bassano del Grappa are included in Figure 71. It is observed that most of emissions come from transport -in the reference year- and it will continue growing since transport sector activity is very increasing according to the historical trends. The use of fossil fuels in such sector (diesel mainly) will cause an increase in the total emitting profile of the city, worsening the current levels. Accordingly, it seems crucial to deploy measures in transport (what will be evaluated through Task 1.5 in alternative scenarios). CO_2 emissions associated to the electricity have not been considered in here since indirect (life cycle-based) emissions will be discussed in depth regarding the allocation concerns for the City Vision. Such debate will be faced in Task 1.5.

Finally, a Sankey diagram on the energy system for the reference year of the city has been included (see Figure 72).

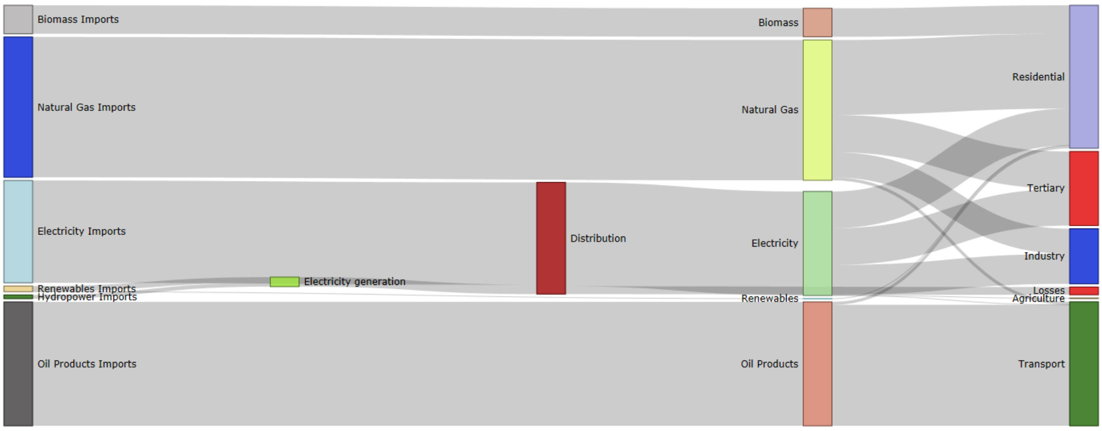


Figure 72: Sankey diagram of Bassano del Grappa's energy flows in BaU scenario (2018)

Figure 72 shows the energy balance of Bassano in 2018. It is highly remarkable the amount of natural gas imports consumed mostly in residential, but also in tertiary and industry. Oil products are imported and consumed in transport while electricity is mostly imported from outside the city (the national grid), with a timid indigenous production. It is noteworthy the share of biomass consumed in residential.

Vidin

The ESM of the city of Vidin (Bulgaria) has been created for the purpose of Making City project. The **reference year selected is 2016**, last year with enough data. Deviation between such reference year and present time has been adjusted using available data from the municipality. Potential mismatches between energy outcomes for in between years (2017, 2018, 2019, 2020) are accepted since they do not entail substantial changes in long-term trends.

As explained previously, to develop the ESM it is necessary to establish the most detailed energy picture of the city for the reference year and subsequently taking projections of the demands to 'evolve' that energy system into the future. To do so it is required to base some hypotheses on the expected behaviour of some socioeconomic drivers such as population, Gross Domestic Product (GDP), households' number, etc. (see Table 37).

Table 37: Hypotheses on key drivers assumed for the city of Vidin

Driver	2016	2017-2050
Population	42,801	Assumed by the municipality: 2017: 42,195; 2018: 41,583; 2019: 40,620; 2025: 39,655; 2030: 38,713; 2035: 37,794; 2040: 36,896; 2045: 36,020; 2050: 35,165
GDP per capita	6,407 €	Historical annual growth rates taken from https://countryeconomy.com/gdp/bulgaria: 2017: 3.5% 2018: 3.1% 2019: 3.4% 2020: -5.5% (based on Bulgarian Central Bank, due to COVID-19) 2021: 4% (based on Bulgarian Central Bank, due to COVID-19)

		https://www.reuters.com/article/bulgaria-gdp-cenbank-forecast/bulgaria-central-bank-revises-up-its-gdp-forecast-to-5-5-decrease-idUSL8N2H468E 2022: 3% – based on historical trends (estimate)
Households	17,700	Annual growth rate: 0,05% – based on an optimistic behaviour attending to the economic and population expectations

Besides, it is required to declare some assumptions about the specific behaviour of the economic sectors, sub-sectors, technologies and/or fuels. These assumptions are founded on establishing a realistic Business as Usual (BaU) scenario and they mix historical trends, binding commitments, and some constraints, but they should not include expectations. Those expectations will be modelled through alternative scenarios in terms of technology penetration, extra enforcement of emission limits, changes in fuels use, etc.

The following table shows the main assumptions taken in the case of Vidin to perform the energy demand projections.

Table 38: Hypotheses on assumptions to make demand projections for the city of Vidin

SECTOR	ASSUMPTION
Residential	Energy demanded by existing buildings is projected with the same behaviour than driver called "households".
Tertiary	Both public lighting and municipal buildings, their energy consumption, evolve like households' behaviour.
Industry	Industrial services like heating and machinery evolve based on GDP per capita's behaviour.
Transport	It has been assumed an annual 0.5% growth rate for public vehicles, both buses and light duty vehicles, based on own estimates and trends. Private passenger cars are assumed to grow 2.16% per year based on historical trends. Private trucks are assumed to grow 2.24% per year based on historical trends.

With the data provided by the municipality as well as the assumptions detailed, a set of results for the city of Vidin has been obtained. Those results are just an excerpt of the potential amount of results that will be exploited by the city in the preparation of its long-term energy plans. The reason for that is founded on readability concerning the present deliverable and has been agreed with the city previously. The results showed in here are those concerned on final energy demands (by sectors, and by fuels) as well as the GHG emissions. In all cases the results are plotted by the BaU scenario only according to the project schedule and commitments. A comparison with alternative scenarios (implementing measures/actions) will be performed in Task 1.5.

Figure 73 shows the evolution of the final energy demand of Vidin from 2016 to 2050 in the BaU scenario.

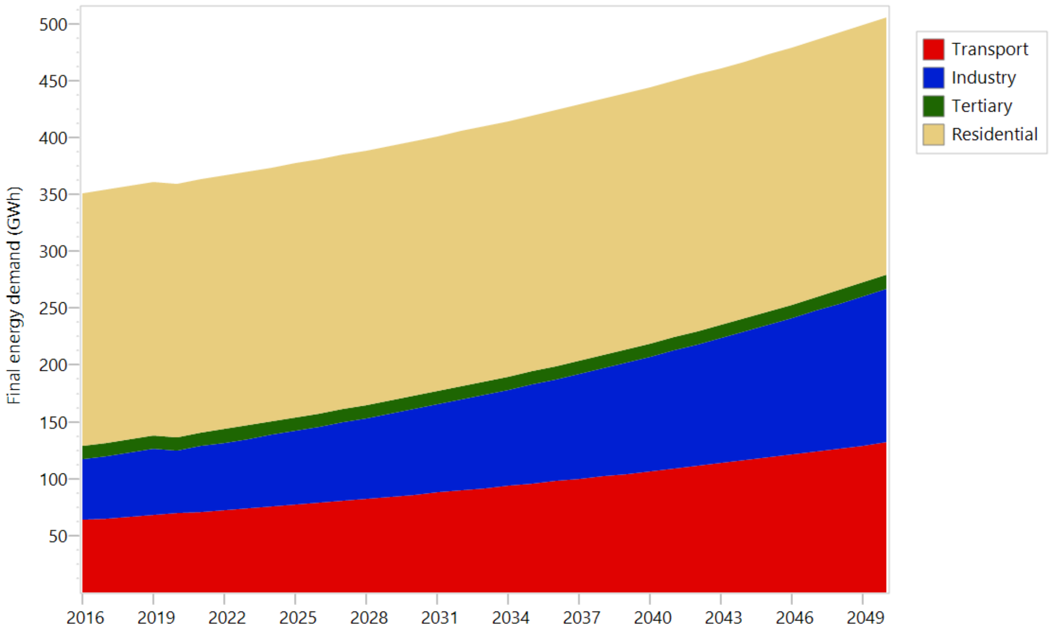


Figure 73: Vidin's final energy demand by sectors in the scenario BaU (GWh)

Final energy demand shown in Figure 73 grows in the BaU scenario narrative. This is due to the expectations from transport and industry mostly. In this sense, transport sector is expected to grow around 2% per year in terms of vehicle fleet according to historical trends, a significant growing trend.

Additionally, Figure 74 includes the final energy demand disaggregated by fuel as an extra analysis regarding demands.

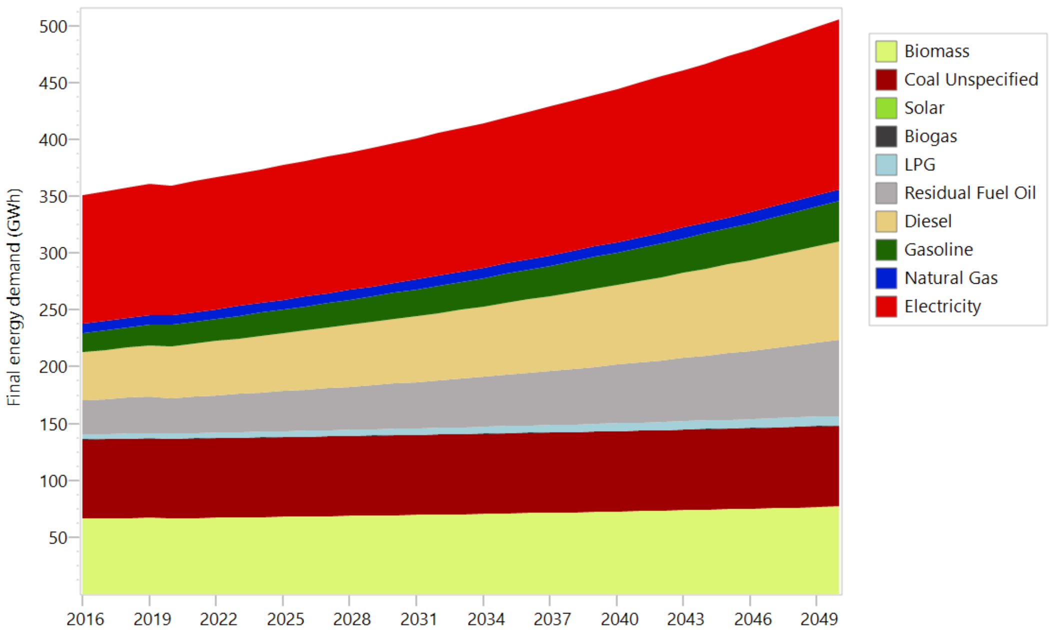


Figure 74: Vidin's final energy demand by fuel in the scenario BaU (GWh)

Results from Figure 74 show the consumption of the different fuels in the city of Vidin according to the data given by the municipality under the BaU scenario. It is possible to see the weight of electricity but also the large share from biomass and coal. Due to the expected growth in transport, diesel consumption will grow in the BaU scenario.

Thus, Figure 75 is included in here to depict the GHG emissions derived from the previous ones.

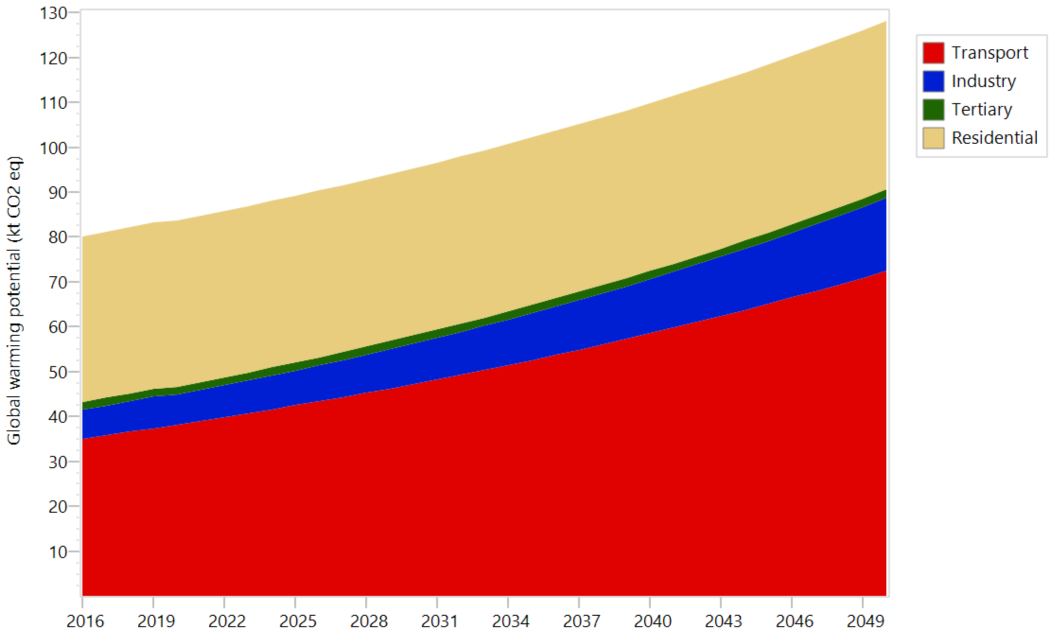


Figure 75: Vidin's global warming potential (kt CO_2eq) in the supply side for the scenario BaU

Figure 75 shows clearly a growing trend in the GHG emissions of Vidin for the BaU narrative. The main reason is the expected behaviour of the transport sector, based on fossil fuels almost entirely. The key consideration to work with afterwards should be focused on decarbonising such sector as well as decreasing energy consumption in residential mostly.

Lastly, a Sankey diagram on the energy system for the reference year of the city has been included (see Figure 76).

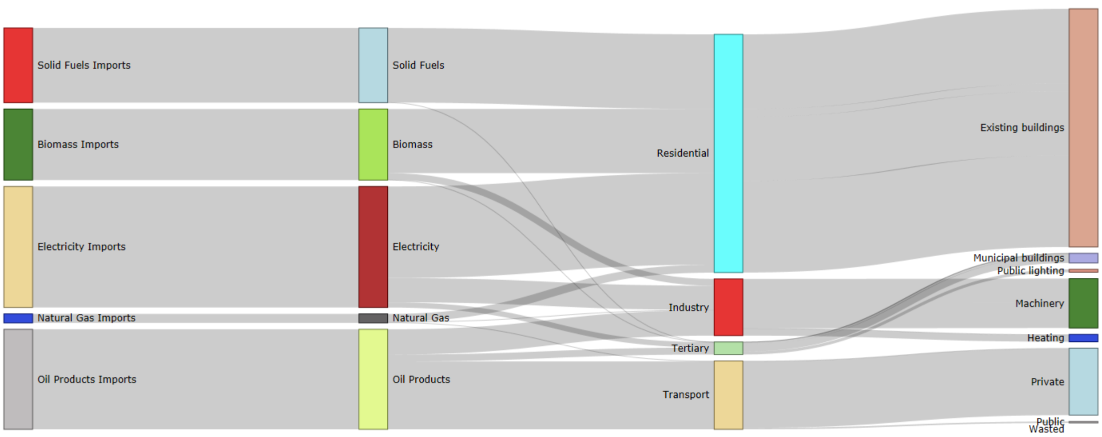


Figure 76: Sankey diagram of Vidin's energy flows in BaU scenario (2016)

The energy balance of Vidin expressed in Figure 76 shows a large import of coal going to residential sector as well as biomass. Oil products are imported too and then consumed in transport, industry and tertiary sector too. Natural gas is not relevant in the city.

Lublin

The ESM of the city of Lublin (Poland) has been created for the purpose of Making City project. The **reference year selected is 2017**, last year with enough data. Deviation between such reference year and present time has been adjusted using available data from the municipality. Potential mismatches between energy outcomes for in between years (2018, 2019, 2020) are accepted since they do not entail substantial changes in long-term trends.

As explained previously, to develop the ESM it is necessary to establish the most detailed energy picture of the city for the reference year and subsequently taking projections of the demands to 'evolve' that energy system into the future. To do so it is required to base some hypotheses on the expected behaviour of some socioeconomic drivers such as population, Gross Domestic Product (GDP), households' number, etc. (see Table 39).

Table 39: Hypotheses on key drivers assumed for the city of Lublin

DRIVER	2017	2018-2050
Population	339,696	Values assumed by the municipality: 2018: 338,874; 2019: 337,985; 2020: 337,028; 2025: 330,855; 2030: 322,618; 2050: 296,731
GDP	7,952.78 (M€) for the Lublin region (the biggest municipalities in voivodeship. GDP was calculated at the level of the most developed communes in the voivodeship. It is the closest to the GDP for Lublin.)	Assumed by the municipality based on "GDP forecast – lubelski (NUTS3)": 2020 adjustment: -4.6% based on COVID-19 effect 2021 adjustment: +4.2% based on COVID-19 effect Annual growth 3,14% up to 2025; 2,69% up to 2030; 2,37% up to 2035; 2,12% up to 2040; 1, 91% up to 2045; 1,75% up to 2050
GDP per capita (Lublin voivodship)	11,200€	Assumed by the municipality based on "GDP per capita forecast – lubelski (NUTS3)": 2020 adjustment: -4.6% based on COVID-19 effect 2021 adjustment: +4.2% based on COVID-19 effect Annual growth 3,10% up to 2025; 2,68% up to 2030; 2,36% up to 2035; 2,11% up to 2040; 1, 91% up to 2045; 1,74% up to 2050
Households	126,338	Annual growth: 0,55% – based on the historical trends

Besides, it is required to declare some assumptions about the specific behaviour of the economic sectors, sub-sectors, technologies and/or fuels. These assumptions are founded on establishing a realistic Business as Usual (BaU) scenario and they mix historical trends, binding commitments, and some constraints, but they should not include expectations. Those expectations will be modelled through alternative scenarios in terms of technology penetration, extra enforcement of emission limits, changes in fuels use, etc.

The following Table 40 shows the main assumptions taken in the case of Lublin to perform the energy demand projections.

Table 40: Hypotheses on assumptions to make demand projections for the city of Lublin

SECTOR	ASSUMPTION
Residential	Every end-use energy service (heating, cooking, DHW, lighting and appliances) is based on Households' behaviour
Tertiary	Every private and public end-use energy service (heating, cooking, DHW, lighting and appliances) is based on GDP per capita's behaviour but softened by a decoupling degrowth of -1% per year. Public lighting activity is based on GDP per capita's evolution
Industry	The whole activity is based on GDP's behaviour
Transport	Private vehicles – annual growth rates are assumed by type of vehicles attending to historical trends in fleets: cars 3%; trucks 3%; buses 1,4%; motorcycles 3%; mopeds 1,5%; others 3%. Public vehicles are assumed constant since population declines so new municipal vehicles will offset those retired ones.

With the data provided by the municipality as well as the assumptions defined, a set of results for the city of Lublin has been obtained. Those results are just an excerpt of the potential amount of results that will be exploited by the city in the preparation of its long-term energy plans. The reason for that is founded on readability concerning the present deliverable and has been agreed with the city previously. The results showed in here are those concerned on final energy demands (by sectors, and by fuels) as well as the GHG emissions. In all cases the results are plotted by the BaU scenario only according to the project schedule and commitments. A comparison with alternative scenarios (implementing measures/actions) will be performed in Task 1.5.

Figure 77 shows the evolution of the final energy demand of Lublin from 2017 to 2050 in the BaU scenario.

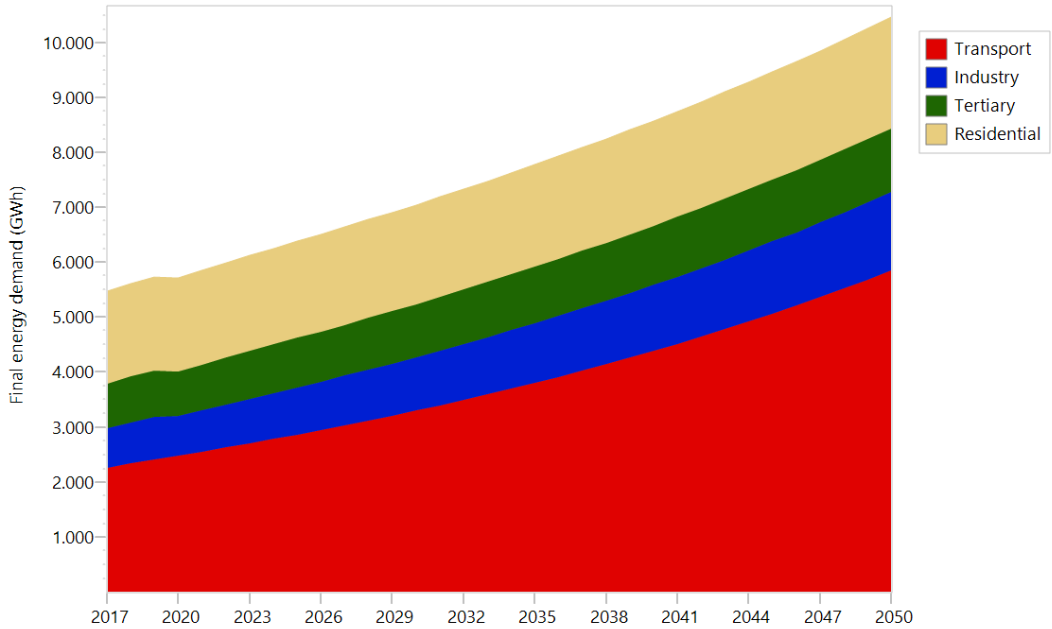


Figure 77: Lublin's final energy demand by sectors in the scenario BaU (GWh)

Final energy demand shown in Figure 77 grows in the BaU scenario narrative. This is due to the expectations from transport mostly. The sector is expected to grow at paces by 3% according to historical trends in the number of vehicles, what leads to a large increase in the use of fossil fuels unless changes in fleet were applied (as expected in alternative scenarios).

Additionally, Figure 78 includes the final energy demand disaggregated by fuel as an extra analysis regarding demands.

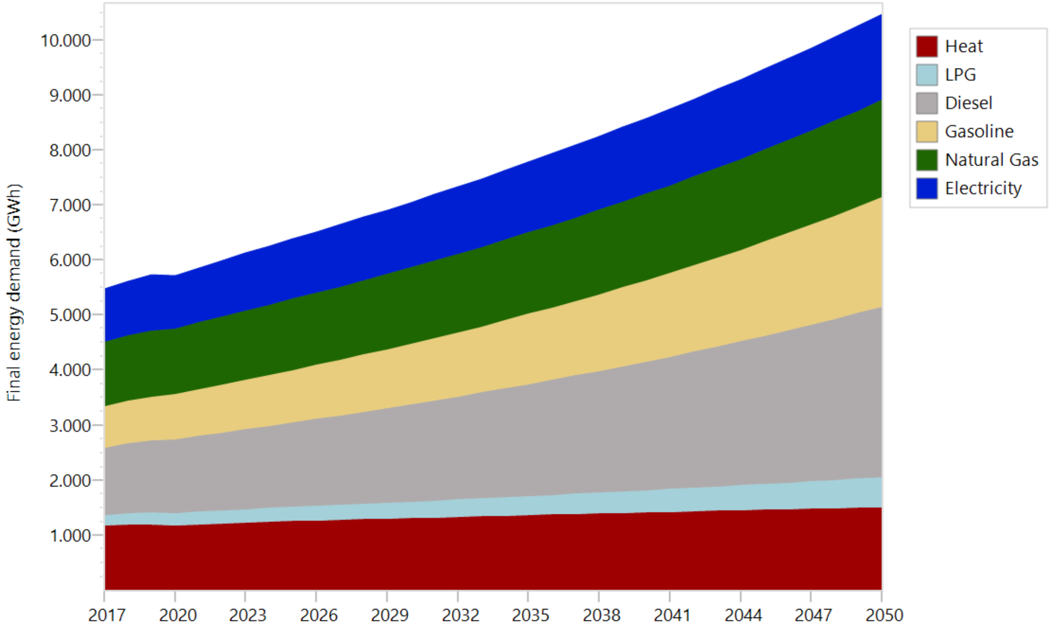


Figure 78: Lublin's final energy demand by fuel in the scenario BaU (GWh)

As seen in Figure 78, fuel disaggregation shows a growing trend for diesel due to the relevance of transport in the future assumed by the BaU scenario. it happens the same with gasoline. The behaviour of electricity, natural gas and heat is more stable since those fuels are linked to the rest of the sectors, which behave smoothly.

In consequence, it is crucial to observe the evolution of GHG emissions due to the relevance of fossil fuels (see Figure 79).

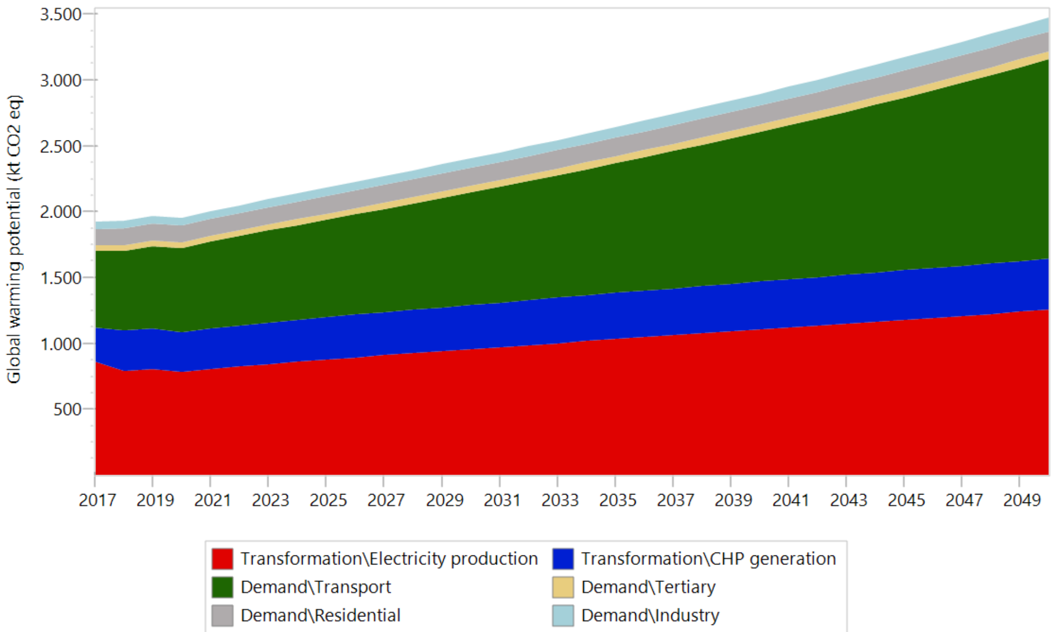


Figure 79: Lublin's global warming potential (kt CO_2eq) in the supply side for the scenario BaU

Results from Figure 79 show two key findings. On the one side, GHG emissions coming from the transport are growing since expectations on the activity for such sector are high (historical trends talk about increases in vehicle fleet per type from 1-3% per year), what causes increases in GHG emission under the BaU scenario narrative. On the other side, there is a growth in emissions coming from the electricity production that talks about the supply side of the model. In that sense, increase in the needs for electricity and heat from the sectors moves the requirements to the CHP plants of the city, which make use of large quantities of coal and natural gas. If no extra measures are applied, the BaU scenario will involve increases in GHG emissions due to those extra requirements of electricity and heat from those plants. Regarding the creation of a City Vision as consequence of Task 1.5 of the project, emissions allocation to sectors as well as emission factors considered should be evaluated in depth.

Differences among sectors between the BaU scenario and emissions reported in a preceding document of Lublin for 2013[6] come from the way emissions are organised. In present analysis, emissions from the residential sector result in 128 kt CO_2eq in 2017 whereas Polish report said 781 kt CO_2eq (some differences would be expected since are 2013 values), but the real difference comes from the allocation of the CO_2 emissions to heat. While the report places those CO_2 into the residential sector, present model allocates such emissions into the supply side where heat was produced in CHP plants. In summary, total emissions of Lublin result in current model around 1,92 kt CO_2eq in 2017, a much closer value to the total referred in the 2013 Lublin's report (less than 5-10% error). Accordingly, it has been concluded that emissions' validation is satisfactory.

Finally, a Sankey diagram on the energy system for the reference year of the city has been included (see Figure 80).

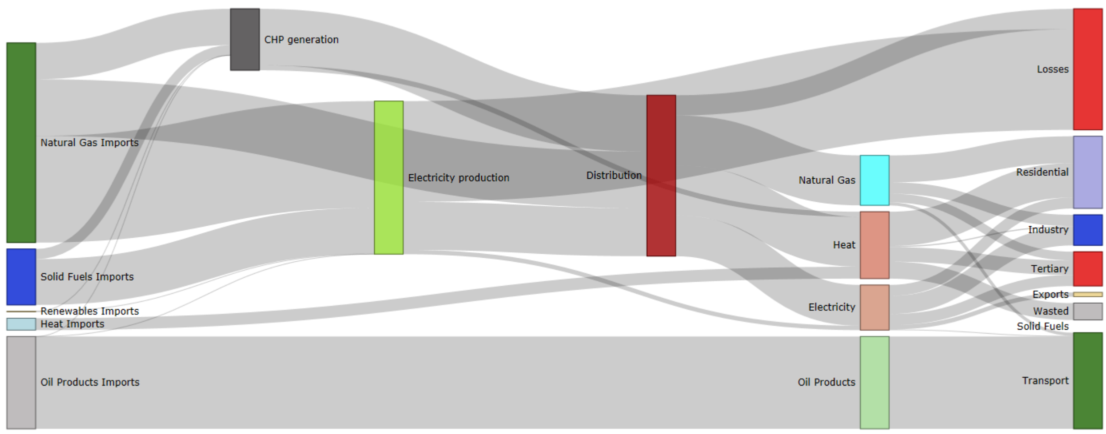


Figure 80: Sankey diagram of Lublin's energy flows in BaU scenario (2017)

Figure 80 shows the energy balance of Lublin for the reference year taken. Thus, it is possible to observe the large amount of natural gas imported and used in electricity and heat production. There is a significant amount of coal used too. As well, oil products imported mean a large contribution to the total and they are consumed in transport almost entirely.

[6] See https://lublin.eu/gfx/lublin/userfiles/_public/urzad_miasta_lublin/jakosc_i_etyka/lublin__raport_pn-iso_37120_1.pdf

Trenčín

The ESM of the city of Trenčín (Slovakia) has been created for the purpose of Making City project. The **reference year selected is 2018**, last year with enough data. Deviation between such reference year and present time has been adjusted using available data from the municipality. Potential mismatches between energy outcomes for in between years (2019, 2020) are accepted since they do not entail substantial changes in long-term trends.

As explained previously, to develop the ESM it is necessary to establish the most detailed energy picture of the city for the reference year and subsequently taking projections of the demands to 'evolve' that energy system into the future. To do so it is required to base some hypotheses on the expected behaviour of some socioeconomic drivers such as population, Gross Domestic Product (GDP), households' number, etc. (see Table 41).

Table 41: Hypotheses on key drivers assumed for the city of Trenčín

Driver	2018	2019-2050
Population	54,900	Values assumed by the municipality: 2020: 54,600; 2025: 55,000; 2030: 57,000; 2035: 58,000; 2040: 59,000; 2045: 60,000; 2050: 61,000
GDP	7,680,000,194€	Assumed by the municipality. Annual growth: 1,3342% Corrected with the COVID-19 effect: a -7.1% decrease in 2020 (based on IMF)
GDP per capita	5,976 €	Assumed by the municipality. Annual growth rates: Correction by -7.1% in 2020 (IMF) 3,72% up to 2025; 3,13% up to 2030; 2,71% up to 2035; 2,39% up to 2040; 2,13% up to 2045; 1,93% up to 2050
Households	27,500	Annual growth: 0,15% – based on the historical trends

Besides, it is required to declare some assumptions about the specific behaviour of the economic sectors, sub-sectors, technologies and/or fuels. These assumptions are founded on establishing a realistic Business as Usual (BaU) scenario and they mix historical trends, binding commitments, and some constraints, but they should not include expectations. Those expectations will be modelled through alternative scenarios in terms of technology penetration, extra enforcement of emission limits, changes in fuels use, etc. The following table Table 42 shows the main assumptions taken in the case of Trenčín to perform the energy demand projections.

Table 42: Hypotheses on assumptions to make demand projections for the city of Trenčín

SECTOR	ASSUMPTION
Residential	Every end-use energy service (heating, cooking, DHW, lighting and appliances) is based on households' behaviour
Tertiary	Every end-use energy service (heating, cooking, DHW, lighting and appliances) is based on GDP per capita's behaviour but softened by a decoupling factor by 2% per year. Public lighting activity is based on households´ evolution.
Industry	The whole activity is based on GDP's behaviour.

Transport	Private vehicles fuelled by fossils in terms of activity grow by 5% up to 2025, by 3% up to 2040, and by 1% up to 2050; electric vehicles are assumed to grow 5% for the whole horizon (such percentage simplifies an "S-curve"). Public vehicles are assumed through "buses" and behave households´ evolution.
Agriculture	The whole activity is based on GDP's behaviour.

With the data provided by the municipality as well as the assumptions defined, a set of results for the city of Trenčín has been obtained. Those results are just an excerpt of the potential amount of results that will be exploited by the city in the preparation of its long-term energy plans. The reason for that is founded on readability concerning the present deliverable and has been agreed with the city previously. The results showed in here are those concerned on final energy demands (by sectors, and by fuels) as well as the GHG emissions. In all cases the results are plotted by the BaU scenario only according to the project schedule and commitments. A comparison with alternative scenarios (implementing measures/actions) will be performed in Task 1.5.

Figure 81 shows the evolution of the final energy demand of Trenčín from 2018 to 2050 in the BaU scenario.

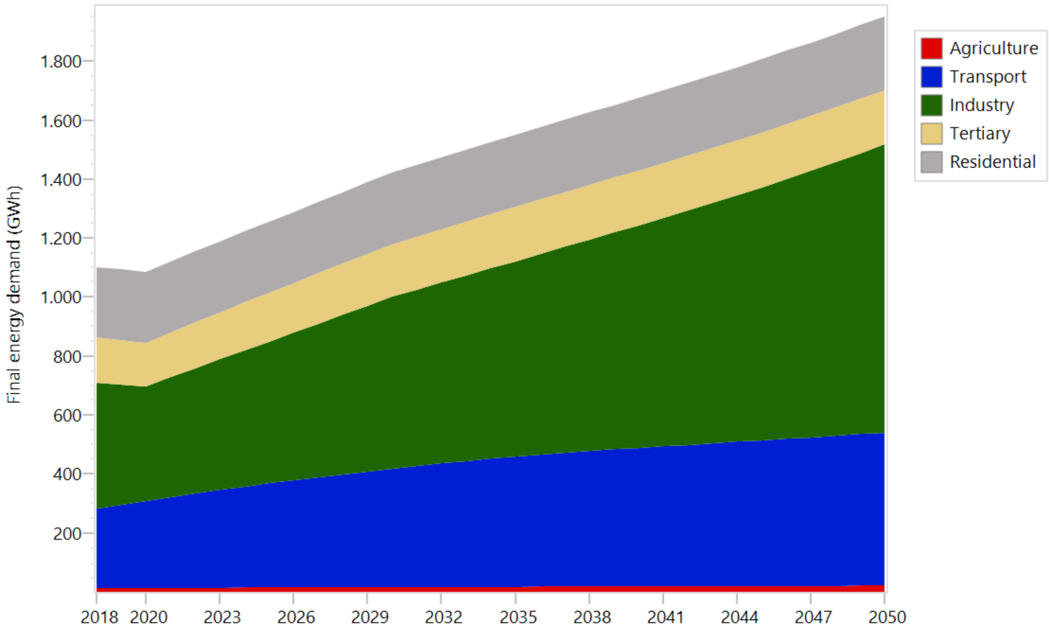


Figure 81: Trenčín's final energy demand by sectors in the scenario BaU (GWh)

Final energy demand shown in Figure 81 grows in the BaU scenario narrative. This is due to the expectations from industry and transport mostly. In this sense, transport sector is expected to have vehicle increases ranging from 1-5% per year according to historical trends, what is huge and causes a significant increase in energy consumption (basically fossil fuels).

Additionally, Figure 82 includes the final energy demand disaggregated by fuel as an extra analysis regarding demands.

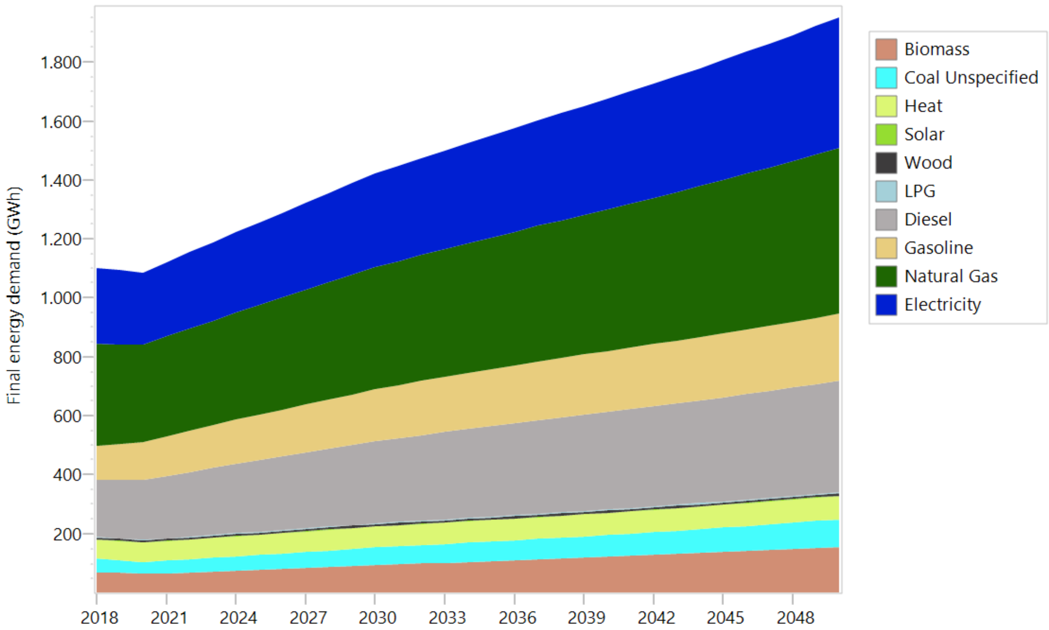


Figure 82: Trenčín's final energy demand by fuel in the scenario BaU (GWh)

According to the behaviour shown in Figure 81, result from Figure 82 translate such evolution into a growing trend in the consumption of fossil fuels such as diesel and gasoline -due to transport- in addition to natural gas increases in industry, residential and tertiary sectors. It also seems significant the share of biomass and coal.

When moving the discussion to GHG emissions related with the energy profile, Figure 83 includes expands such analysis to the evolution of those emissions for the BaU scenario of Trenčín.

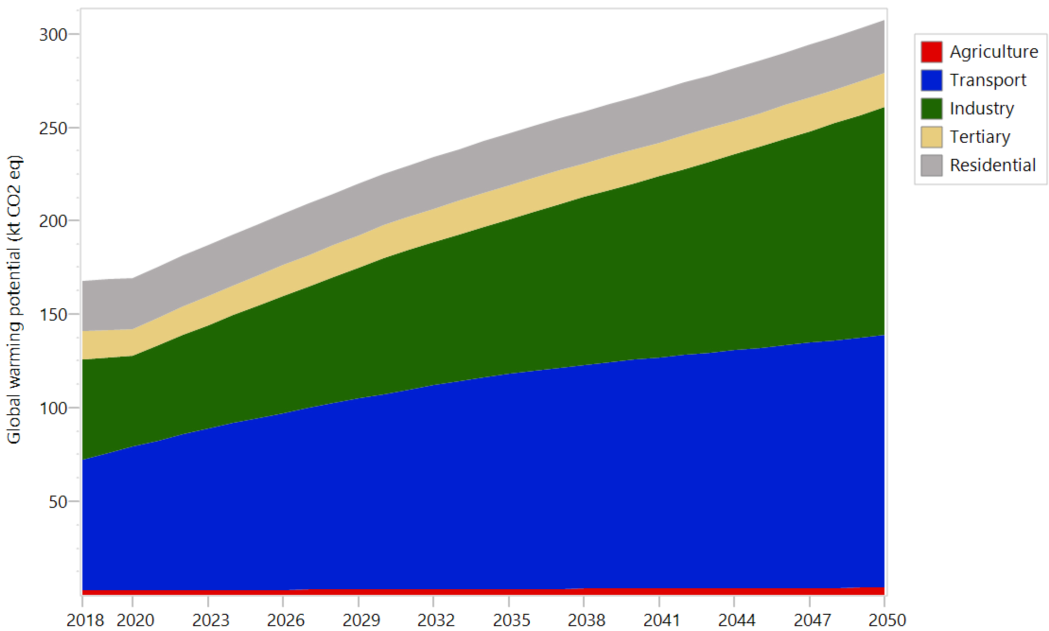


Figure 83: Trenčín's global warming potential (kt CO_2eq) in the supply side for the scenario BaU

Figure 83 shows the GHG emissions derived from the behaviour observed in Figure 82. It is possible to see how emissions from transport will grow significantly in the first decade and slow down their growth in the long-term. Besides, the natural gas consumption in industry causes an increase in emissions in the long-term attending to the expected activity of the sector in the BaU scenario. These two sectors are the most important ones regarding emissions and should be the first ones to face when implementing measures to decarbonise the city.

Finally, a Sankey diagram on the energy system for the reference year of the city has been included (Figure 84).

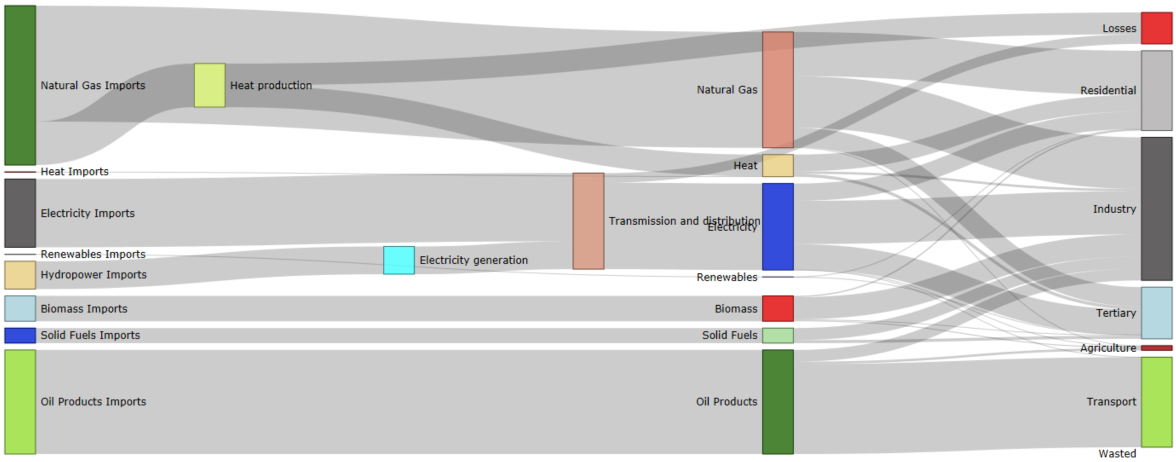


Figure 84: Sankey diagram of Trenčín's energy flows in BaU scenario (2018)

Figure 84 includes the energy balance of Trenčín for the reference year. It is observed the large contribution of imported oil products going to feed the transport sectors as well as natural gas imported to supply heat and satisfy the needs in industry, residential and tertiary sectors too. In terms of electricity, it is remarkable the local production from hydropower, being the rest of the electricity imported from the national grid.

Kadiköy

The ESM of the city of Kadiköy (Turkey) has been created for the purpose of Making City project. The **reference year selected is 2016**, last year with enough data. Deviation between such reference year and present time has been adjusted using available data from the municipality. Potential mismatches between energy outcomes for in between years (2017, 2018, 2019, 2020) are accepted since they do not entail substantial changes in long-term trends.

As explained previously, to develop the ESM it is necessary to establish the most detailed energy picture of the city for the reference year and subsequently taking projections of the demands to 'evolve' that energy system into the future. To do so it is required to base some hypotheses on the expected behaviour of some socioeconomic drivers such as population, Gross Domestic Product (GDP), households' number, etc. (see Table 43).

Table 43: Hypotheses on key drivers assumed for the city of Kadiköy

Driver	2016	2017-2050
Population	452,302	Values assumed by the municipality up to 2018: 2017: 451,453 2018: 458,638 2019: 482,713 From 2020: 1% annual growth (looking at historical trends and assuming an optimistic swap)

GDP	127,434,148,346€	By 2017 is assumed a 14% annual growth rate as historical 10 years average; 2020: -3.5% due to COVID-19 effect based on Turkey forecast 2021: 5% due to COVID-19 effect based on Turkey forecast By 2025, annual growth is assumed 8% By 2030, annual growth is assumed 5% By 2040, annual growth is assumed 4% The deceleration in the annual GDP growth rates is assumed as a natural process of a macroeconomic driver in the long term (very high annual rates are not sustainable in time and socioeconomic system tends to stabilise according to the associated growth in welfare and social justice standards). Such deceleration can be observed as a long-term flattening process in GDP of highly developed economies, where population's ageing starts to take an effect.
Income per capita	16,355.90 €	Annual growth rates: 1.28% based on 10-years historical trend.
Total private vehicles	243,444	n. a.
Vehicles per capita	0,54	It is assumed the formula "Total private vehicles / Population" to obtain this driver. Resulting value for 2016 is 0,54. In some European countries, it is frequent to see current values around 0,7 (even though talking about a municipality such ratio could be unsuitable due to parking problems). Accordingly, it has been assumed that in a BaU paradigm Kadiköy people would behave as some other EU countries but reaching such a ratio by 2050.

Besides, it is required to declare some assumptions about the specific behaviour of the economic sectors, sub-sectors, technologies and/or fuels. These assumptions are founded on establishing a realistic Business as Usual (BaU) scenario and they mix historical trends, binding commitments, and some constraints, but they should not include expectations. Those expectations will be modelled through alternative scenarios in terms of technology penetration, extra enforcement of emission limits, changes in fuels use, etc.

The following table shows the main assumptions taken in the case of Kadiköy to perform the energy demand projections.

Table 44: Hypotheses on assumptions to make demand projections for the city of Kadiköy

SECTOR	ASSUMPTION
Residential	Every type of building described (and end-use energy services (heating, cooking, DHW, lighting and appliances) within) is based on population's behaviour. Within the building types described, it has been assumed an annual 0,5% rehabilitation rate (up to 2030) and 1%/year beyond 2030 and up to 2050. Regarding new buildings entrance, it has been assumed an annual 1% increase up to 2030, and later 0,5% per year.
Tertiary	Every type of building (and their end-use energy services (heating, cooking, DHW, lighting and appliances) within) is based on Income per capita's behaviour. That is assumed for the "commercial" buildings. Public and municipal buildings (and end-use energy services within) perform like population's behaviour
Outdoor lighting	The whole activity is based on population's behaviour
Transport	Public vehicles' energy consumption is projected based on population's behaviour. The entire branch of private vehicles is assumed to project as the drivers called "vehicles per capita"

With the data provided by the municipality as well as the assumptions defined, a set of results for the city of Kadiköy has been obtained. Those results are just an excerpt of the potential amount of results that will be exploited by the city in the preparation of its long-term energy plans. The reason for that is founded on readability concerning the present deliverable and has been agreed with the city previously. The results showed in here are those concerned on final energy demands (by sectors, and by fuels) as well as the GHG emissions. In all cases the results are plotted by the BaU scenario only according to the project schedule and commitments. A comparison with alternative scenarios (implementing measures/actions) will be performed in Task 1.5.

Figure 85 shows the evolution of the final energy demand of Kadiköy from 2016 to 2050 in the BaU scenario.

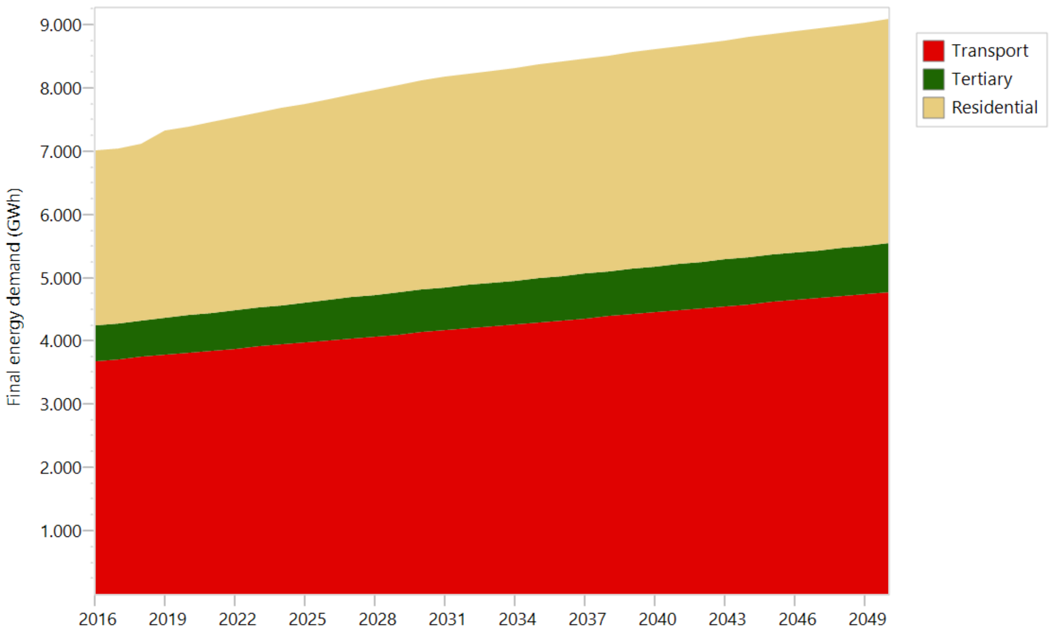


Figure 85: Kadiköy's final energy demand by sectors in the scenario BaU (GWh)

Final energy demand shown in Figure 85 grows in the BaU scenario narrative. This is due to the expectations from transport mostly. In this sense, transport sector is expected to grow very in connection to population expectations through the vehicles per capita driver reaching 0,7 in the long term.

Additionally, Figure 86 includes the final energy demand disaggregated by fuel as an extra analysis regarding demands.

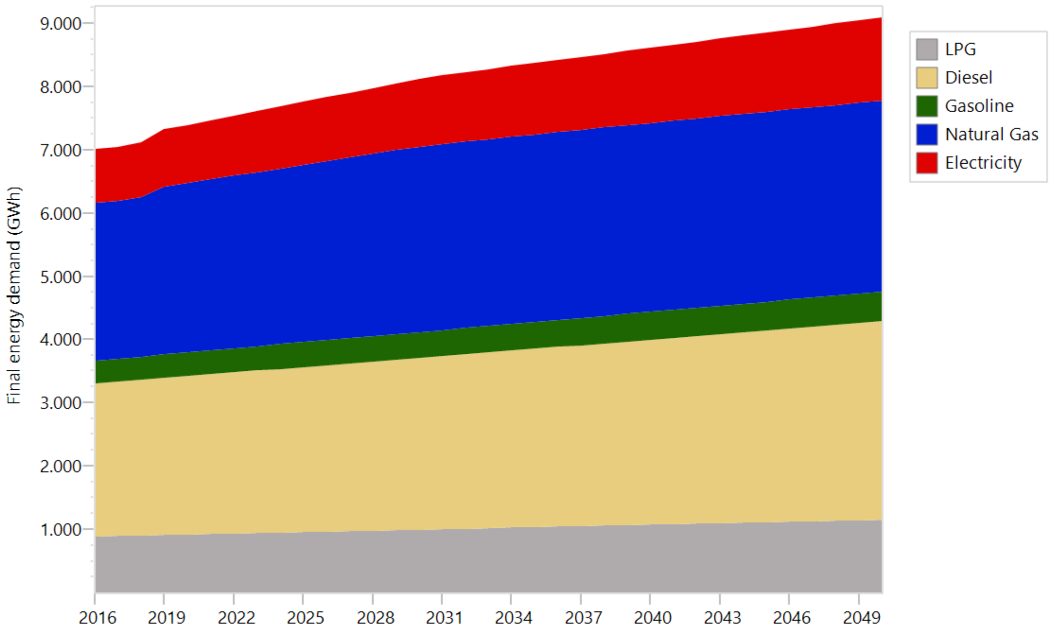


Figure 86: Kadiköy's final energy demand by fuel in the scenario BaU (GWh)

The evolution of the final energy demand looking at fuels in the BaU scenario for Kadiköy (Figure 86) talks about the relevance of diesel and LPG due to their importance in transport. In addition, the role of natural gas is related with the consumption in the residential sector.

The following Figure 87 shows the GHG emissions for the BaU scenario.

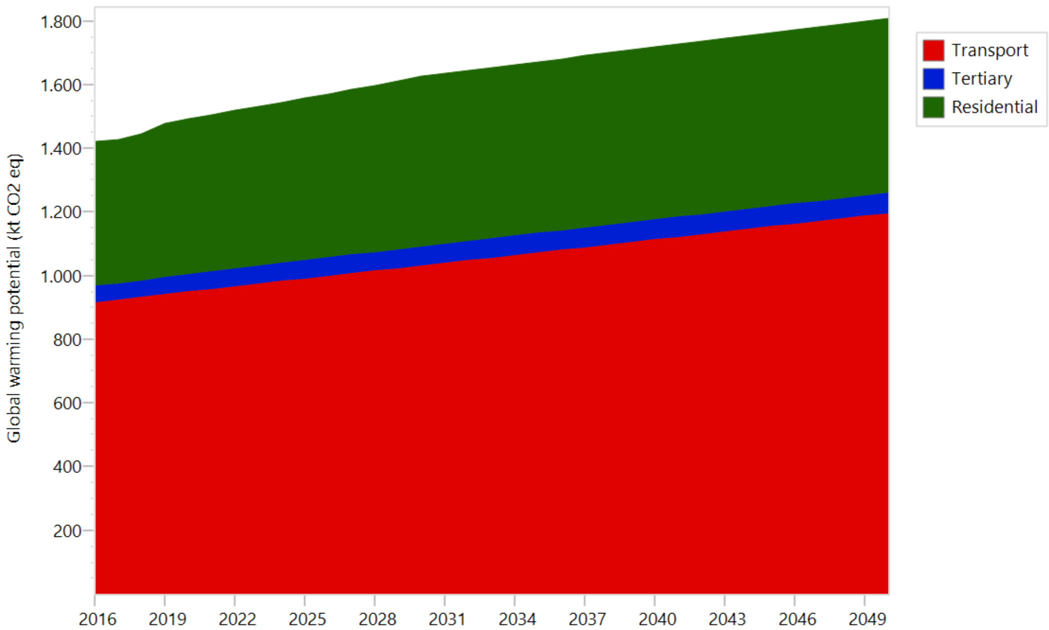


Figure 87: Kadiköy's global warming potential (kt CO_2eq) in the supply side for the scenario BaU

From Figure 86, it is expected to understand that combustion of fossil fuels in transport causes a large amount of GHG emissions, as observed in Figure 87, whereas natural gas burnt in residential sector is so large to have a weight in the total emitting profile of Kadiköy. Accordingly, regarding conclusions on hotspots to tackle in Task 1.5, both residential and transport decarbonisation will be crucial areas to design and deploy measures through alternative scenario narratives.

Finally, a Sankey diagram on the energy system for the reference year of the city has been included (see Figure 88).

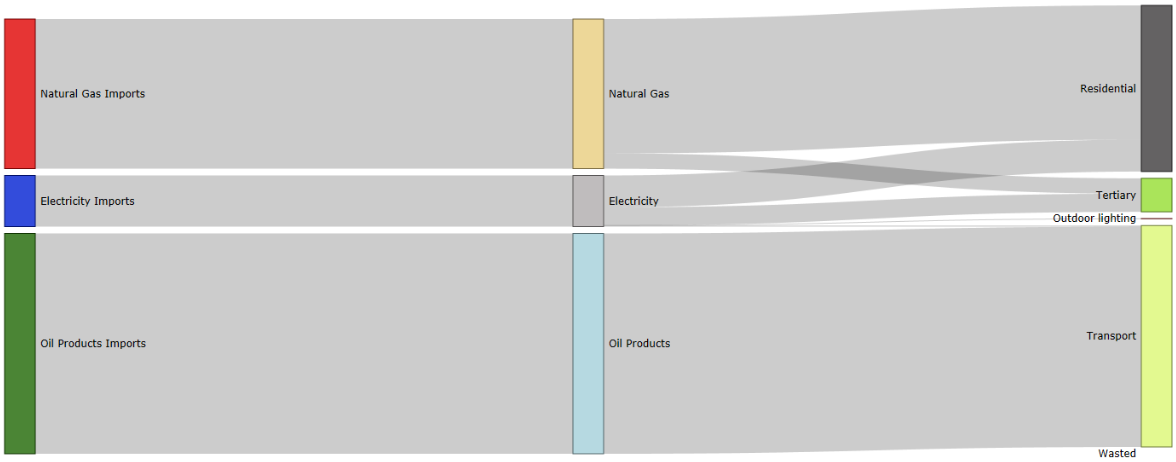


Figure 88: Sankey diagram of Kadiköy's energy flows in BaU scenario (2016)

The energy balance plotted in Figure 88 for Kadiköy in the reference year says that natural gas imports are huge, and they go to satisfy residential and tertiary needs. Almost all electricity is imported from the national grid and is consumed similarly both in residential and tertiary at the same pace. Finally, oil products are imported completely and consumed in transport.

Appendix V - Citizen and stakeholder engagement

PROCESS FOR THE DESIGN OF THE CITIZEN & STAKEHOLDER ENGAGEMENT STRATEGY (Task 1.5.2)

1. Identify the **ACTORS**: civil society, professionals from Energy, Mobility, ICT sectors, urban related fields, public administration, research and knowledge creation (From WP6)
   Note: They must be interested parties to contribute to the strategy. Their role must be clearly defined
2. The **main objectives, PURPOSE** to be achieved with the strategy:
   - What do we want to reach? Examples: Co-creation, Open innovation, resource efficiency, inclusiveness, legitimacy, ETC.
     Note: Think on the culture of the city: the customs and beliefs, way of life and social organisation of a particular group of people. Cultures can be country, region, city or even district-specific.
   - Where? In what sectors: in Energy, Mobility, ICT, Environment, Policy and Planning, Social.
   - When? When would they come into action during the process, in what phase? In planning & design (when all options are still opened) or implementation (when most of the decisions have been already taken). What the timing is?
     Note: This influences the potential impact stakeholders can still have and the type of activities the city can organize. Ideally, citizen engagement is initiated even before the start of any other activity. This allows citizens to be involved in the problem definition, and even the governance of the engagement activities themselves.

3. To detect the main **BARRIERS** or bottlenecks to achieve the objectives identified and the **ENABLERS**. Identify also the lessons learnt from other past experiences if any.
   Note: Consider problems' size: simple or complex, well known or new, impact a limited number of people or have far-reaching consequences for a large community.
4. To define **SOLUTIONS** to overcome the identified barriers or bottlenecks.
5. In what **FORMAT**? Offline/Online?
   Note: Online activities and tools can be very useful (can be organised quickly, high degree of responsiveness, broad reach, etc.). Offline and face-to-face engaging actions are also important to establish personal connections. Online platforms to be complemented by more small scale, neighbourhood level face-to-face meetings. Besides, even today not everyone is active online.
6. What **tools/resources** would be needed or desirable to implement it. Are them available? What would be the budget required?

NOTES:

This process was shared/refined with Cities by Sept 2020.

It has been developed in collaboration with Demir and will be tested in a workshop in the beginning of 2021

Should be applicable to every level, boundary or size (City, PED, etc.)

The possible approaches/methods to consider in point 2 and their definition will be included so that every city selects the most appropriate one for their case: Systemic approach, Co-creation, Co-design, etc.

We should include some helping material, with examples of strategies outcomes from other cities (https://smartcities-infosystem.eu/sites/www.smartcities-infosystem.eu/files/scis_library/scis_solution_booklet_citizen_engagement.pdf

Bibliography

[1] L. G. Swan and V. I. Ugursal, "Modeling of end-use energy consumption in the residential sector: A review of modeling techniques," *Renew. Sustain. Energy Rev.*, vol. 13, no. 8, pp. 1819–1835, 2009.

[2] M. Kavgic, A. Mavrogianni, D. Mumovic, A. Summerfield, Z. Stevanovic, and M. Djurovic-petrovic, "A review of bottom-up building stock models for energy consumption in the residential sector," vol. 45, no. 2010, pp. 1683–1697, 2010.

[3] L. Bourdic and S. Salat, "Building energy models and assessment systems at the district and city scales: a review," *Build. Res. Inf.*, vol. 40, no. 4, pp. 518–526, 2012.

[4] E. Naber, R. Volk, and F. Schultmann, "From the building level energy performance assessment to the national level : How are uncertainties handled in building stock models," *Procedia Eng.*, vol. 180, pp. 1443–1452, 2017.

[5] D. Robinson *et al.*, "CITYSIM: Comprehensive Micro-Simulation Of Resource Flows For Sustainable Urban Planning," *Int. IBPSA Conf.*, pp. 1083–1090, 2009.

[6] H. Erhorn-kluttig, H. Erhorn, J. Weber, S. Wössner, and E. Budde, "The District Energy Concept Adviser : a software tool to support urban decision makers in planning district energy supply schemes," pp. 721–727.

[7] N. Heeren, M. Jakob, G. Martius, N. Gross, and H. Wallbaum, "A component based bottom-up building stock model for comprehensive environmental impact assessment and target control," *Renew. Sustain. Energy Rev.*, vol. 20, pp. 45–56, 2013.

[8] M. Mattinen, J. Heljo, J. Vihola, A. Kurvinen, S. Lehtoranta, and A. Nissinen, "Modeling and visualization of residential sector energy consumption and greenhouse gas emissions," *J. Clean. Prod.*, vol. 81, pp. 70–80, Oct. 2014.

[9] J. Brenner, "Anforderungen an energieeffiziente und klimaneutrale Quartiere (EQ): Ein Projekt des Forschungsprogramms Experimenteller Wohnungs- und Städtebau (ExWoSt) ist ein Forschungsprogramm des Bundesministeriums für Verkehr , Bau und Stadtentwicklung (BMVBS) ," vol. 81, 2013.

[10] A. Mastrucci, O. Baume, F. Stazi, and U. Leopold, "Estimating energy savings for the residential building stock of an entire city: A GIS-based statistical downscaling approach applied to Rotterdam," *Energy Build.*, vol. 75, pp. 358–367, Jun. 2014.

[11] G. Kazas, E. Fabrizio, and M. Perino, "Energy demand profile generation with detailed time resolution at an urban district scale : A reference building approach and case study," *Appl. Energy*, vol. 193, pp. 243–262, 2017.

[12] C. Hachem, A. Athienitis, and P. Fazio, "Evaluation of energy supply and demand in solar neighborhood," *Energy Build.*, vol. 49, pp. 335–347, 2012.

[13] R. Bu, A. Froemelt, N. Heeren, M. Raubal, and S. Hellweg, "Big data GIS analysis for novel approaches in building stock modelling," vol. 208, no. November, pp. 277–290, 2017.

[14] J. Huang, H. Akbari, L. Rainer, and R. Ritschard, *481 Prototypical commercial buildings for 20 urban market areas*. 1991.

[15] Y. Joe Huang, "A Bottom-Up Engineering Estimate of the Aggregate Heating and Cooling Loads of the Entire US Building Stock," vol. 10, Jan. 2000.

[16] P. Jones and S. Lannon, "Modelling building energy use at urban scale," 2001.

[17] R. Choudhary, "A probalistic model for assessing energy consumption of the non-domestic building stock," *Build. Simul.*, pp. 14–16, 2011.

[18] EUROSTAT, "Building." 2019.

[19] C. Kunze and R. Hecht, "Semantic enrichment of building data with volunteered geographic information to improve mappings of dwelling units and population," *Comput. Environ. Urban Syst.*, vol. 53, pp. 4–18, 2015.

[20] P. Nageler, G. Zahrer, R. Heimrath, T. Mach, F. Mauthner, and I. Leusbrock, "Novel validated method for GIS based automated dynamic urban building energy simulations," *Energy*, vol. 139, pp. 142–154, 2017.

[21] A. Hartmann, G. Meinel, R. Hecht, and M. Behnisch, "A Workflow for Automatic Quantification of Structure and Dynamic of the German Building Stock Using Official Spatial Data," 2016.

[22] S. Evans, R. Liddiard, P. Steadman, S. Evans, and R. Liddiard, "Modelling a whole building stock : domestic , non- domestic and mixed use Modelling a whole building stock : domestic , non-domestic and mixed use," vol. 3218, 2019.

[23] U.S. Department of Energy, "Energy Plus." .

[24] I. Andríc *et al.*, "Modeling the long-term effect of climate change on building heat demand : Case study on a district level," vol. 126, pp. 77–93, 2016.

[25] T. Santos, N. Gomes, S. Freire, M. C. Brito, L. Santos, and J. A. Tenedório, "Applications of solar mapping in the urban environment," *Appl. Geogr.*, vol. 51, pp. 48–57, 2014.

[26] C. O. Wene, "Energy-economy analysis: Linking the macroeconomic and systems engineering approaches," *Energy*, vol. 21, no. 9, pp. 809–824, 1996.

[27] P. I. Helgesen, "Top-down and Bottom-up : Combining energy system models and macroeconomic general equilibrium models," *Cent. Sustain. Energy Stud. Work. Pap.*, p. 30, 2013.

[28] M. Grubb, "The Costs of Limiting Fossil-Fuel CO2 Emissions: A Survey and Analysis," *Annu. Rev. Energy Environ.*, 1993.

[29] R. Murphy, N. Rivers, and M. Jaccard, "Hybrid modeling of industrial energy consumption and greenhouse gas emissions with an application to Canada," *Energy Econ.*, 2007.

[30] J. Algehed, S. Wirsenius, and J. Jönsson, "Modelling energy efficiency and carbon dioxide emissions in energy-intensive industry under stringent CO 2 policies : comparison of top-down and bottom-up approaches and evaluation of usefulness to policy makers," *Eur. Counc. an energy Effic. Econ.*, pp. 1181–1191, 2009.

[31] T. Fleiter, E. Worrell, and W. Eichhammer, "Barriers to energy efficiency in industrial bottom-up energy demand models - A review," *Renew. Sustain. Energy Rev.*, vol. 15, no. 6, pp. 3099–3111, 2011.

[32] A. Herbst, F. Toro, F. Reitze, and E. Jochem, "Introduction to energy systems modelling," *Swiss J. Econ. Stat.*, vol. 148, no. 2, pp. 111–135, 2012.

[33] J. R. McFarland, J. M. Reilly, and H. J. Herzog, "Representing energy technologies in top-down economic models using bottom-up information," *Energy Econ.*, vol. 26, no. 4, pp. 685–707, 2004.

[34] N. Van Beeck, "Classification of energy models," no. May, 1999.

[35] D. Connolly, H. Lund, B. V. Mathiesen, and M. Leahy, "A review of computer tools for analysing the integration of renewable energy into various energy systems," *Appl. Energy*, vol. 87, no. 4, pp. 1059–1082, 2010.

[36] P. J. Chévez, I. Martini, and C. Discoli, "Methodology developed for the construction of an urban-energy diagnosis aimed to assess alternative scenarios: An intra-urban approach to foster cities' sustainability," *Appl. Energy*, vol. 237, no. December 2018, pp. 751–778, 2019.

[37] P. Nojedehi, M. Heidari, A. Ataei, M. Nedaei, and E. Kurdestani, "Environmental assessment of

energy production from landfill gas plants by using Long-range Energy Alternative Planning (LEAP) and IPCC methane estimation methods: A case study of Tehran," *Sustain. Energy Technol. Assessments*, vol. 16, no. 2016, pp. 33–42, 2016.

[38] F. M. de A. Collaço, L. P. Dias, S. G. Simoes, T. Pukšec, J. Seixas, and C. Bermann, "What if São Paulo (Brazil) would like to become a renewable and endogenous energy -based megacity?," *Renew. Energy*, vol. 138, pp. 416–433, 2019.

[39] R. Chen, Z. Rao, G. Liu, Y. Chen, and S. Liao, "The long-term forecast of energy demand and uncertainty evaluation with limited data for energy-imported cities in China: A case study in Hunan," *Energy Procedia*, vol. 160, no. 2018, pp. 396–403, 2019.

[40] H. Chen and W. Chen, "Carbon mitigation of China's building sector on city-level: Pathway and policy implications by a low-carbon province case study," *J. Clean. Prod.*, vol. 224, pp. 207–217, 2019.

[41] G. Hu, X. Ma, and J. Ji, "Scenarios and policies for sustainable urban energy development based on LEAP model – A case study of a postindustrial city: Shenzhen China," *Appl. Energy*, vol. 238, no. January, pp. 876–886, 2019.

[42] J. Lin, J. Kang, N. Khanna, L. Shi, X. Zhao, and J. Liao, "Scenario analysis of urban GHG peak and mitigation co-benefits: A case study of Xiamen City, China," *J. Clean. Prod.*, vol. 171, pp. 972–983, 2018.

[43] J. Lin, J. Kang, X. Bai, H. Li, X. Lv, and L. Kou, "Modeling the urban water-energy nexus: A case study of Xiamen, China," *J. Clean. Prod.*, vol. 215, pp. 680–688, 2019.

[44] D. Yang, B. Liu, W. Ma, Q. Guo, F. Li, and D. Yang, "Sectoral energy-carbon nexus and low-carbon policy alternatives: A case study of Ningbo, China," *J. Clean. Prod.*, vol. 156, pp. 480–490, 2017.

[45] D. Zhang, G. Liu, C. Chen, Y. Zhang, Y. Hao, and M. Casazza, "Medium-to-long-term coupled strategies for energy efficiency and greenhouse gas emissions reduction in Beijing (China)," *Energy Policy*, vol. 127, no. December 2018, pp. 350–360, 2019.

[46] B. Turnheim *et al.*, "Evaluating sustainability transitions pathways: Bridging analytical approaches to address governance challenges," *Glob. Environ. Chang.*, vol. 35, pp. 239–253, 2015.

[47] S. Bolwig *et al.*, "Review of modelling energy transitions pathways with application to energy system flexibility," *Renew. Sustain. Energy Rev.*, vol. 101, pp. 440–452, 2019.

[48] Oxford College of Marketing, "What is a PESTEL analysis? - Oxford College of Marketing Blog," *Oxford*, 2016. .

[49] "J. N. Ferrer, I. Taranic, K. Veum, P. van den Oosterkamp, and C. Wilson, 'The making of a smart city: replication and scale-up of innovation in Europe,' 2017."

[50] "A. Kumar et al., 'A review of multi criteria decision making (MCDM) towards sustainable renewable energy development,' Renew. Sustain. Energy Rev., vol. 69, no. March, pp. 596–609, 2017."

[51] "K. Govindan and M. B. Jepsen, 'ELECTRE: A comprehensive literature review on methodologies and applications,' Eur. J. Oper. Res., vol. 250, no. 1, pp. 1–29, Apr. 2016."

[52] "I. Y. Kim and O. L. De Weck, 'Adaptive weighted sum method for multiobjective optimization: A new method for Pareto front generation,' Struct. Multidiscip. Optim., vol. 31, no. 2, pp. 105–116, 2006."

[53] "R. T. Marler and J. S. Arora, 'The weighted sum method for multi-objective optimization: New insights,' Struct. Multidiscip. Optim., vol. 41, no. 6, pp. 853–862, 2010."

[54] "H.-S. Shih, H.-J. Shyur, and E. Lee, 'An extension of TOPSIS for group decision making,' Math. Comput. Model., vol. 45, pp. 801–813, Apr. 2007."

[55] "K. Shahroodi, Kambiz; Keramatpanah, Amin; Amini, Shabnam; Sayyad Haghighi, 'Application of Analytical Hierarchy Process (AHP) Technique to Evaluate and Selecting Suppliers in an Effective Supply Chain,' Kuwait Chapter Arab. J. Bus. Manag., 2012."

[56] "M. Ilangkumaran, V. Sasirekha, L. Anojkumar, and M. Raja, 'Machine tool selection using AHP and VIKOR methodologies under fuzzy environment,' Int. J. Model. Oper. Manag., vol. 2, p. 409, Jan. 2012."

[57] "J.-P. Brans and B. Mareschal, 'Promethee Methods,' in Multiple Criteria Decision Analysis: State of the Art Surveys, New York, NY: Springer New York, 2005, pp. 163–186."

[58] "M. Wang, S. Liu, S. Wang, and K. K. Lai, 'A weighted product method for bidding strategies in multi-attribute auctions,' J. Syst. Sci. Complex., vol. 23, no. 1, pp. 194–208, 2010."

[59] D. Ürge-Vorsatz *et al.*, "Measuring multiple impacts of low-carbon energy options in a green economy context," *Appl. Energy*, vol. 179, pp. 1409–1426, 2016.

[60] E. Igos, B. Rugani, S. Rege, E. Benetto, L. Drouet, and D. S. Zachary, "Combination of equilibrium models and hybrid life cycle-input-output analysis to predict the environmental impacts of energy policy scenarios," *Appl. Energy*, vol. 145, pp. 234–245, 2015.

[61] A. Mirakyan and R. De Guio, "Integrated energy planning in cities and territories: A review of methods and tools," *Renew. Sustain. Energy Rev.*, vol. 22, pp. 289–297, 2013.

[62] A. Rose and W. Miernyk, "Input–Output Analysis: The First Fifty Years," *Econ. Syst. Res.*, vol. 1, no. 2, 1989.

[63] M. D. Partridge and D. S. Rickman, "Computable General Equilibrium (CGE) Modelling for Regional Economic Development Analysis," *Reg. Stud.*, vol. 44, no. 10, 2010.

[64] W. Leontief, "The Structure of the American Economy, 1919e1939," *Oxford Univ. Press. Oxford, UK.*, 1941.

[65] B. Wicke, E. Smeets, A. Tabeau, J. Hilbert, and A. Faaij, "Macroeconomic impacts of bioenergy production on surplus agricultural land-A case study of Argentina," *Renew. Sustain. Energy Rev.*, vol. 13, no. 9, pp. 2463–2473, 2009.

[66] K. Kratena, "Un Modelo Input-Output para la Cuantificación del Impacto Macroeconómico (MIOCIM)," 2015.

[67] E. Arrizabalaga, "Multi-criteria methodology for the prioritisation of alternative energy transition scenarios of cities," University of the Basque Country, 2017.

[68] Arrizabalaga, E., García-Gusano, D., Hernandez, P., "P.,16 - Toward sustainable long-term energy planning for cities: an economic and environmental assessment of sustainable fuel technologies in the city of Donostia-San Sebastián," in *Sustainable Fuel Technologies Handbook, Academic Press*, Dutta, Suman and C. M. Hussain, Eds. 2021, p. Pages 483-510.

[69] "The World Input-Output Database (WIOD): Contents, Sources and Methods. Marcel Timmer (University of Groningen), 2012."

[70] E. Gorevaya and M. Khayrullina, "Evolution of Business Models: Past and Present Trends," *Procedia Econ. Financ.*, 2015.

[71] M. Spring, "Which business models might ensure UK value from emerging sectors ?," *Futur. Manuf. Proj. Evid. Pap. 33*, pp. 1–48, 2013.

[72] L. Anthopoulos, P. Fitsilis, and C. Ziozias, "What is the source of smart city value? A business model analysis," *Int. J. Electron. Gov. Res.*, vol. 12, no. 2, pp. 56–76, 2016.

[73] P. Lindgren, "Multi Business Model Innovations in a World of 5G-Towards a World of Advanced Persuasive Business Models Embedded with Sensor- and Persuasive Technologies," *5G Outlook - Innov. Appl.*, pp. 211–224, 2016.

[74] European Commission, “EU Buildings Stock Observatory.” 2017.

[75] European Union, “TABULA WebTool.” .

[76] European Union’s Horizon 2020 research and innovation programme, “mySMARTLife Project.” Grant Agreement 731297 — H2020-SCC-2016-2017/H2020-SCC-2016.

[77] European Union’s Horizon 2020 research and innovation programme, “MAtchUP Project.” Grant Agreement 774477 — H2020-SCC-2016-2017/H2020-SCC-2017.

[78] Ministerio de Fomento, “Código técnico de la edificación. Documento Básico de Ahorro de Energía.” .

[79] R. Kemna and J. Acedo, “Average EU building heat load for HVAC equipment,” *Final Rep. Framew. Contract ENER C*, no. August, 2014.

[80] N. Harmati and Z. Magyar, “Influence of WWR, WG and glazing properties on the annual heating and cooling energy demand in buildings,” in *Energy Procedia*, 2015, vol. 78, pp. 2458–2463.

[81] X. Oregi, P. Hernandez, and R. Hernandez, “Analysis of life-cycle boundaries for environmental and economic assessment of building energy refurbishment projects,” *Energy Build.*, vol. 136, pp. 12–25, 2017.

[82] F. Ascione, N. Bianco, C. De Stasio, G. M. Mauro, and G. P. Vanoli, “Multi-stage and multi-objective optimization for energy retrofitting a developed hospital reference building: A new approach to assess cost-optimality,” *Appl. Energy*, vol. 174, pp. 37–68, 2016.

[83] F. Ascione, N. Bianco, R. F. De Masi, G. M. Mauro, and G. P. Vanoli, “Energy retrofit of educational buildings: Transient energy simulations, model calibration and multi-objective optimization towards nearly zero-energy performance,” *Energy Build.*, vol. 144, pp. 303–319, 2017.

[84] A. P. Melo and R. Lamberts, “Envelope insulation and heat balance in commercial buildings,” *Build. Simul.*, pp. 2243–2250, 2009.

[85] T. Buso, F. Dell’Anna, C. Becchio, M. C. Bottero, and S. P. Corgnati, “Of comfort and cost: Examining indoor comfort conditions and guests’ valuations in Italian hotel rooms,” *Energy Res. Soc. Sci.*, 2017.

[86] DesignBuilder Software Ltd, “Design Builder Simulation Tool.” Version: 3.04.041.

[87] Ministerio de Fomento, “Código Técnico de la Edificación. Documento Básico de Ahorro de Energía.” .

[88] J. Galvez-martos, D. Styles, and H. Schoenberger, “Identified best environmental management practices to improve the energy performance of the retail trade sector in Europe,” *Energy Policy*, vol. 63, pp. 982–994, 2013.

[89] EUROSTAT, Ministerio de industria energía y turismo, and IDAE, “Análisis del consumo energético del sector residencial en España,” 2011.

[90] ASHRAE Standing Standard Project Committee, “ASHRAE STANDARD,” vol. 2010, pp. 209–211, 2010.

[91] European Commission, “Cooling and heating degree days by NUTS 2 regions,” *EUROSTAT*. .

[92] P. Tuominen, R. Holopainen, L. Eskola, J. Jokisalo, and M. Airaksinen, “Calculation method and tool for assessing energy consumption in the building stock,” *Build. Environ.*, vol. 75, pp. 153–160, 2014.

[93] City of Helsinki, “Helsinki’s Energy and Climate Atlas.” .

[94] M. Hukkalainen (née Sepponen), M. Virtanen, S. Paiho, and M. Airaksinen, “Energy planning of low carbon urban areas - Examples from Finland,” *Sustain. Cities Soc.*, vol. 35, no. April, pp. 715–728, 2017.

[95] BPIE, *Europe's buildings under the microscope*. 2011.

[96] A. Ruusala, A. Laukkarinen, and J. Vinha, "Energy consumption of Finnish schools and daycare centers and the correlation to regulatory building permit values," *Energy Policy*, vol. 119, pp. 183–195, 2018.

[97] T. Sekki, M. Airaksinen, and A. Saari, "Measured energy consumption of educational buildings in a Finnish city," *Energy Build.*, vol. 87, pp. 105–115, 2015.

[98] Enerdata, "Odyssee-Mure." .

[99] "Italian Energy Efficiency Action Plan June 2017," no. June, 2017.

[100] European Union, "EU Building Stock Observatory database." .

[101] Ministerio de hacienda and Dirección General del Catastro, "Sede Electrónica del Catastro." .

[102] M. L. Luis and J. Las-heras-casas, "Energy performance certificates as tools for energy planning in the residential sector. The case of La Rioja (Spain)," vol. 137, pp. 1280–1292, 2016.

[103] Ministerio de Fomento, "Estudio de la distribución del consumo energético residencial para calefacción en España." p. 185, 2017.

[104] J. Las-heras-casas, L. M. López-ochoa, L. M. López-gonzález, and J. P. Paredes-sánchez, "A tool for verifying energy performance certificates and improving the knowledge of the residential sector : A case study of the Autonomous Community of Aragón (Spain)," *Sustain. Cities Soc.*, vol. 41, no. May, pp. 62–72, 2018.

[105] L. Itard and H. Visscher, "Statistical model of the heating prediction gap in Dutch dwellings : Relative importance of building , household and behavioural characteristics Daˇ," vol. 105, no. 2015, pp. 43–59, 2020.

[106] D. Majcen, L. C. M. Itard, and H. Visscher, "Theoretical vs . actual energy consumption of labelled dwellings in the Netherlands : Discrepancies and policy implications," *Energy Policy*, vol. 54, pp. 125–136, 2013.

[107] M. Sunikka-blank, R. Galvin, M. Sunikka-blank, and R. Galvin, "Introducing the prebound effect : the gap between performance and actual energy consumption.," no. June, pp. 37–41, 2012.

[108] Central Statistical Office and The Polish National Energy Conservation Agency (KAPE), "Energy Efficiency trends and policies in Poland in years 2006-2016," 2018.

[109] Ministry of Economy, "National Energy Efficiency Action Plan for Poland." 2014.

[110] Enerdata, "Odyssee - Mure Key indicators." .

[111] European Commission, "EU Buildings Factsheets - Slovakia." .

[112] T. Csoknyai *et al.*, "Building stock characteristics and energy performance of residential buildings in Eastern-European countries," *Energy Build.*, vol. 132, pp. 39–52, 2016.

[113] Ministry of Economy and Energy, "National Energy Efficiency Action Plan - REPUBLIC OF BULGARIA," no. July. pp. 1–93, 2014.

[114] European Commission, "EU Buildings Factsheets - Bulgaria." .