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D6.6.- COMPILATION OF ENERGY SYSTEM SCENARIOS FOR EACH FOLLOWER CITY

WP6, Task 6.2

Transition of EU cities towards a new concept of Smart Life and Economy

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Project Acronym	mySMARTLife		
Project Title	**Transition of EU cities towards a new concept of Smart Life and Economy**		
Project Duration	1st December 2016 – 30th November 2021 (60 Months)		
Deliverable	D6.6 Compilation of energy system scenarios for each follower city		
Diss. Level	PU		
Status	☐ Working		
	☐ Verified by other WPs		
	■ Final version		
Due date	31/03/2019		
Work Package	WP6		
Lead beneficiary	TECNALIA		
Contributing beneficiary(ies)	NBK, CAR, BYD, RIJ, PAL		
Task description	Task 6.2: The working methodology of Task 1.4 will be replicated with follower cities in order to evaluate impacts in follower cities (BYD, RIJ, PAL) from the social, economic and environmental field to understand the interaction of the different interventions as a system. Subtask 6.2.2: Simulation of the demand side for the next 10-20 years. In this subtask simulations of demand, forecasting will be done by the cities by using tools that take into account the whole energy system (EnergyPlan or similar). Cities will be supported by technical partners, and different scenarios will be provided according to different type of sources.		

Date	Version	Author	Comment
30/01/2019	0.1	Eneko Arrizabalaga Iñigo Muñoz (TEC)	Interim Version
15/02/2019	0.2	Eneko Arrizabalaga Iñigo Muñoz (TEC)	Intermediate version
15/03/2019	0.3	Eneko Arrizabalaga Iñigo Muñoz (TEC)	Version for review
31/03/2019	0.3	Eneko Arrizabalaga Iñigo Muñoz (TEC) Internal review by HCU And CER	Reviewed version

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Abbreviations and Acronyms

Acronym	Description
BaU	Business as usual
D	Deliverable
DH	District Heating
DHW	Domestic hot water
EV	Electric vehicles
GDP	Gross Domestic Product
GDPP	Gross Domestic Product per Capita
GHG	Greenhouse gases
LED	Light-emitting diode
LPG	Liquid petroleum gas
mySMARTLife	Transition of EU cities towards a new concept of Smart Life and Economy
PV	Photovoltaic
RES	Renewable energy source
VA	Value added

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1. Executive Summary

The main objective of mySMARTLife project is the demonstration of the Innovative Transformation Strategy concept through piloting different actions, considering advanced technologies, towards the global transformation of the urban life in the cities. The methodology that will be applied in the three Lighthouse cities will foster the replication of the foreseen actions, at different levels, in the follower cities and the smart city network that will be created during the project lifetime.

As a global vision, mySMARTLife will follow the next approach:

Figure 1: Global vision of the mySMARTLife Project

This Urban Transformation Strategy aims to respond in a holistic and integrated way to the transformation process, overcoming the existing technical and non-technical barriers. During this process the technical support to the different phases is a critical issue. In this regard, the application of existing methods and tools, as well as the development and the adaptation of new methods is essential to provide the needed criteria for the prioritization of measures that will guide this transformation.

In this framework, the deliverable D6.6 aims to describe the energy scenarios developed for the next 10-20 years for the three follower cities of the project. It is necessary to remark that these scenarios and this report in general focus on trend projection (not forecasts). Therefore, it does not predict how the energy, transport and climate landscape will change in the future for the cities, but merely provides a model-derived simulation of one of its possible future states given some certain conditions.

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2. Introduction

2.1 Purpose and target group

This deliverable is allocated within Task 6.2, which is related to evaluating the replication potential in follower cities (Palencia, Rijeka and Bydgoszcz) covering the social, economic and environmental fields to understand the interaction of the different interventions as a system. The Advanced Integrated Urban Planning is divided in four stages, corresponding with the five deliverables of the task:

- **Deliverable 6.5:** This deliverable is related to the subtask 6.2.1 and is focused on the description of 3D models which includes the energy assessment of the area selected by each city. This is a key step, which can be scaled-up to cover a larger area of the city. Thus, it can serve to evaluate aspects that can be used to feed the different scenarios that will be evaluated for the cities in the subtask 6.2.2.
- **Deliverable 6.6:** This deliverable is related to the subtask 6.2.1 which is focused on the energy scenario development at city scale.
- **Deliverable 6.7:** This deliverable is related to the subtask 6.2.1 which is focused on the techno-economic assessment of the interventions that will be replicated by follower cities.
- **Deliverables 6.8/6.8/6.10:** These deliverables are related to the definition of the replication plan for each follower city. The information generated in this deliverable and in the above mentioned other two deliverables will generate an important part of the information needed for the definition of these plans.

The present deliverable is structured as follows:

Chapter 3: Shows the overall methodological approach to the Advanced Integrated Urban Planning in mySMARTLife project, describing the relation between the different phases of the assessment for the follower cities.

Chapter 4: Provides an introduction with the methodological approach to the city energy characterization and scenario modelling of the three follower cities.

Chapter 5: Describes more in detail the first phase of the energy scenario modelling which is focused on the base year modelling. It describes the data gathering process as well as the modelling of the base year in LEAP energy scenario modelling software. This section distinguishes the cases of the three follower cities.

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Chapter 6: Describes more in detail the second phase of the energy scenario modelling which is focused on the scenario modelling analysis. It describes the data gathering process as well as the modelling of the base Business as Usual (BaU) scenario and the replication scenarios in LEAP energy scenario modelling software. This section distinguishes the cases of the three follower cities.

Chapter 7: Describes the main conclusions obtained from the work carried out in the subtask 6.2.2.

Chapter 8: Shows the references of the literature consulted to develop the work.

2.2 Contributions of partners

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

Table 1: Contribution of partners

Participant short name	Contributions
TEC	Overall content and redaction of all the sections of the deliverable
CAR	General review of the content of the deliverable
NBK	General review of the content of the task and deliverable as WPL
PAL	Contribution (data provision) to the sections 5 and 6
RIJ	Contribution (data provision) to the sections 5 and 6
BYD	Contribution (data provision) to the sections 5 and 6
HCU	Overall review of the deliverable
CER	Overall review of the deliverable

2.3 Relation to other activities in the project

The following table depicts the main relationship of this deliverable to other activities (or deliverables) developed within the mySMARTLife 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 Number	Contributions

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D1.13	This deliverable provides the description of the energy scenario modelling each lighthouse city
D6.1	Baseline assessment & PESTEL Analysis of Palencia's Initial Replication Plan
D6.2	Baseline assessment & PESTEL Analysis of Bydgoszcz's Initial Replication Plan
D6.3	Baseline assessment & PESTEL Analysis of Rijeka's Initial Replication Plan
D6.5	This deliverable provides the compilation of the 3D modelling and energy characterization of the area selected by each follower city
D6.7	This deliverable provides the techno-economic analysis of each intervention for the replication which will depend on the results of this deliverable
D6.8	This deliverable provides the Replication Plan of the City of Palencia
D6.9	This deliverable provides the Replication Plan of the City of Bydgoszcz
D6.10	This deliverable provides the Replication Plan of the City of Rijeka

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3. Overall methodological approach to the Advanced Integrated Urban Planning in mySMARTLife project

This section aims to provide a general overview of the overall methodological and modelling approach of the Advanced Integrated Urban Planning of mySMARTLife project. The figure below shows how each of the phases of the methodology corresponds with the different subtasks of the Task 6.2 of the project and how each subtask contributes to the rest with their corresponding outcomes.

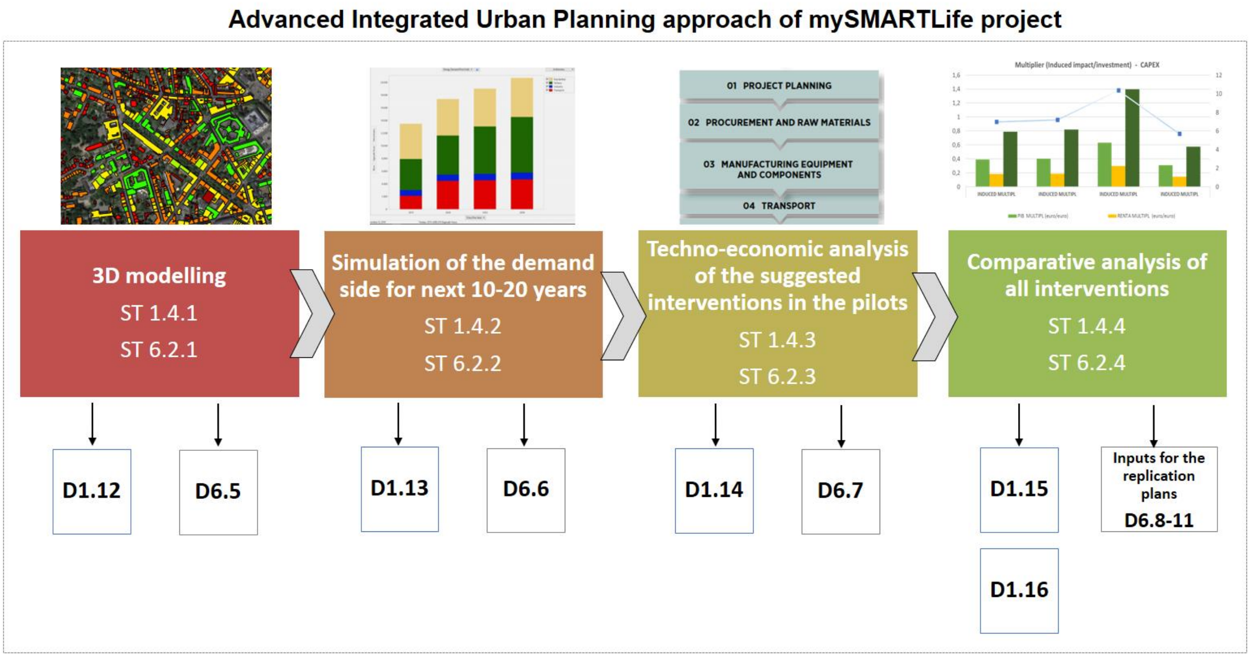

Figure 2: Methodological approach of the Advanced Integrated Urban Planning in mySMARTLife project.

The methodology is composed by four main phases that correspond with the main subtasks showed in the figure above. It can be seen that the entire process is applied to both the lighthouse and to the follower cities of the project. The analysis is first applied to lighthouse cities (in WP1) and with the experience gained and with the lessons learnt, it is applied in a second step to the follower cities of the project (in the subtasks specified within the WP6).

The **first phase** is focused on the **3D modelling and energy demand analysis** of the three lighthouse cities. The 3D modelling is applied at city scale to prepare the data available in the city in the way that is required for the energy modelling of the building stock. In this phase, the area selected in each city is evaluated through an energy model. The energy modelling evaluates the energy demand of the building stock taking into account several characteristics that are specific for each building. The results of the

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modelling provide the hourly energy demands (heating, cooling, DHW) and the hourly electricity consumption (lighting, equipment, etc.) individually for each building but also in an aggregated way according to a classification depending on the construction period and use of the buildings. The procedure is carried out in a way that the model is calibrated so that it can be used for other areas of the city or for the entire city. The visual representation of the results allows a quick understanding of the energy needs of the city but also an initial idea of the refurbishment potential or the potential for the implementation of renewable energy technologies, such as the solar thermal and the solar photovoltaic systems. This is a bottom-up modelling approach that provides some specific results that are useful for the scenario definition in the following phase of the methodology, which follows a top-down approach to the city energy modelling. The main outputs of this phase are the deliverables D1.12 and D6.5.

The **second phase** of the modelling methodology is focused on **simulating the energy demand for the next 10-20 years for the city**. In this case, the entire city is evaluated including not only the built environment but also the rest of the sectors of the city such as the industry and mobility. In this case other types of modelling tools are required to define the energy matrix of the city (Sankey diagram) for the base year. Then, the evolution of several characteristics (such as the evolution of the socioeconomic characteristics of the city; population, GDP, etc.) are evaluated for each city, establishing the interrelation between these parameters and the future energy needs of the city. This will allow to generate the Business as Usual (BaU) scenario for the city, which defines the expected evolution of the energy demands/consumptions of the different sectors of the city, as well as the required local energy generation or the energy import needs in the following years. This BaU scenario is the base for future evaluations of the expected impact of alternative efficient scenarios that can be proposed for the cities. As explained before, the potential results of the modelling in the first phase can serve to define some aspects of these alternative scenarios. The main outputs of this phase are the deliverables D1.13 and D6.6.

The **third phase** is focused on the **technoeconomic analysis of the suggested interventions in the pilots**. In this case, a supply chain analysis is carried out for the interventions that can be implemented in the pilots, evaluating the disaggregation of the cost components that compose the intervention, as well as the existing capabilities at city/regional scale for the manufacturing or distribution of each component. Besides, an analysis of the socioeconomic structure of each city and its corresponding region is carried out to define the sectoral disaggregation that is required for the supply chain analysis. The result of this phase will be the specific “shocks” that will serve as input for the macroeconomic modelling that is carried out in the last phase of the methodology. Each intervention will be represented as a specific increase of the production of the corresponding subsectors in the region. The main outputs of this phase are the deliverables D1.14 and D6.7.

Finally, the **fourth phase** is focused on the **comparative analysis of all the interventions based on the impact assessment results**. In this phase the impact assessment of each intervention is carried out based on the results of the previous phases. On the one hand, the shocks created in the third phase are

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used to evaluate the potential impact associated to each intervention to generate a direct, indirect and induced effect in the development of several socioeconomic characteristics of the cities/regions such as the increase of the GDP or the employment. This information can also be combined with the results of the phases one and two which will provide an idea of the deployment potential of each type of intervention in the cities which will affect the final impact. Finally, this socioeconomic analysis for each intervention is combined with the expected energy and environmental impact analysis which will provide extra criteria that will be useful for the prioritization of the technologies. Here, a multicriteria methodology will be used to compare the different interventions for each city based on the expected impacts. The main outputs of this phase are the deliverables D1.15 and D1.6.

In the case of the follower cities, a similar process will be carried out to get a better understanding of the potential impact that the future implementation of actions can have in each follower city. This, as well as all the intermediate results obtained for the follower cities will be important inputs for the replication plans (D6.8-11).

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4. Methodological approach to the city energy characterization and scenario modelling of the three follower cities

4.1 General description and purpose

This section describes the methodology followed for the city energy characterization and scenario modelling. The main objective is to portray different possible future situations that the city can face in the next years as a consequence of demographic, economic and social unfolding, political actions, and external changes. The aim of these scenarios is to provide the city planners with a tool for the assessment of the different energy related interventions and policies to develop their urban action plans, seeking a reduction in the city's energy consumption and a decrease in the associated environmental emissions.

Starting from the depiction of the city's actual situation, a BaU (Business as Usual) scenario with the most likely unfolding is developed. Based on that BaU, an alternative scenario can be developed taking into account the project's interventions and allowing the evaluation of the effect of these measures in the entire city development. The figure below is a visual representation of the scenario modelling approach considered in the project.

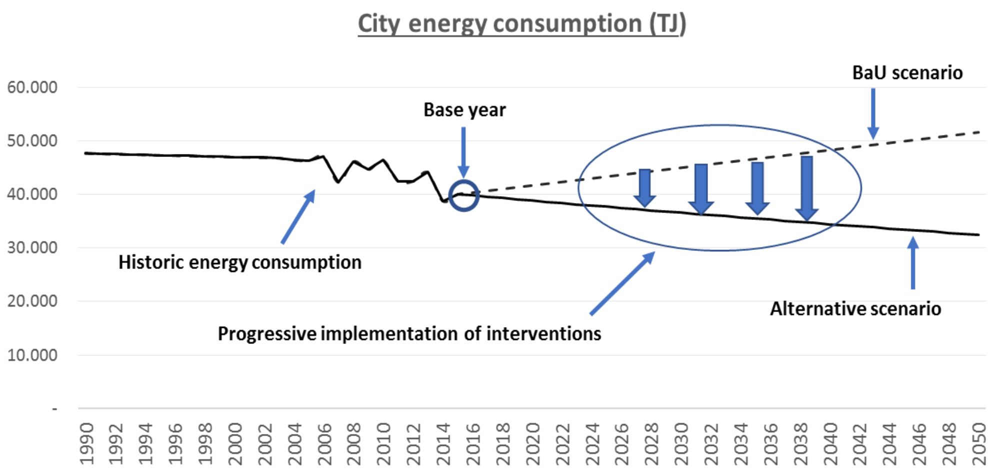

Figure 3: Scenario modelling in mySMARTLife project.

The methodology adopted for the scenario development has integrated the two energy scenario modelling approaches: Top-down and bottom-up. At a city level, characterization and evolution of the specific consumption and efficiencies of different technologies/devices, fuel shares for a given energy use, technological changes and non-price related policies allows to forecast energy consumption through a bottom-up perspective; whereas sectors and energy general consumption can be modelled following a top-down approach through use of production functions linking economic variables to energy use. In this

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case the bottom-up perspective has been considered according to the 3D modelling and energy demand analysis carried out in subtask 6.2.1.

The main steps to consider for the city scenario development is briefly explained here:

1. Information gathering and treatment for the Base year modelling of the city: data is needed to develop the model of the energy system of the city for the base year.
2. City energy modelling for the base year: the baseline is the picture of the city for the base year and the starting point for the development and analysis of scenarios.
3. Historic data analysis and driver's identification for the BaU scenario: The analysis of the historic development of the energy consumption of a city will provide the needed context for both for the selection of the drivers and for the definition of the tendencies for the following years. A driver is defined as the variable which, can be taken into account for guiding a specific sector´s energy consumption.
4. BaU scenario generation: the BaU (Business as Usual) scenario represents how the events will unfold in the expected way, based on actual and realistic trends and assumptions.
5. Alternative scenarios generation: they represent different storylines where the events unfold based on alternative (to the BaU) assumptions. Here, the analysis of the interventions that will be implemented (replicated) and deployed in the city during the following years is a critical step.

4.2 City energy modelling: Base year analysis

The first step is the modelling of the current situation of a city so that it can serve as the main starting point for the development of the future scenarios. In this step, 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 accurate) 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 with the following three main modules:

- Demand side
- Supply side
- City resources

4.2.1 Demand side module

This module defines the energy consumption of the end-use sectors within the city: residential, tertiary, industry and transport, etc. Each of one can be divided into several subsectors or sub-divisions (e.g. apartment blocks and single-family houses for the residential sector; offices buildings, educational buildings, healthcare buildings, etc. for the tertiary sector; iron and steel industry, chemical, consumer goods, etc. for the industry sector; public/private, road/non- road for the transport sector) which in turn are characterized by their final energy uses (e.g. heating and cooling, lighting, appliances, etc.). For each energy use many technologies/devices can be detailed (e.g. boiler, solar collectors, heat pumps, DH network, etc.). Finally, every technology/device needs to be defined by their fuel consumption. Thus, the city's energy consumption is determined through a bottom-up approach, with a detailed description of the energy requirement and use technologies.

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 3: Most usual disaggregation for the apartment blocks

Subsector	Final energy use	Technology	Fuel
Apartment block	Heating and DHW	Boiler	Natural gas
		District Heating	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 (for self-consumption) need to be also considered in this section by defining a relation between the energy consumed and the on-site energy generation (usually by renewable energy technologies such as the solar thermal or the solar photovoltaic among others).

4.2.2 Supply side

This module defines the energy production (and consumption) of all the transformation processes/plants within the city boundaries where primary energy is converted into final energy. The supply side produces the total or part of the energy consumed by the end-use sectors described above.

This module usually includes:

- Electricity generation processes: PV plants, hydro plants, wind farms, other non-renewable processes for electricity production, etc.
- Thermal energy generation processes: heat only boiler plants, heat pump plants, etc.
- CHP plants
- Other conversion processes: refineries, biomass treatment plants, biofuel production plants, etc.

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- Import/export: the energy needs that are not met by the local supply side will have to be supplied by the energy imports. In the same way, the energy surpluses can be exported.
- Heat and electricity networks losses: characteristics of the city's heat and power grids mainly focused on the energy losses.

Based on the final energy demand and the characteristics of the supply side (i.e. processes efficiencies, plants capacities, DH and power networks losses, etc.), the final energy requirements are calculated, and the primary energy consumed in the transformation processes in order to produce these energy requirements. Besides, in the case that the energy needs remain unmet, the energy to be imported is calculated. In the same way, if there is an energy surplus situation in the city different export options can modelled.

4.2.3 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.

4.3 City energy scenario modelling: Business as Usual (BaU) and alternative scenarios

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:

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- **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 fulfill 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 CO2 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 study 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.

4.4 Selection of the city energy modelling software

There is a wide variety of tools that could be considered for this type of analysis. The review carried out by [1] offers a complete analysis of the various tools for evaluating the energy systems at different scales. This 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, and the time-step or the modelling approach.

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

It needs to be remarked that most of the software mentioned above are not specifically designed for modelling the energy system at city scale. The most common use of these type of tools is the national energy modelling and therefore several modifications or considerations need to be done for their use for the city analysis. In this sense, LEAP offers a high flexibility.

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5. Base year modelling for the three Follower cities

5.1 Common aspects and procedures

The three follower cities have been modelled with the LEAP (Long range Energy Alternatives Planning) software. For each city, a specific energy demand and transformation tree has been adopted based on the data available. In this regard, cities have provided the information available for the modelling. In the cases in which the required information was incomplete or not available, other data sources have been used and several assumptions have been made.

For the three cities the demand side has been modelled including the principal energy consuming sectors in the cities: residential, tertiary, industry, agriculture and transport sectors. Each sector has been then disaggregated into several subsectors and energy uses according to the data available. As mentioned above when data was unavailable assumptions have been made always maintaining the coherence with the total energy consumption data supplied by the cities. Both top-down and bottom-up approaches have been used to characterize the city's energy use.

The supply side and city resources are very city-specific, and in each case the specific generation plants have been considered. This provides a specific "transformation tree" structure for each follower city.

In the cases where self-consumption needs to be considered an innovative modelling solution has been adopted in LEAP. This new procedure allows to allocate specific local energy generation to specific consumptions of the demand side, allowing also to distinguish the energy use from on-site generation respect to the rest of energy generation options.

5.2 Case of Palencia

5.2.1 General considerations

The city of Palencia is located in the northwest of Spain. Palencia is an important city of the Castilla y León region as it's the capital of the province, which has the same name. 2010 has been taken as the baseline year for the city model.

5.2.2 Data processing and base year modelling

5.2.2.1 Demand side

For this case, data supplied by the municipality was available for the year 2010. Moreover, updated information (2017) was accessible for some public sectors and has been taken into account in the scenarios.

The table below shows the followed structure to disaggregate the demand side consumption in the model:

Table 4. Palencia demand side disaggregation

Sector	Subsectors	Final uses

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<table>
<tr><td>Residential</td><td colspan="2">-</td><td>Space heating, DHW, Cooking, Cooling, Lighting, Appliances</td></tr>
<tr><td rowspan="3">Tertiary</td><td colspan="2">Private services</td><td>Heating uses, Lighting and appliances</td></tr>
<tr><td rowspan="2">Public services. Municipality</td><td>Municipal buildings and facilities</td><td>Heating uses, Lighting and appliances</td></tr>
<tr><td>Outdoor lighting</td><td>Mercury lamps, Sodium lamps, LED lamps</td></tr>
<tr><td>Industry</td><td colspan="3">No data was available about subsectors or uses, only final energy consumption by fuel has been introduced</td></tr>
<tr><td rowspan="3">Transport</td><td rowspan="2">Public vehicles</td><td>Municipal fleet</td><td>Cars, Motorcycles, Light utility vehicles, Trucks, Other vehicles</td></tr>
<tr><td>Public transport</td><td>Buses, Taxis</td></tr>
<tr><td>Private vehicles</td><td>-</td><td>Cars, Motorcycles, Light utility vehicles, Buses, Trucks, Other vehicles</td></tr>
</table>

For each final use, consumption of one or more fuels is defined filling up the final energy consumption for this specific use.

The residential sector has been disaggregated from the sector's fuel consumption by fuel following the IDAE's SPAHOUSEC [3] report for the Spanish household sector.

Table 5. Energy consumption disaggregation by fuel and use in the residential sector in Palencia

Uses	LPG	Light heating oil	Natural gas	Electricity
Space heating	47%	93%	49%	8%
DHW	34%	7%	43%	4%
Cooking	18%	-	8%	12%
Cooling	-	-	-	3%
Lighting	-	-	-	9%
Appliances	-	-	-	64%

As shown in the following figure, total consumption in the residential sector accounts for 427,79 GWh in Palencia in the baseline year. Space heating is the most consuming use with 36% share of the sector's total final consumption followed by the electricity consumed in the appliances usage (31%). This specific fuel represents 49% of the total final consumption and is consumed among all the energy usages, while natural gas (35 of the total final consumption) is mostly used in space heating and DHW uses.

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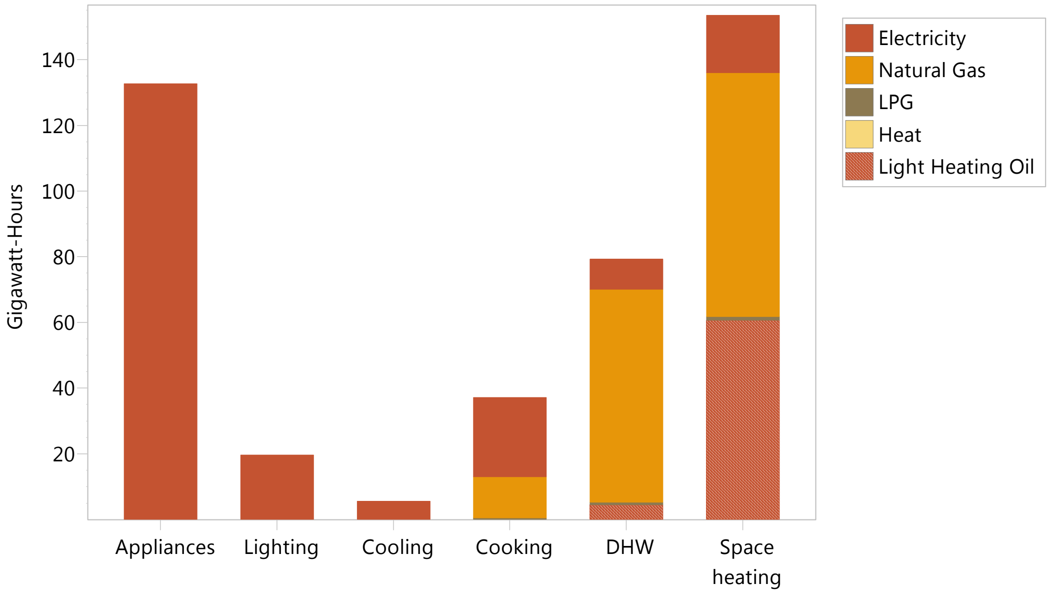

Figure 4. Residential sector consumption by fuel and use in Palencia

Energy consumption in the tertiary sector has been separated between private and public services, the latter containing the consumption of the municipal buildings and facilities and the outdoor lighting. As no specific data was available, it has been assumed that 76% of the electricity consumption is used for appliances and lighting uses, whereas the rest is consumed in heating appliances. These shares are taken from the IDAE's report used for the residential sector (see table 5). In total, 267,41 GWh were consumed in the sector. Public services only represented 6,88% of that total consumption. Electricity from PV panels installed in both public and public buildings (and modelled through a self-consumption approach) was consumed, but only symbolized 1,57% of the sector's total energy consumption.

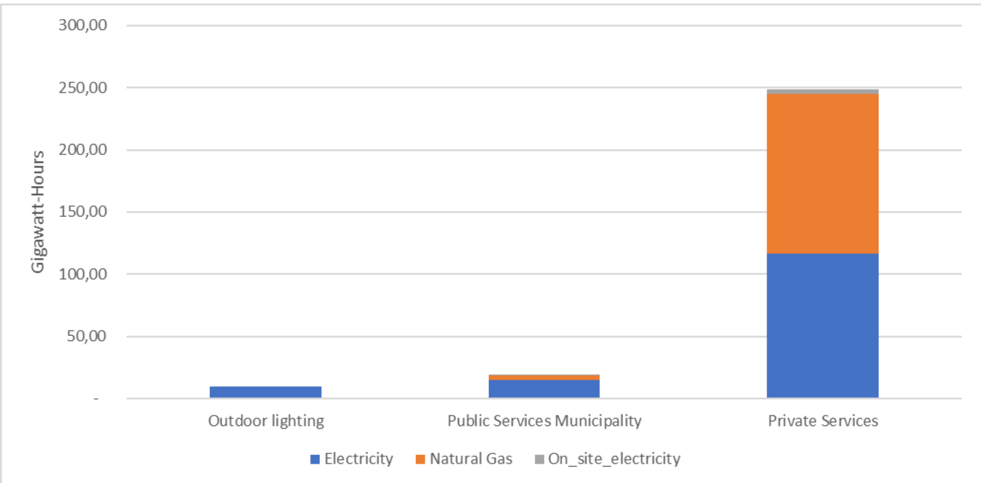

Figure 5. Tertiary sector consumption by subsector and fuel

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Finally, for the outdoor lighting, number of lamps and energy consumption was supplied by the municipality. Thus, energy intensity for each lamp type was calculated for the baseline year.

Table 6. Outdoor lighting characteristics in Palencia

Lamp type	Number of lamps (2010)	Energy intensity (MWh/lamp.year)
Mercury	1390	1,298
Sodium	10418	0,741
LED	-	0,126

Regarding the industrial sector in Palencia in the baseline year, 303,7 GWh were consumed. Electricity and natural gas were the most consumed fuels (49,12% and 30,53% share of the total final consumption respectively). Residual fuel oil was also consumed and electricity from PV facilities represented only 0,0067% of the total electric consumption of the sector.

For the transport sector, the following assumptions have been made:

Table 7. Fuel efficiencies and mileage in the Palencia model

Vehicle type	Diesel fuel efficiency(l/km) [4] [5]	Diesel mileage (km/vehicle)	Gasoline fuel efficiency(l/km)	Gasoline mileage (km/vehicle) [6] [7]
Cars	0,061	15000	0,078	10000
Motorcycles	0,049	3792	0,079	4000
Light utility vehicles	0,12	18908	0,19	18908
Buses	0,24	36849	0,24	36849
Trucks	0,4	54388	0,64	54388
Other vehicles	0,41	19298	0,66	19298

With this hypothesis and knowing the vehicle fleet of the city, an energy intensity has been calculated for each type of vehicle in order to disaggregate the sector's total consumption by fuel which was supplied by the municipality.

Table 8. Palencia transport fleet characteristics

Subsector	Type of vehicle	Number of vehicles	Energy intensity (MWh/vehicle)
Public vehicles. Municipal fleet [8]	Diesel Cars	38	1,90
	Gasoline Motorcycles	35	0,48
	Diesel Light utility vehicles	13	5,86
	Diesel Trucks	4	56,20
	Diesel Other vehicles	18	20,44

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Public vehicles. Public transport [9]	Diesel Buses		14	301,86
	Diesel Taxis		52	25,04
Private vehicles [10]	Cars	Diesel	19246	0,54
		Gasoline	17406	0,95
	Motorcycles	Diesel	38	0,11
		Gasoline	4574	0,38
	Light utility vehicles	Diesel	2661	1,33
		Gasoline	496	4,39
	Buses	Diesel	145	5,18
		Gasoline	0	-
	Trucks	Diesel	3051	12,75
		Gasoline	75	42,14
	Other vehicles	Diesel	979	4,64
		Gasoline	162	15,32

In conclusion, total final energy consumption increased to 90,93 GWh in the transport sector, of which 71,3% was diesel use and the rest gasoline consumption. The private fleet formed by both passenger and freight transport constituted 92,54% of the sector's total final consumption. The disaggregation by type of vehicle is shown below.

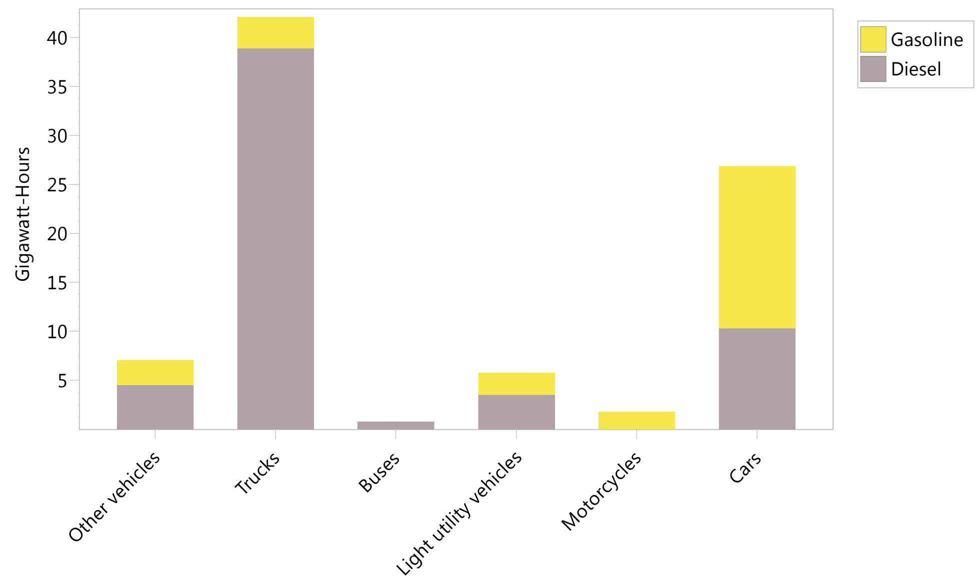

Figure 6. Private fleet energy consumption disaggregated by type of vehicle in Palencia

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For the public fleet, the energy consumption is shown in the next figures.

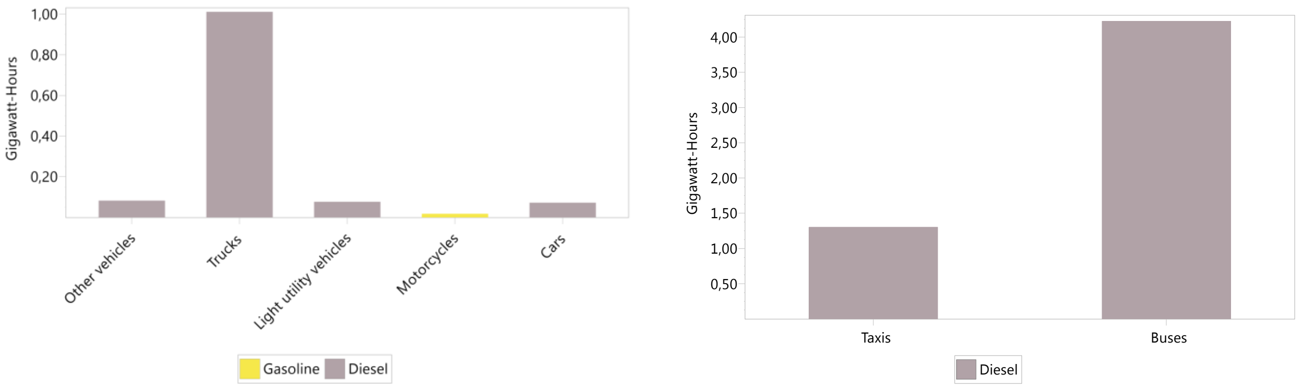

Figure 7. Municipal (left) and public transport (right) fleet consumption disaggregated by type of vehicle in Palencia (left)

5.2.2.2 Supply side

The supply side of the city of Palencia is mainly formed by small PV systems that are integrated in buildings (mostly in the tertiary sector). These facilities are able to cover a little part of the final electricity consumption of the sectors where they are installed. Hence, the electricity coming from the PV panels can be distinguished from the one that comes from the grid. The city also accounts for one mini-hydro facility which has been modelled in the same way.

The installed capacity data has been extracted from the Spanish Ministry of Ecological Transition [11] while the energy generation in the baseline year has been respected from the data given by the municipality, therefore obtaining the maximum operating hours of the PV and hydro facilities.

Table 9. On-site generation systems' characteristics in Palencia

Process/Plant name	Installed capacity (MW)	Max. operating hours	Historical production (MWh) (2015)
PV private tertiary	1,42925	28,54%	3573,35
PV public tertiary	0,0247	28,54%	61,75
PV industry	0,005	28,54%	12,50
River Hydro private tertiary	0,1	63,13%	552,99

In addition, the municipal waste treatment plant has been included too. This facility is in fact a CHP plant, however, as the heat generated is only consumed in the plant's own processes, only the electricity generation has been modelled as the heat is not injected in a District Heating network and hence not consumed in the end-use sectors.

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Table 10. Waste treatment plant's characteristics [12] in Palencia

Process/Plant name	Installed capacity (electric) (MW)	Max. operating hours (%)	Process efficiency (electric)	Historical production (MWh) (2015)
Waste treatment plant	0,499	90%	25%	3934,12

Finally, 2,36% distribution electric losses have been considered in the model.

5.2.2.3 Resources

Based on the Baseline document [13], the municipal solid waste generation in Palencia is about 0,33 ton/cap/year. It has been assumed that only 50% of the generated waste is used in the waste treatment plant, thus in the baseline year 13558 ton of waste can be used as fuel in the waste treatment plant. This number will vary in the scenarios as population will change in the future.

5.2.3 Base year summary

Total final energy consumption in the end-use sectors in 2010 accounted for 1089,83 GWh in Palencia. Residential was the most consuming sector (427,79 GWh), followed by industry (303,7 GWh) and tertiary (267,41 GWh). The transport sector only represented 8,34% of the total final consumption. The most consumed fuel was the electricity with 45,26% of the total final consumption (only 1,65% of that electric consumption came from renewable sources: (on-site generation systems and waste treatment plant, the rest being imported). Natural gas was the second most consumed fuel (34,55%) followed by diesel (11,92%, including in this share the light heating oil consumed in buildings which is in practice a very similar fuel).

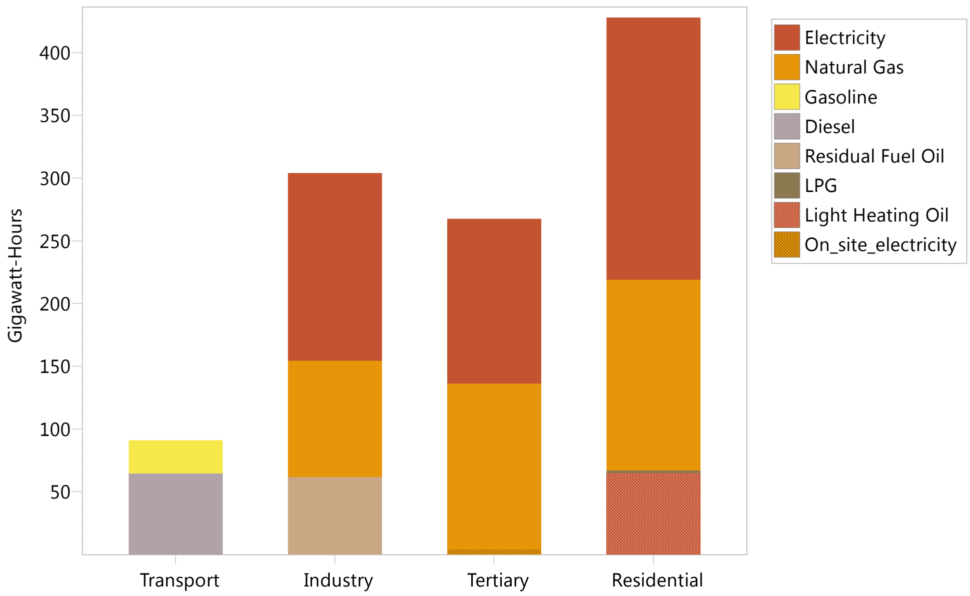

Figure 8. Final energy consumption by fuel and sector in Palencia

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Concerning the city's supply side, 4,2 GWh of electricity were generated in the on-site generation plants (PV panels integrated in buildings and mini-hydro plant), while the waste treatment plant produced 3,93 GWh of electricity which were injected to the grid. The consumption in this plant was 15,74 GWh of municipal solid waste. It should be noted that only electric generation has been considered (and not heat generation which is re-used in the plant's processes). Hence, the considered efficiency considered is low and therefore the consumption so high.

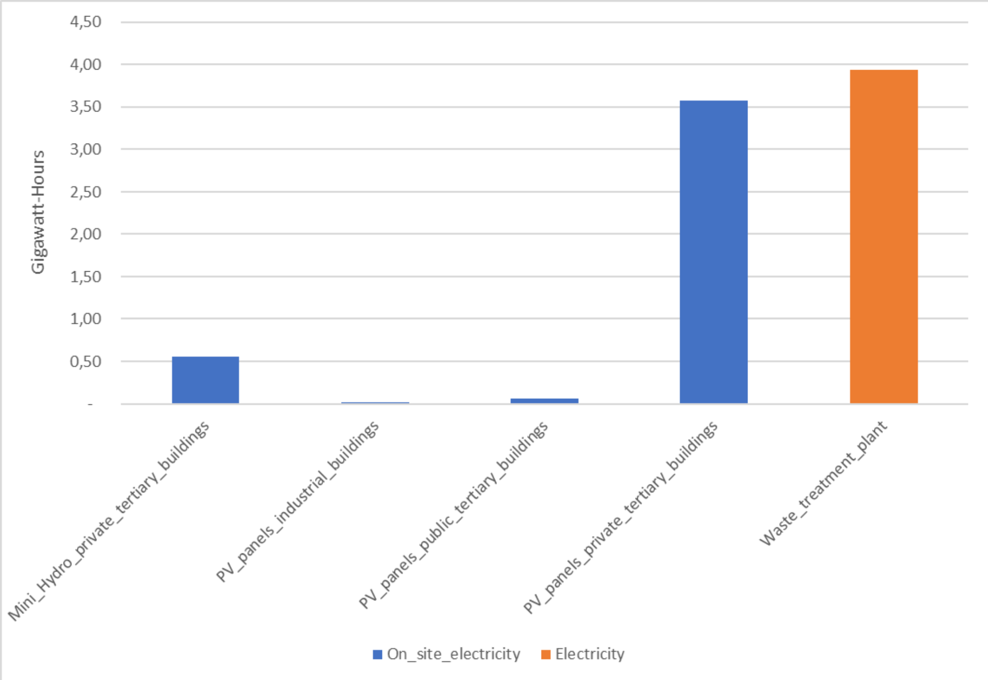

Figure 9. Energy generation in transformation processes in Palencia

In conclusion, the source and final use of the energy can be seen in the Sankey diagram for the baseline year in Palencia. Excepting the electricity generated in the small plants and facilities located in Palencia and the municipal solid waste resource, all the demanded energy is imported from outside the city. Electricity and gas natural are the most consumed fuels, mostly used in the residential, tertiary, and industrial sectors.

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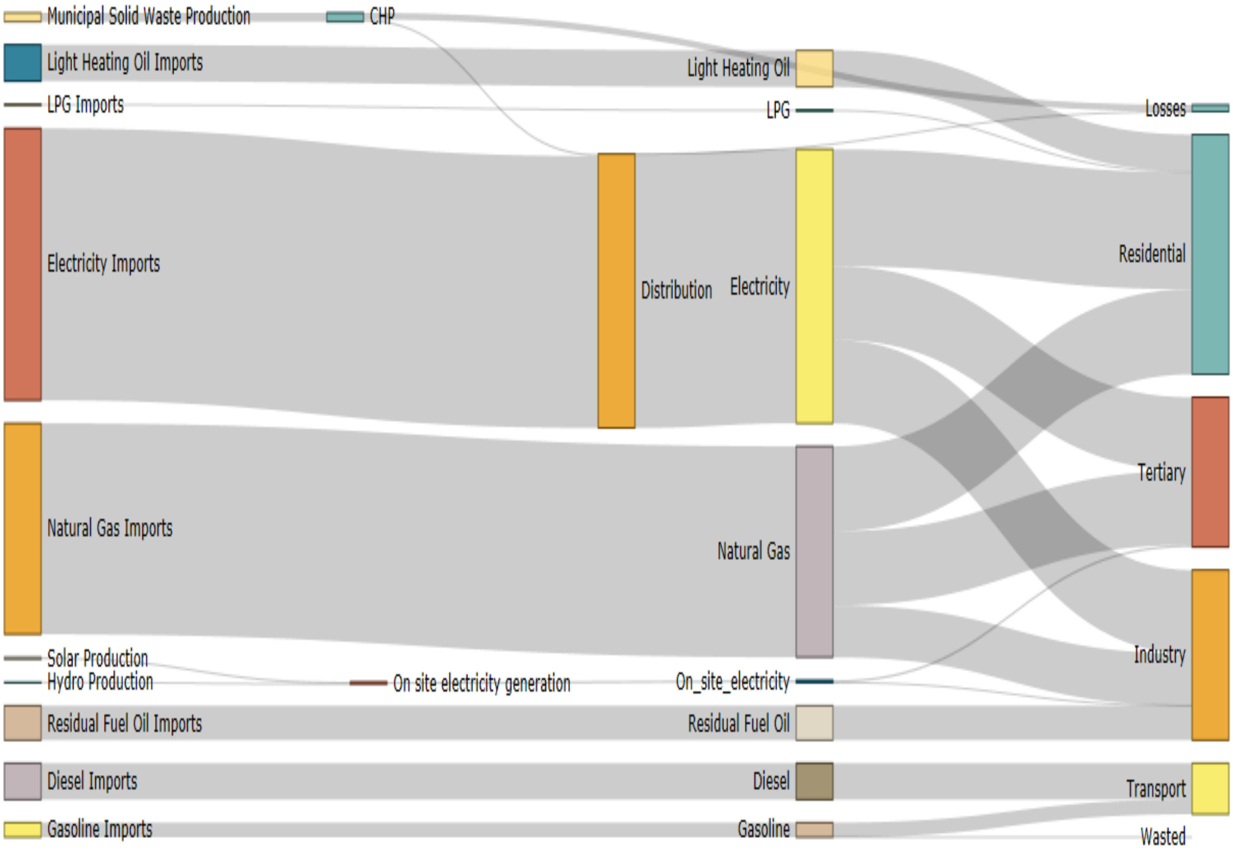

Figure 10. Sankey diagram. Palencia. 2010

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5.3 Case of Rijeka

5.3.1 General considerations

Rijeka is the third most populated city in Croatia and holds the principal seaport of the country. They city is located in the Primorje-Gorski Kotar county. For the Rijeka city model, 2008 has been selected as the baseline year which has been updated when possible with data of the year 2014 provided by the city.

5.3.2 Data processing and base year modelling

5.3.2.1 Demand side

Data from 2008 was available in the city's SEAP [14] and updated information for 2014 was supplied by the city and taken into account in the scenarios. Industrial energy consumption has not been included in the model as information was not available. For each sector, the electricity used for heating uses was indicated and has been separated from the rest of the electric consumption.

The table below shows the followed structure to disaggregate the demand side consumption in the model:

Table 11. Rijeka demand side disaggregation

Sector	Subsectors		Final uses
Residential	-		Heating uses, Lighting and appliances
Tertiary	Private services		Heating uses, Lighting and appliances
	Public services. Municipality	Education	Heating uses, Lighting and appliances
		Health	Heating uses, Lighting and appliances
		City administration	Heating uses, Lighting and appliances
		Culture	Heating uses, Lighting and appliances
		Technical culture. Sports	Heating uses, Lighting and appliances
		City owned homes and business premises	Heating uses, Lighting and appliances
		Edit city companies	Heating uses, Lighting and appliances
		Fire brigade buildings	Heating uses, Lighting and appliances
		Outdoor lighting	-
Transport	Public vehicles	Municipal fleet	No data was available about subsectors or uses, only final energy consumption by fuel has been introduced
		Public transport	Buses
	Private vehicles	-	Two wheels, Private cars, Duty vehicles

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For each final use, consumption of one or more fuels is defined filling up the final energy consumption for this specific use.

The final energy consumption of the residential sector accounts for 562,58 GWh in 2008. Heating uses like space heating or DHW, are responsible for 73,52% of the final consumption. Electricity is the most consumed fuel (62,69%), followed by the heat from the district heating (12,1%), light heating oil (9,2%), natural gas (8,92%), and biomass (7,09%). As said before, the electric share for heating uses was known: 57,82% of the total electric consumption. The final energy consumption disaggregated by use and fuel is shown in the figure below for the baseline year.

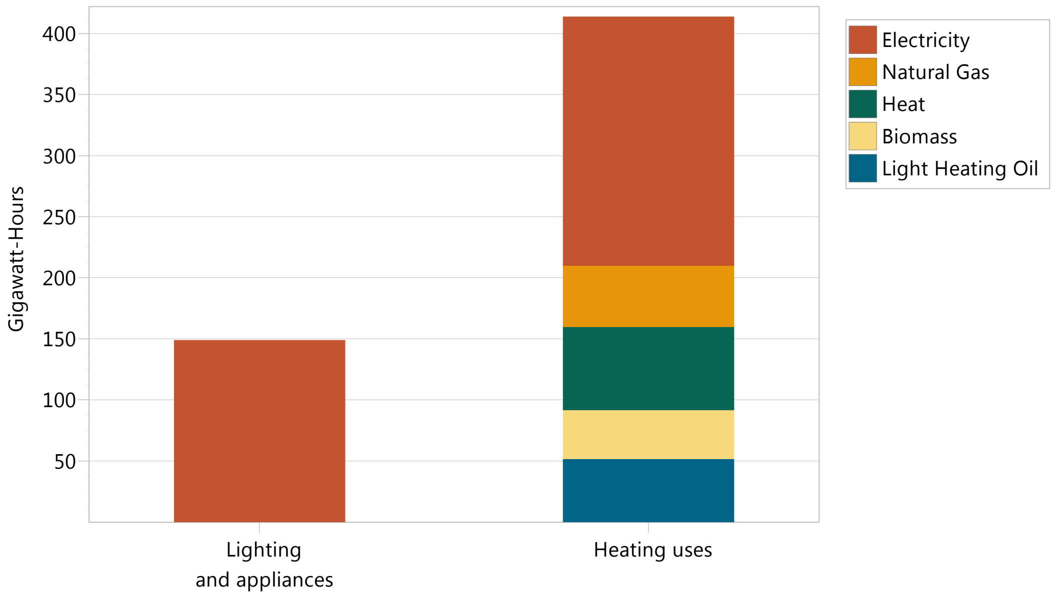

Figure 11. Residential sector consumption by fuel and use in Rijeka

The tertiary sector has been divided between private and public services, the latter containing different municipal buildings and facilities and the outdoor lighting consumption. Comparing only the buildings' consumption of both subsectors (excluding electric consumption for outdoor lighting in the public sector), the private services account for 83,49 GWh in the baseline year, while the buildings of the public services consumed 83,13 GWh. It should be noted that, as it is remarked in the SEAP document, it was not possible to conduct a good analysis of the private services sector and therefore the sector's consumption could differ. In both cases, electricity is the most used fuel (53,55% and 51,6% respectively), however, natural gas is by far the second most consumed fuel in the private services buildings (36,52%), while light heating oil and natural gas are both similarly consumed in public buildings (15,31% and 17,73% respectively).

Also, it should be noted that the share of electricity consumed for heating uses in the private services is 44,37%, while in the public services' subsectors where electricity is used for heating purposes (education,

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city administration, sports facilities, city owned homes and businesses, edit city companies), the average share is about 24%. The disaggregated consumption by fuel in the buildings of both sectors is shown in the figure below for the baseline year.

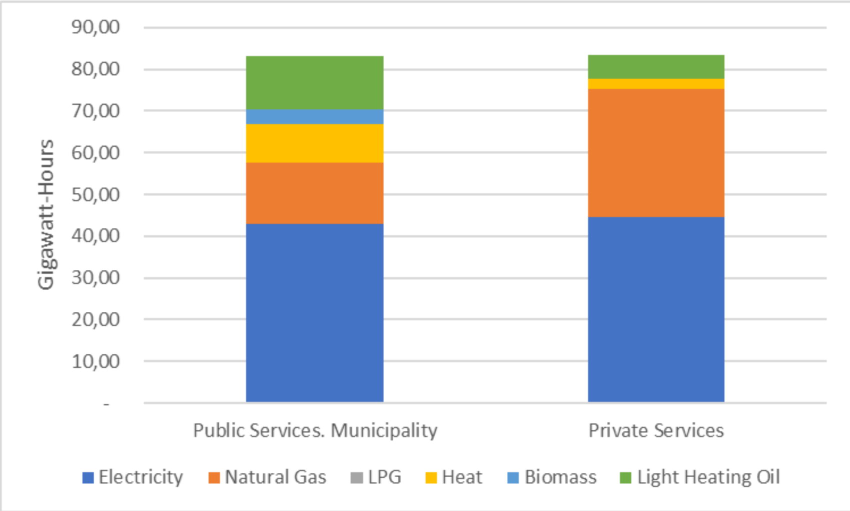

Figure 12. Public and private buildings consumption in Rijeka

Concerning the public services subsectors (including outdoor lighting), the city owned homes and businesses are the most consuming subsector (49,38 GWh), followed by the education buildings (11,9 GWh), and the technical culture and sports facilities (8,5 GWh). The outdoor lighting sums up a consumption of 8333 MWh in the baseline year: 12695 lamps have been taken into account with an energy intensity of 0,66 MWh per lamp.

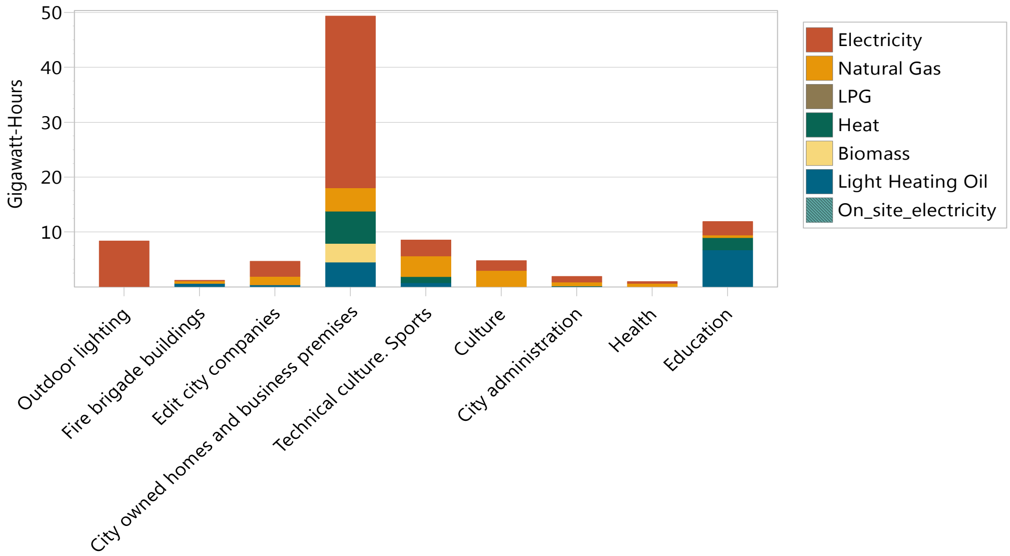

Figure 13. Public services sector consumption by fuel and subsector in Rijeka

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Regarding the transport sector, the next table shows the fleet disaggregation which has been considered for the baseline year.

Table 12. Rijeka transport fleet characteristics

Subsector	Type of vehicle		Number of vehicles	Energy intensity (MWh/vehicle)
Public vehicles. Municipal fleet	-		591	92,54
Public vehicles. Public transport	Buses	Conventional (Diesel)	79	249,85
		Euro I (Diesel)	26	249,85
		Euro II (Diesel)	30	249,85
		Euro III (Diesel)	28	249,85
		Euro IV (Diesel)	23	249,85
Private vehicles	Two wheels	Gasoline	8314	1,23
	Private cars	Gasoline	39138	6,98
		Diesel	19587	6,11
		LPG	880	5,99
	Duty vehicles	Gasoline	1283	30,50
		Diesel	4646	26,59

The sector as a whole consumed 672,07 GWh in 2008. Diesel was the most consumed fuel (51%) followed by gasoline (48,2%). The private fleet represented 84,94% of the sector's total consumption. The consumption disaggregated by type of vehicle is shown in the figure below.

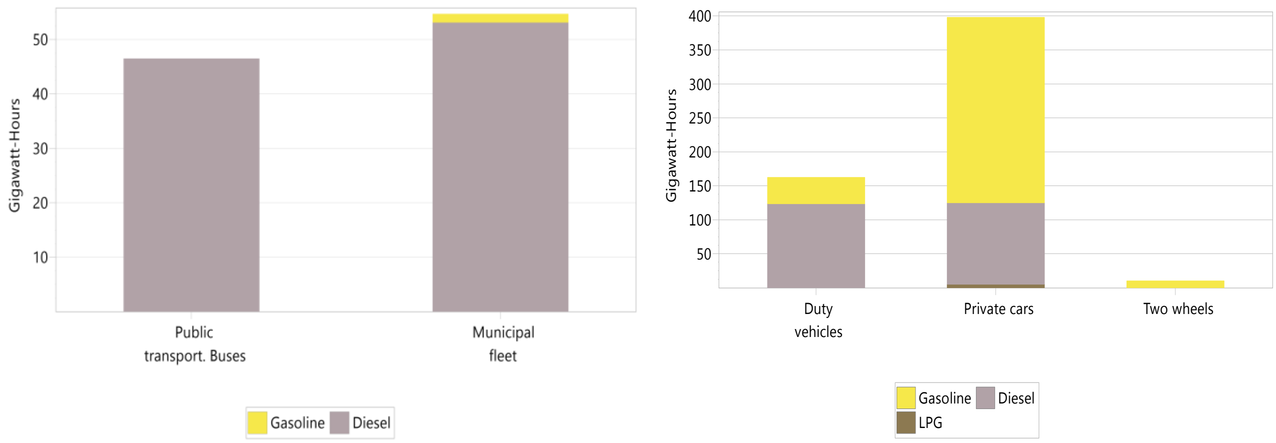

Figure 14. Public (left) and private (right) fleet consumption in Rijeka

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5.3.2.2 Supply side

The supply side in Rijeka is formed by a District Heating network which groups heat only boilers plants and a single CHP plant. Besides, from 2011 to 2014, solar PV facilities in educational buildings have been installed. The characteristics of these systems will be explained in the BaU scenario section of the city.

Data of the installed capacity and energy generation of the District Heating plants was supplied by the city for the year 2017. As the heat consumption was higher in 2008 than in 2017, the maximum operating hours had to be modified so the District Heating plants were able to supply the heat demanded in the baseline year (maintaining the same installed capacity and distribution losses). Only the maximum operating hours of the heat only boilers plants were modified, while the generation and availability of the CHP remain the same through all the years of simulation. In any case, the generation data for the year 2017 has been respected as it will be explained in the Rijeka's BaU scenario section. The following table shows the heat only boilers plants characteristics.

Table 13. Heat Only Boilers plant's characteristics in Rijeka

Process/Plant name	Input fuel	Installed capacity (MW)	Max. operating hours	Process technical efficiency	Historical production (GWh) (2008)
Gornja Vežica	Natural gas	20,75	13,23%	86,28%	22,46
Vojak	Residual fuel oil	14,49	13,32%	90,13%	15,79
V44	Residual fuel oil	2,53	4,32%	62,47%	0,89
Zamet	Residual fuel oil	9,28	8,67%	74,17%	6,59
PO-18	Natural gas	2,85	8,01%	74,32%	1,87
PO-48	Natural gas	10,9	10,51%	72,69%	9,38
Podmurvice	Natural gas	4,15	6,81%	84,80%	2,31
Malonji	Natural gas	3,68	7,44%	64,65%	2,24
Kozala	Natural gas	9,24	9,41%	84,34%	7,12
Srdoči	Natural gas	6,2	9,33%	82,05%	4,73
Krnjevo	Natural gas	10,62	4,00%	78,59%	3,47
Škurinje	Natural gas	9,1	15,15%	90,37%	11,29
I.Marinkovića	Natural gas	0,38	8,49%	92,37%	0,26
Neboder	Diesel	0,72	7,18%	72,56%	0,42
N.Tesle	Diesel	0,99	4,20%	91,94%	0,34

Respect to the CHP plant the considered installed capacity, operating hours and efficiencies are:

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Table 14. CHP plant characteristics in Rijeka

Plant name	Input fuel	Electric capacity (MW)	Heat capacity (MW)	Max. operating hours	Electric production (GWh) (2008)	Heat production (GWh) (2008)	Electric technical efficiency	Heat technical efficiency
Bazen	NG	0,256	3,06	23,39%	1,85	6,27	20,48%	69,58%

Finally, the following distribution losses have been considered:

Table 15. Fuel distribution losses in Rijeka

Fuel	Losses
Electricity	2,36%
Heat	16,5%

5.3.2.3 Resources

Based on the lack of information, it has been assumed that the biomass consumed in Rijeka has its origin in within the city's boundaries, thus a high yield of the resource has been supposed. However, for the case of the scenarios it is recommended for the future to evaluate more in detail the potential source of biomass in order to make sure that all the required resource in the scenario can be supplied by local biomass.

5.3.3 Base year summary

In 2008, 1409,61 GWh were consumed by the end-use sectors (industry not included) in Rijeka, being the transport sector the most consuming sector (47,68% of the total final consumption), followed by residential (39,91%) and tertiary (12,41%). Electricity was the most used fuel with a 31,82% share of the total consumption. Diesel and gasoline mostly consumed in the transport sector represented 29,31% (including here 70,36 GWh of light heating oil which are consumed in buildings) and 23% respectively.

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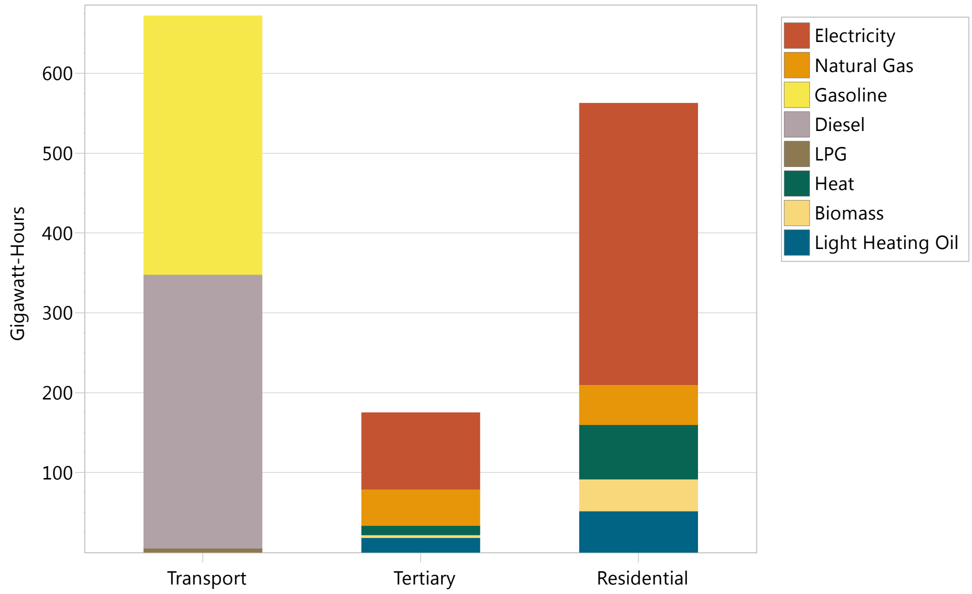

Figure 15. Final energy consumption by fuel and sector in Rijeka

Concerning the transformation processes, which occurred in the city in the baseline year, 95,45 GWh of heat were produced in the District Heating plants (heat only boilers and CHP) which covered (after considering the distribution losses) the city’s full heat final consumption. On the other hand, only 1,85 GWh of electricity were generated in the CHP plant, which only represented 0,41% of the total electric final consumption of the city. 116,85 GWh were consumed in the transformation processes: mostly natural gas (76,68%) and residual fuel oil (23,83%).

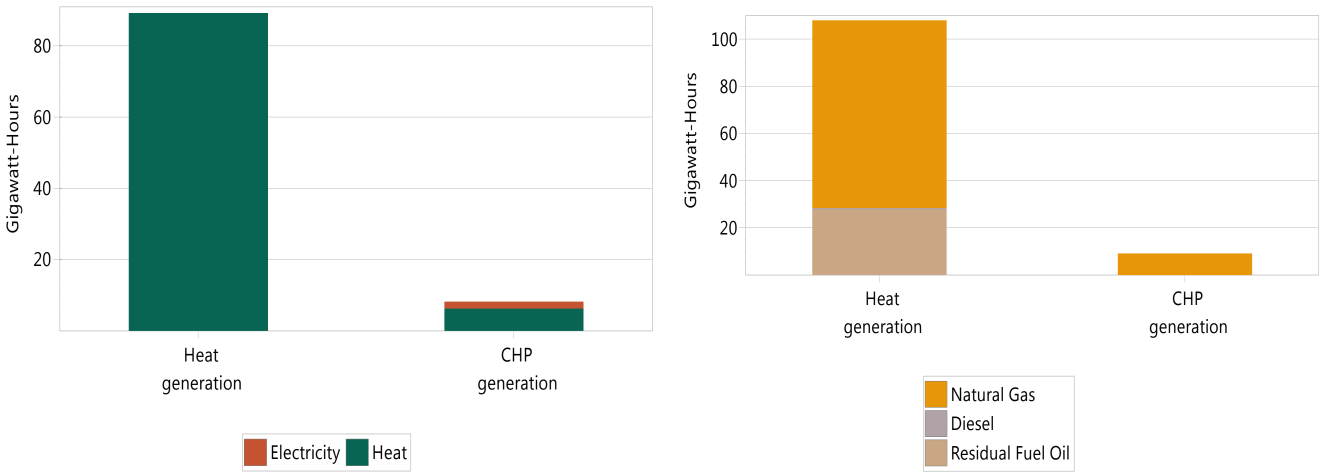

Figure 16. Energy generation (left) and energy consumption (right) in transformation processes in Rijeka

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Finally, in the Sankey diagram presented below, the source, distribution and allocation of the energy consumption in Rijeka can be seen. Almost all the energy is imported in Rijeka, excepting the consumed heat which is fully generated within the city's boundaries. Electricity is entirely consumed in the residential and tertiary sectors, while gasoline and diesel are used in the transport sector. Other fuels consumed in the residential and tertiary sectors are: biomass, heat, natural gas, and light heating oil (similar characteristics to diesel fuel).

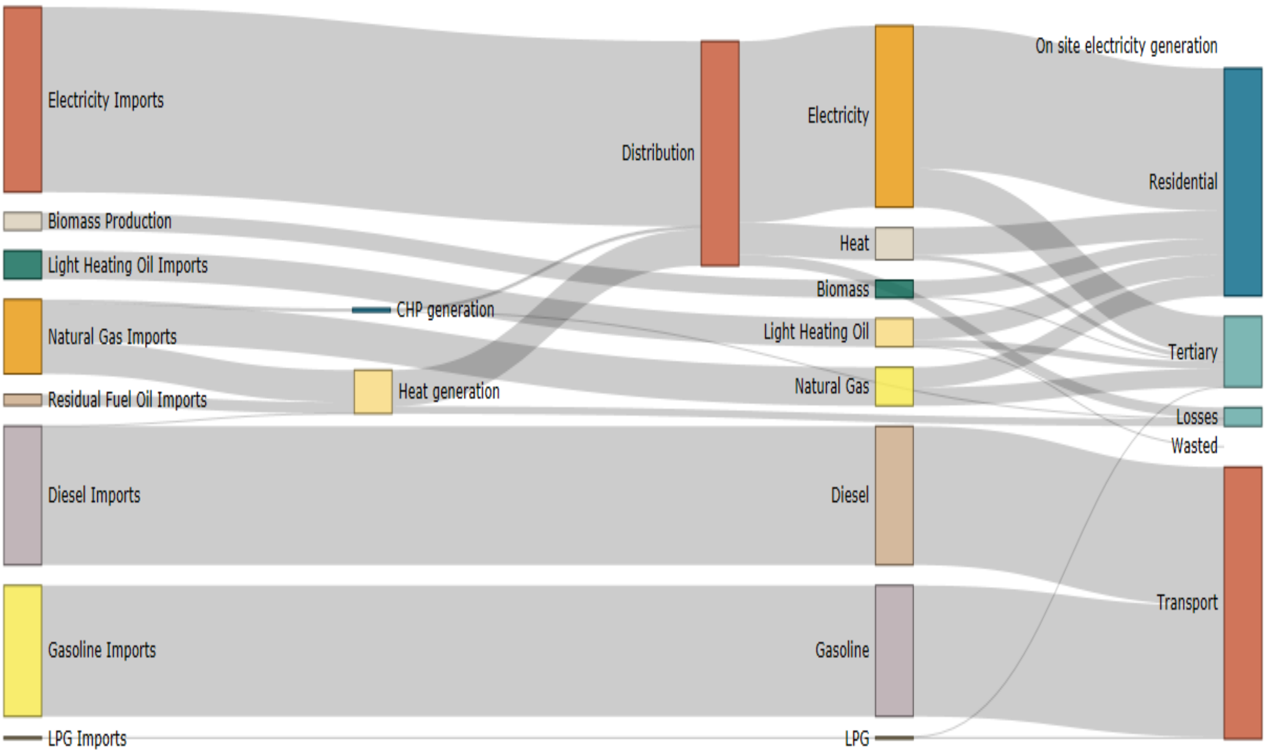

Figure 17. Sankey diagram. Rijeka. 2008

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5.4 Case of Bydgoszcz

5.4.1 General considerations

Bydgoszcz is located in the north of Poland. As the co-capital (along with the city of Torun) of the Kuyavian-Pomeranian Voivodeship, the city is the eight-largest urban area in Poland. For the Bydgoszcz model, 2015 has been selected as baseline year.

5.4.2 Data processing and base year modelling

5.4.2.1 Demand side

For this case, data from 2015 was extracted from the city's SEAP, in addition from information supplied by the city (District Heating consumption and energy plants information).

The table below shows the followed structure to disaggregate the demand side consumption in the model:

Table 16. Bydgoszcz demand side disaggregation

Sector	Subsectors		Final uses
Residential	-		Space heating, DHW, Cooking, Lighting, Appliances
Tertiary	Private services		No data was available about subsectors or uses, only final energy consumption by fuel has been introduced
	Public services. Municipality	Municipal buildings and facilities	No data was available about subsectors or uses, only final energy consumption by fuel has been introduced
		Outdoor lighting	-
Industry	No data was available about subsectors or uses, only final energy consumption by fuel has been introduced		
Transport	Public vehicles	Municipal fleet	No data was available about subsectors or uses, only final energy consumption by fuel has been introduced -
		Public transport	No data was available about subsectors or uses, only final energy consumption by fuel has been introduced
	Private vehicles	-	No data was available about subsectors or uses, only final energy consumption by fuel has been introduced

For each final use, consumption of one or more fuels is defined filling up the final energy consumption for this specific use.

For the residential sector, the following disaggregation by fuel and use was considered: a percentage of the total consumption of each fuel was assigned to a specific use, based on national level data of household's owned devices [15] and household's final use consumption share [16].

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Table 17. Energy consumption disaggregation by fuel and use in the residential sector in Bydgoszcz

Uses	Coal	Biomass	DH	Natural gas	Electricity	Oil
Space heating	89%	89%	85%	41%	5%	89%
Water heating	11%	11%	15%	32%	20%	11%
Cooking	-	-	-	27%	20%	-
Lighting	-	-	-	-	9%	-
Appliances	-	-	-	-	46%	-

In total, 1943 GWh were consumed in Bydgoszcz in the baseline year. Most of the consumption was used for space heating (64,73% of the total final energy consumption), and only a small share was employed in appliances and lighting (6,23% and 1,22% respectively). Heat from District Heating network was the most consumed fuel (708,13 GWh), followed by natural gas (465,95 GWh), coal (460,95 GWh) and electricity (263,08 GWh).

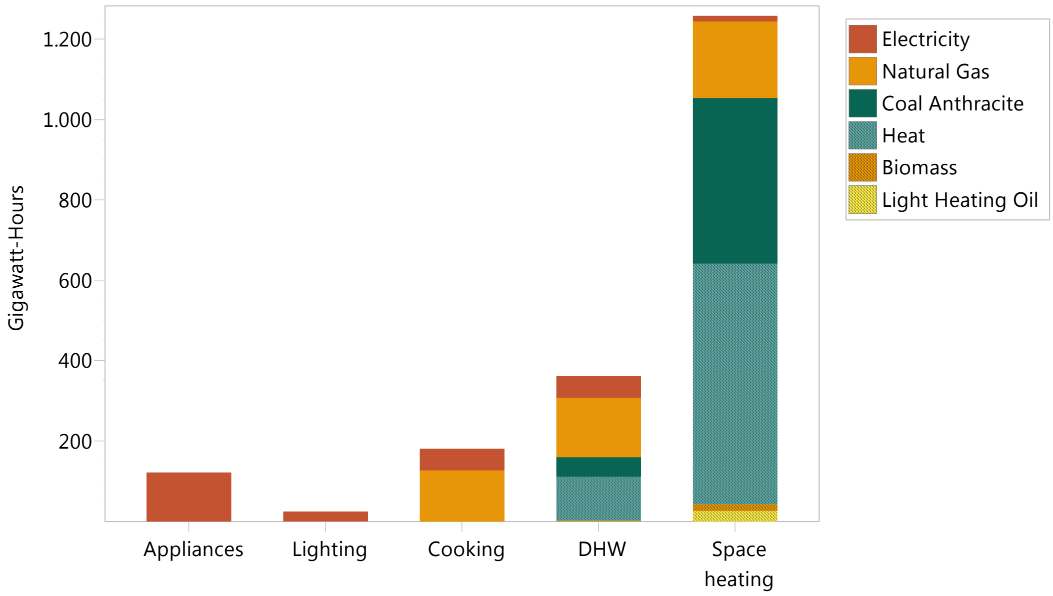

Figure 18. Residential sector consumption by fuel and use in Bydgoszcz

As in the case of the other cities, the tertiary sector was disaggregated into private and public services, the latter containing the consumption of the municipal buildings and facilities and the outdoor lighting. In this case however, data to disaggregate the consumption by final uses was unavailable and only the disaggregation by fuel has been taken into account. The next figure shows the consumption distribution between private and public services.

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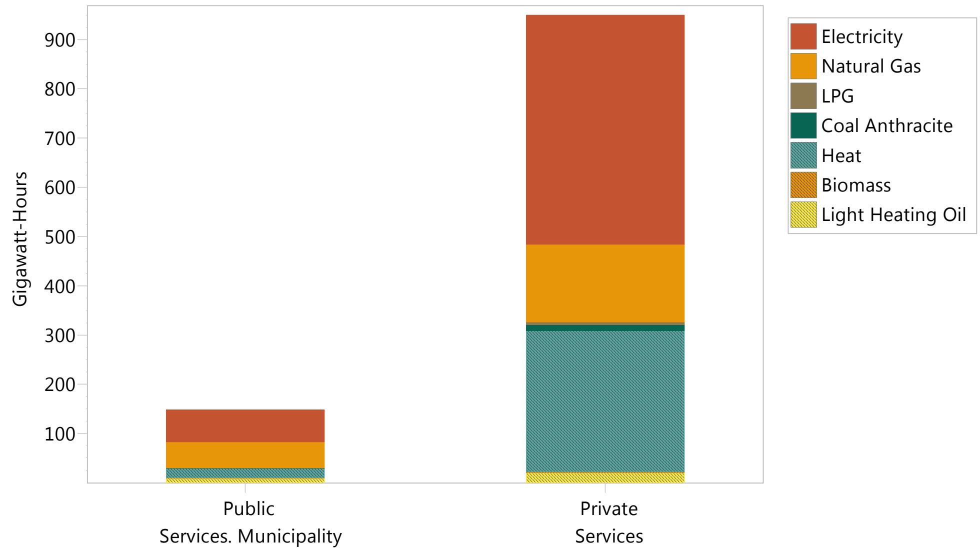

Figure 19. Tertiary sector consumption by fuel and subsector in Bydgoszcz

Tertiary sector accounted for 1098,24 GWh in 2015 in Bydgoszcz. Private sector represents the great share of the final consumption (86,5%). In this subsector, electricity was the most consumed fuel (49,07% of the subsector's final consumption), followed by heat (30,1%) and natural gas (16,57%).

In the next figure, the consumption in the public buildings is shown. Municipal buildings and facilities consumed 122,21 GWh (mostly natural gas and electricity), while outdoor lighting was responsible for the consumption of 26,08 GWh of electricity in the baseline year.

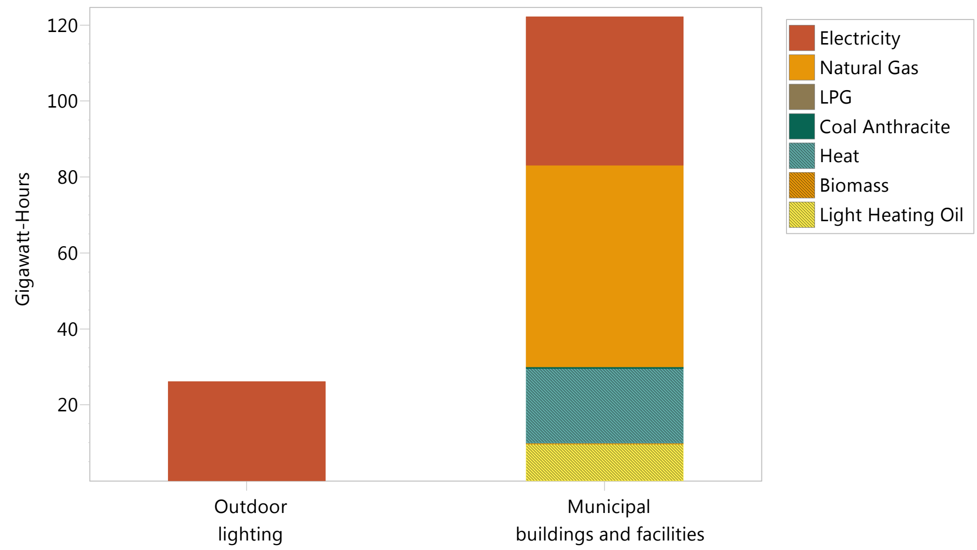

Figure 20. Public services consumption in Bydgoszcz

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Also, the following assumptions have been considered for the modelling of the outdoor lighting:

- Only two types of lamps have been considered: LED and sodium lamps
- Sodium lamps' energy intensity is twice as high as LED ones [17]
- All lamps have been taken into account without ownership (public or private) consideration

Table 18. Outdoor lighting characteristics in Bydgoszcz

Lamp type	Number of lamps	Energy intensity (MWh/lamp.year)
Sodium	14131	1,15
LED	17032	0,575

For its part, the industrial sector has been only disaggregated by fuel as data was unavailable. The sector accounted for 545,05 GWh in the baseline year, with electricity (309,44 GWh) and natural gas (190,98 GWh) being the most consumed fuels. Solar collectors installed in industrial facilities had a minimal contribution of 0,007% to the sector's final energy consumption.

Transport sector hasn't been disaggregated by type of vehicle but by subsector: Municipal fleet, public transport and private vehicles (both passenger and freight). Transport's total final energy consumption in the baseline year was 2243,39 GWh, of which 2149,11 GWh came from the private fleet. Diesel represented 42,75% of the total final energy consumption, followed by gasoline with 40,88% of the total share. Electricity, consumed in the city's tramway network, only accounted for 0,73% of the total final consumption.

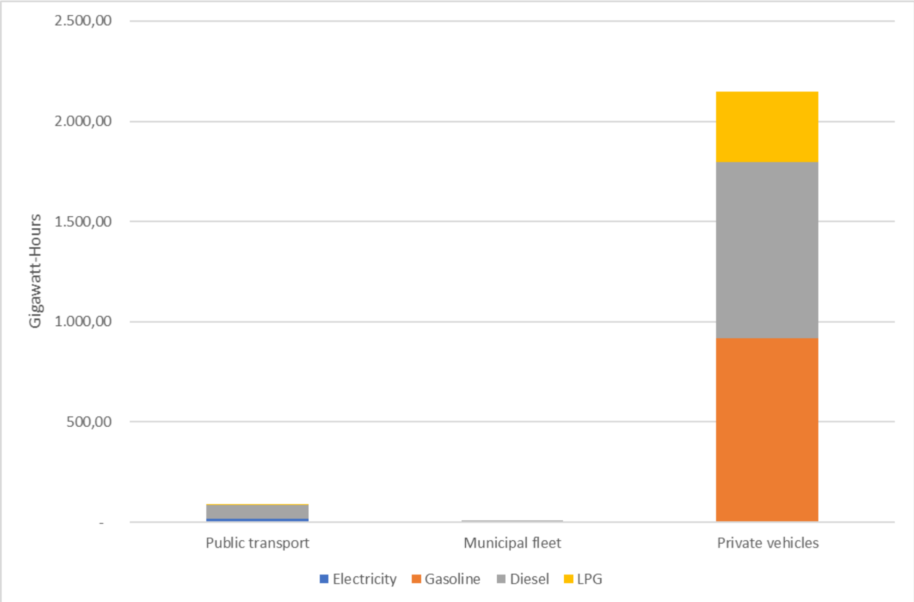

Figure 21. Transport energy consumption by subsector in Bydgoszcz

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5.4.2.2 Supply side

The supply side of Bydgoszcz is formed by:

- Renewable electricity generation processes: PV plants, hydro plants and biogas plants
- District Heating network: heat only boilers and CHPs plants

All the data concerning the transformation processes was supplied by the city.

5.4.2.2.1 Renewable electricity generation processes

The renewable electricity generation in the city is carried out by three processes which characteristics are shown in the table below.

Table 19. Renewable electricity generation processes' characteristics in Bydgoszcz

Plant name	Installed capacity (MW)	Max. operating hours	Process technical efficiency	Historical production (GWh) (2015)
Photovoltaic[1]	1,2	10,34%	-	1,15
River Hydro	5,525	61,98%	-	30
Biogas	2,64	53,87%	35%	12,46

Electric distribution losses have been considered as 2,36%.

5.4.2.2.2 District Heating network

Bydgoszcz's District Heating is supplied by two heat only boilers plants and three CHPs plants.

For the heat only boilers plants, installed capacity and production was known for the year 2016. The same values have been assumed for the baseline year. Their characteristics are shown below:

Table 20. Heat Only Boilers plant's characteristics in Bydgoszcz

Process/Plant name	Input fuel	Installed capacity (MW)	Max. operating hours	Process efficiency	Production (GWh) (2015)
Cieplownia Biale Blota	Coal	36,76	22,52%	87%	72,52
Cieplownia Osowa Gora	Coal	23	16,33%	87%	32,90

On the other hand, generation of the CHP plants (except ZTPOK for which data was available) has been calculate assuming 12,4% DH's heat losses [18], and supposing that al the heat final consumption in the end-use sectors is covered by the network. Maximum operating hours and technical efficiencies have been obtained from ETSAP's databases [10] [11].

[1] Considered as a plant injecting the generated electricity to the grid (NOT on-site generation)

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Table 21. CHP plants' characteristics in Bydgoszcz

Plant name	Input fuel	Electric capacity (MW)	Heat capacity (MW)	Max. operating hours	Electric production (GWh) (2015)	Heat production (GWh) (2015)	Electric technical efficiency	Heat technical efficiency
EC I	Coal	0	116	95%	0	160,64	26%	63%
EC II	Coal	227	663	95%	378,91	918,12	26%	63%
ZTPOK	Municipal Solid Waste	9,2	27,7	80%	0,599	1,15	17,45%	33,50%

5.4.2.3 Resources

Municipal solid waste is consumed in the CHP ZTPOK. Baseline document [21] estimated a municipal solid waste generation of about 0,418 ton/cap/year in Bydgoszcz. As in the case of Palencia it has been supposed that only 50% of the generated waste is useful for the incineration process. Thus, in the baseline year 74330 ton of waste are available for incineration. This number will vary in the scenarios as population will change in the future. On the other hand, biogas consumed in the biogas plant, and biomass consumed in the end-use sectors are supposed to come entirely from inside the city's boundaries, thus a high yield of both resources has been considered.

5.4.3 Base year summary

Total final consumption in Bydgoszcz in 2015 accounted for 5829,67 GWh. Transport was the most consuming sector, with 38,48% share of the total final consumption. Residential and tertiary sectors represented for their part 33,33% and 18,84% respectively. Electricity was the most consumed fuel (1120,31 GWh), followed by heat from the DH network (1038,34 GWh), diesel (1015,91 GWh including the light heating oil consumed in buildings), gasoline (917,22 GWh) and natural gas (867,49 GWh). Heat from solar collectors only accounted for 0,04 GWh.

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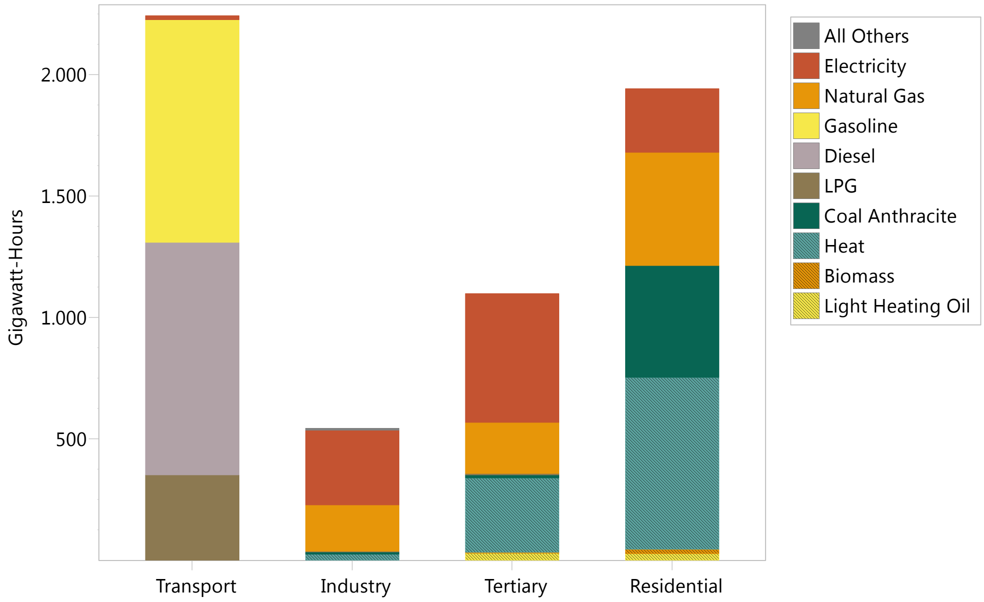

Figure 22. Final energy consumption by fuel and sector in Bydgoszcz

On the other hand, 1836,91 GWh were consumed in the transformation processes in Bydgoszcz in 2015: mainly coal (99,81%) used in the heat only boiler plants and CHP plants ECI and ECII; and municipal solid waste (0,19%) in the ZTPOK CHP plant. 35,59 GWh of biogas were consumed too in the renewable electricity generation processes. Conversely, 423,12 GWh of electricity and 1185,33 GWh of heat were produced in Bydgoszcz's energy transformation plants.

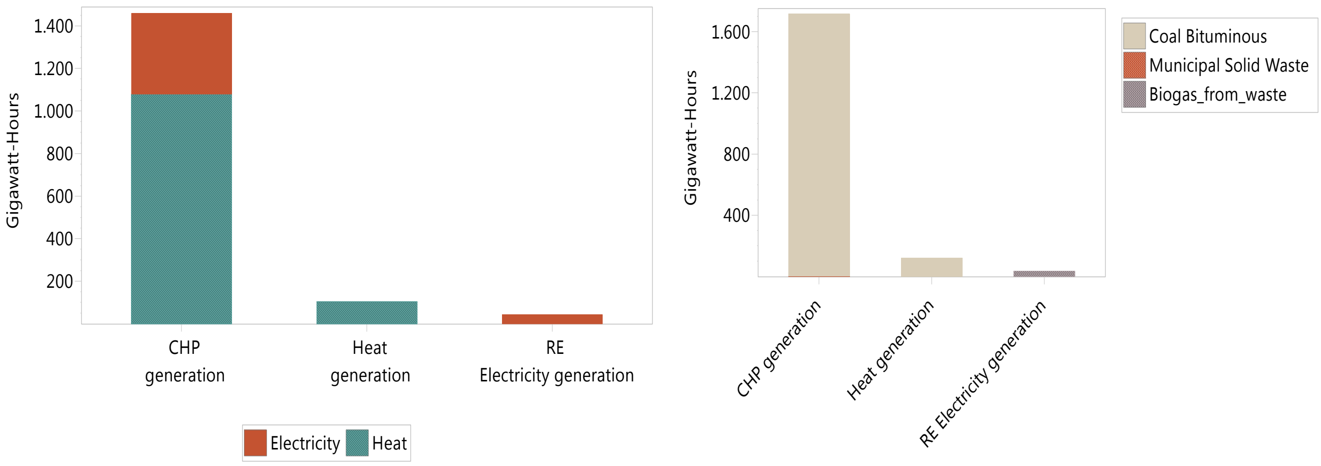

Figure 23. Energy generation (left) and energy consumption (right) in transformation processes in Rijeka

In conclusion, almost all the energy consumed in Bydgoszcz is imported. Heat and power are generated within the city. However, in the case of the electricity its share in the final consumption in the end-use sectors is very small. The fuel mix consumed in the final sectors is homogenous and no one fuel is

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extensively more consumed than others. Coal, heat, electricity and natural gas are largely in residential, tertiary and industrial sectors, while gasoline, diesel and LPG are used in the transport sector. It should be noted that all the DH's heat consumed in the city comes almost exclusively from the combustion of coal.

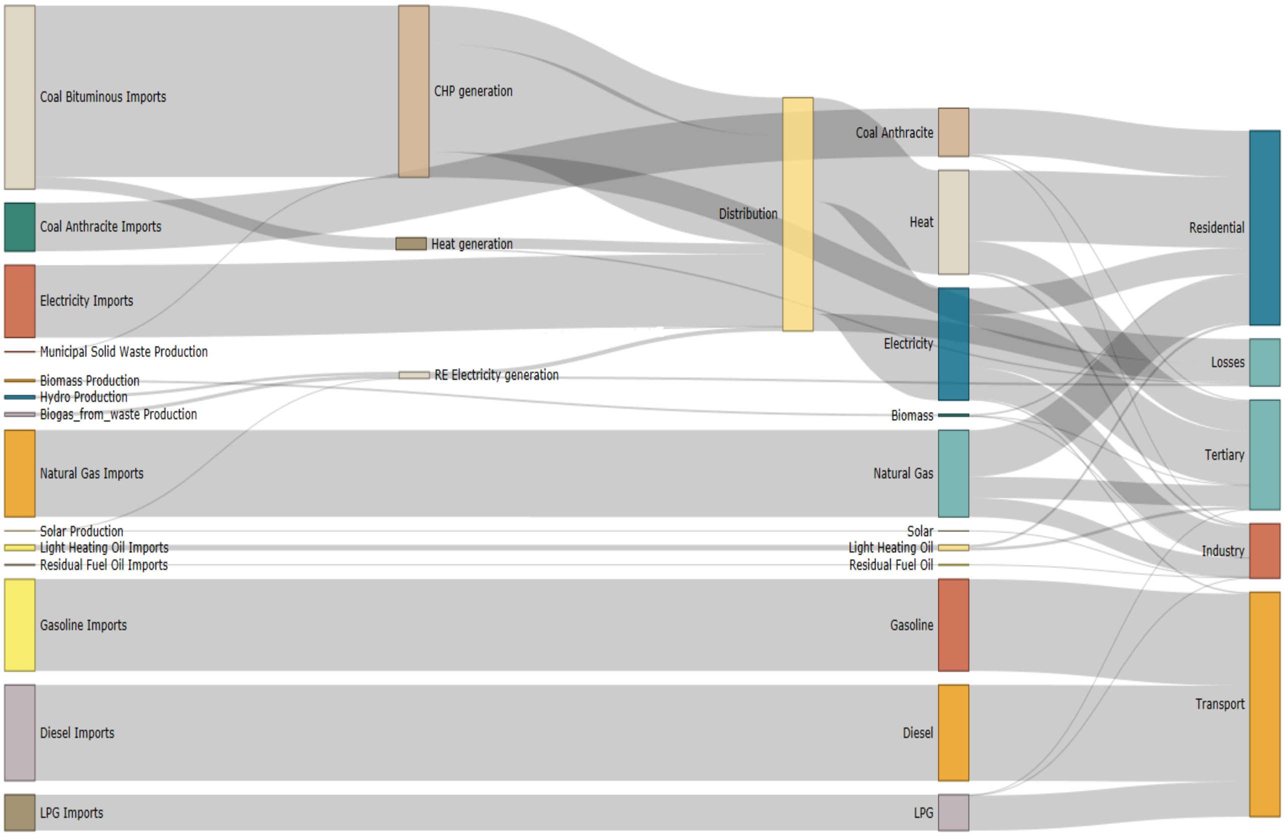

Figure 24. Sankey diagram. Bydgoszcz. 2015

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6. Scenario modelling: Case studies

This section focuses on the description of the energy scenario analysis of the three follower cities for the following years. The scenario definition and description is divided in three main subsections, each of them focused on one city.

Besides, it needs to be taken into account that as described in section 4 different scenarios are defined by each follower city (Business as Usual (BaU) scenario, mySMARTLife replication scenario).

The Business as Usual (BaU) scenario provides an idea of the expected developments and evolution of the energy demand and consumptions of the city for the following years. This scenario describes the evolution of the city considering its current performance and considering that the relation between these energy consumptions and their main drivers remain similar. This scenario provides the baseline that can be used to compare the alternative scenarios.

The alternative scenario is called in this case "mySMARTLife replication scenario" which evaluates the evolution of the city as in the case of the BaU scenario but considering that the interventions that can be replicated in each follower city will be implemented. In this way, the replication potential of each intervention will provide an idea of the impact that would have in the energy consumption and generation of the city in the following years.

In all the cases, the base year selected and described in the previous section is the basis for the modelling and therefore the first simulation year is considered the following year to it.

6.1 Scenario analysis for Palencia

In the case of Palencia, the energy model created covers for the entire city considering the different energy consumptions of each sector of the city, as well as the different energy supply systems. This section focuses on the projections generated for the energy consumption and generation of the city for the following decades.

6.1.1 BaU scenario for Palencia

The first step followed for the definition of the BaU scenario is to understand the potential relation between different socioeconomic parameters and other type of characteristics of the city with the energy consumption of each city. These parameters that guide the future development of the energy consumptions are called drivers. The relation between driver and energy consumption has been carried out in this case per each sector to provide a higher level of flexibility in the scenario development.

In the case of the lighthouse cities link between driver and energy consumption was usually established through historical analysis of the evolution of both variables. However, in the case of Palencia and the

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other follower cities, historical data was generally dispersed or unavailable at a local level, and thus it was difficult to build a relationship between driver and the final energy use. Hence, in the follower cities' BaU scenarios, the evolution of the energy consumption has been defined and linked to a specific driver based on the conclusions obtained from the analysis carried out with the lighthouse cities in WP1.

In the case of Palencia various data sources have been evaluated to obtain the historic evolution of the selected drivers and therefore project their (and hence the sector consumption to which they are linked) future development. The main data sources evaluated are the followings:

- **Municipal Open Data site** [22]: population data was extracted from the "Observatorio Socioeconómico de Palencia" managed by the city
- **Spanish Statistical Office** [23]: values of regional GDP were extracted from the "Instituto Nacional de Estadística" (INE) for the province of Palencia
- **Spanish Traffic Ofice** [10]: vehicle stock for the city of Palencia has been issued from the "Dirección General de Tráfico" (DGT)

6.1.1.1 Driver selection for the definition of the BaU Scenario

Not historical energy consumption data but only socioeconomic historical data was available for Palencia. Therefore, historical analysis was only conducted for these variables. Future evolution of these drivers was assumed and the link to a specific sector's energy consumption was made.

- Residential sector:

For the residential sector, regional GDP per capita (available for Palencia province) has been considered as the main driver of the sector's energy consumption. The evolution of this parameter has been calculated assuming a 2,3% GDP yearly growth since 2018; 1,5% since 2025; and 1% since 2030, whereas the city's population is estimated to decrease 0,58% every year. Moreover, a decoupling factor has been considered between the evolution of the GDP per capita and the energy consumption of the city in order to reflect that Palencia's population is ageing which will imply a gradual stagnation.

Table 22. Decoupling factor values considered for the definition of the tendency of the energy consumption

2010	2020	2030	2040	2050
1	0,95	0,9	0,8	0,7

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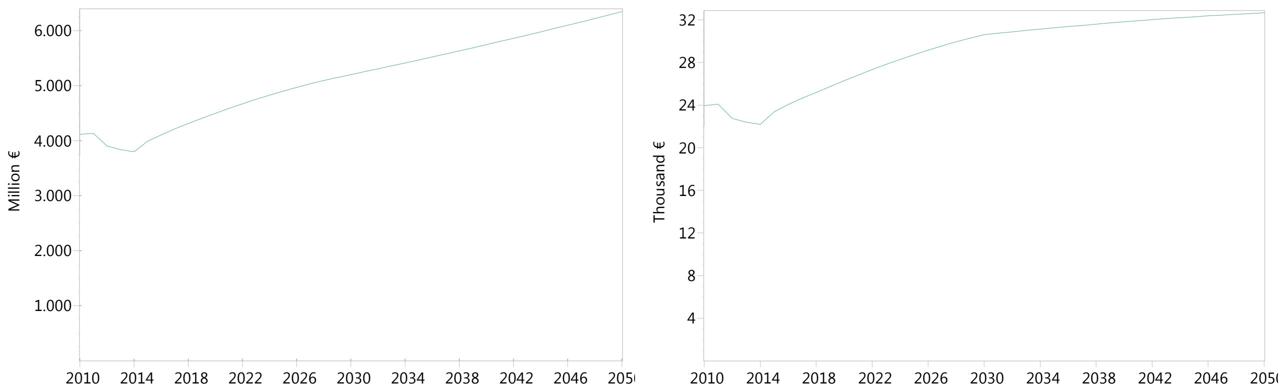

Figure 25. GDP (left) and GDP per capita (right) evolution in Palencia for the BaU scenario

- <u>Tertiary sector:</u>

As for the residential sector, it has been assumed that the tertiary sector (both private and public subsectors) changes as the GDP per capita.

- <u>Industrial sector:</u>

The energy consumption in the industrial sector has been considered to evolve as the regional GDP which evolves as it has been explained previously.

- <u>Mobility sector:</u>

As for the residential and tertiary sectors, GDP per capita has been chosen as main driver for the evolution of the transport sector. Keeping the energy intensity constant (except for municipal fleet and public transport as it is explained in the following subsections), number of vehicles growths as the GDP per capita, and thus the final energy consumption is projected.

6.1.1.2 BaU modelling

Considering the base year energy balance and the tendencies described in the previous subsection that are used to project the energy consumption of Palencia, the BaU scenario is modelled in LEAP.

For this case, updated data for the 2017 was supplied by the city and has been included in the city's BaU scenario. This information contained updated consumption of the public buildings, outdoor lighting and municipal and public transport fleets. Also, information extracted from the Spanish "Direccion General de Tráfico" has been used with private fleet data for the years 2011, 2014, 2015, 2016 and 2017 in Palencia. Consequently, consumption (number of vehicles in private transport fleet case) has changed for these sectors respecting the data available. After 2017, consumption evolves as explained in the previous section.

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It should be noted that a different approach has been followed in the projection of the private and municipal cars, and buses. While total number of vehicles has been respected (following the GDP per capita growth), final share by type of vehicle has been set.

Table 23. Cars and public transport buses vehicle shares by fuel in 2050 in Palencia

	Private cars	Municipal fleet cars	Public transport buses
Diesel share	15%	13%	59%
Gasoline share	70%	69%	-
Electric share	14%	16%	30%
LPG/Hybrid/Natural gas share	1%	3%	11%
Total number of vehicles	49890	32	19

Finally, in the case of the municipal and public transport fleets energy intensities had to be recalculated in order to respect the consumption values given by the municipality for the year 2017. It was assumed that the public fleet remains unchanged until 2017, when it is renovated.

Table 24. Changes in public transport fleet characteristics in Palencia (2017)

Subsector	Type of vehicle	Number of vehicles (2010)	Number of vehicles (2017)	Energy intensity (MWh/vehicle) (2017)
Public vehicles. Municipal fleet	Diesel Cars	38	18	1,32
	Gasoline Cars	0	2	1,41
	Electric Cars	0	3	0,43
	Hybrid (gasoline) Cars	0	1	1,38
	Diesel Motorcycles	0	0	-
	Gasoline Motorcycles	35	38	0,48
	Diesel Light utility vehicles	13	24	4,08
	Gasoline Light utility vehicles	0	1	4,36
	Electric Light utility vehicles	0	1	1,31
	Diesel Trucks	18	23	39,1
	Gasoline Trucks	0	4	41,80
	Diesel Other vehicles	4	7	14,24

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	Gasoline Other vehicles	0	1	15,20
Public vehicles. Public transport	Diesel Buses	14	11	420,85
	Electric Buses	0	1	140,28
	Natural Gas Buses	0	2	429,10
	Diesel Taxis	52	52	25,04

Concerning the supply side of the city, PV installed capacity has been added through 2011 to 2013 as indicated in the next table.

Table 25. Additional PV installed capacity in Palencia

	2011	2012	2013
PV private tertiary	379,65 kW	19,95 kW	760 kW
PV public tertiary	7,5 kW	15,5 kW	-

In addition, in 2011, a micro-CHP was installed in the public tertiary subsector as an on-site generation system to supply heat and electricity to a public building. It has been assumed that the natural gas consumed in the plant is already included in the consumption of the subsector.

Table 26. Public tertiary micro-CHP plant characteristics

Process/Plant name	Electric installed capacity (MW)	Max. operating hours (%) [20]
CHP private tertiary	0,015	55%

Finally, the following figure resumes the energy consumption evolution in Palencia in the BaU scenario.

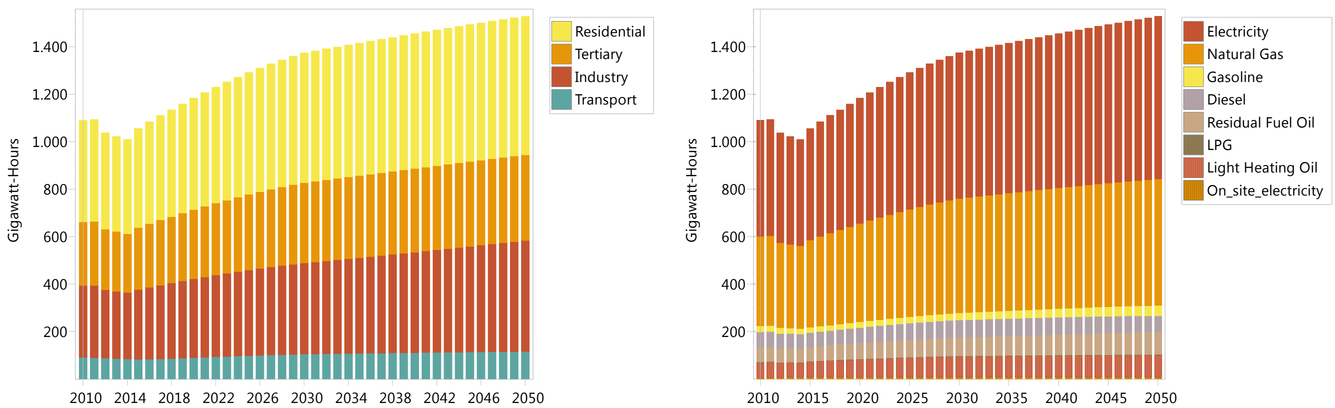

Figure 26. Projection of the sectoral final energy consumption (left) and fuel consumption (right) in Palencia for the BaU scenario

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Also, the energy consumed in each sector disaggregated by fuel is presented in the next figure for the last simulated year.

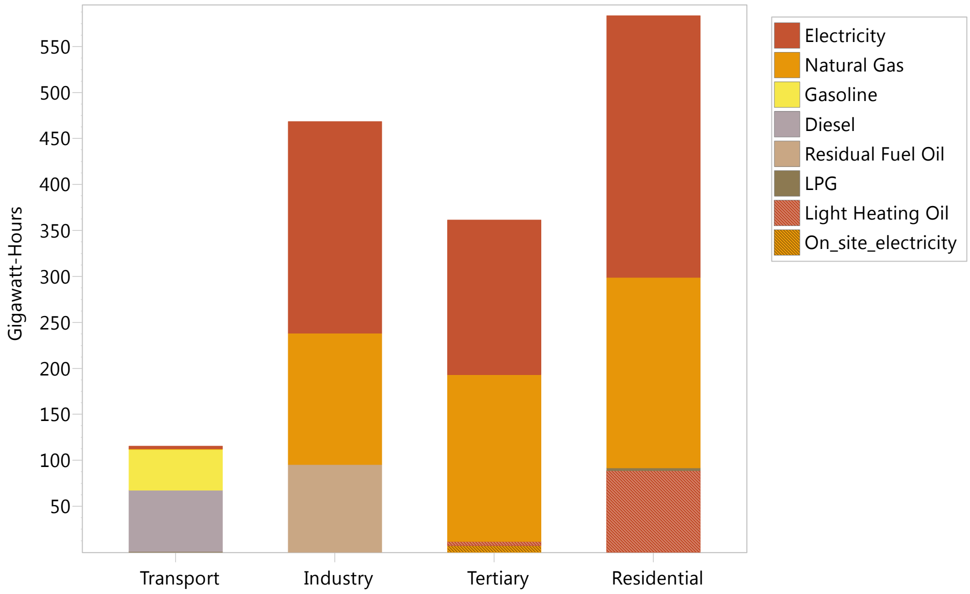

Figure 27. Energy consumption disaggregated by fuel and sector in Palencia for the BaU scenario in the year 2050

Concerning the energy generation in the city, on-site electricity production rises from 4,2 GWh in the baseline year to 7,23 GWh in 2013 due to the new micro-CHP plant and the new installed PV panels. From that year onwards, no new capacity is planned, and generation remains unchanged as it is assumed that plants work the same hours as in the baseline year. Electricity produced in the waste treatment plant remains constant too.

6.1.2 Alternative scenarios for Palencia

This subsection describes the replication scenario developed for Palencia. This scenario takes into account the implementation of the interventions that have been selected by the city for its replication. The following subsections describe the type of interventions considered, their level of deployment and the influence of these interventions in the entire city.

6.1.2.1 Analysis of the interventions to be replicated in city and replication scenario modelling

The scenario modelled is based on the interventions that can be replicated in the city, which have been selected and evaluated in detail through the PESTEL analysis carried out in previous studies carried out in the WP6. The figure below shows the general overview of the pros and cons of each intervention for the dimensions considered in the PESTEL analysis. The results obtained here have been considered as general criteria for the definition of the replication potential of each intervention in the replication scenario.

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Figure 28. Synthesis of PESTEL analysis for the interventions selected in Palencia.

- <u>Intervention 1. District Heating:</u>

The specific action corresponds to the replacement of the existing gasoil boiler of three municipal buildings by a district heating system that uses biomass as an ideal solution. The initially planned buildings correspond to a public library, the local police building and a public service centre. Apart of these buildings, two other private buildings (Art School and a Kindergarten) and private residential buildings (around 160 dwellings) can also be connected once the District Heating is in service with proper promotion.

Taking into account this description and after the discussion with the municipality of Palencia it has been decided that the replication scenario will explore the effect of extending this district heating intervention to the entire district in which it planned.

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In order to limit the extent and the heat demand covered by this intervention, the results obtained in the analysis carried out in the ST6.2.1 have been consulted. Here, the energy characterization of the entire city was performed as it is showed in the figure below.

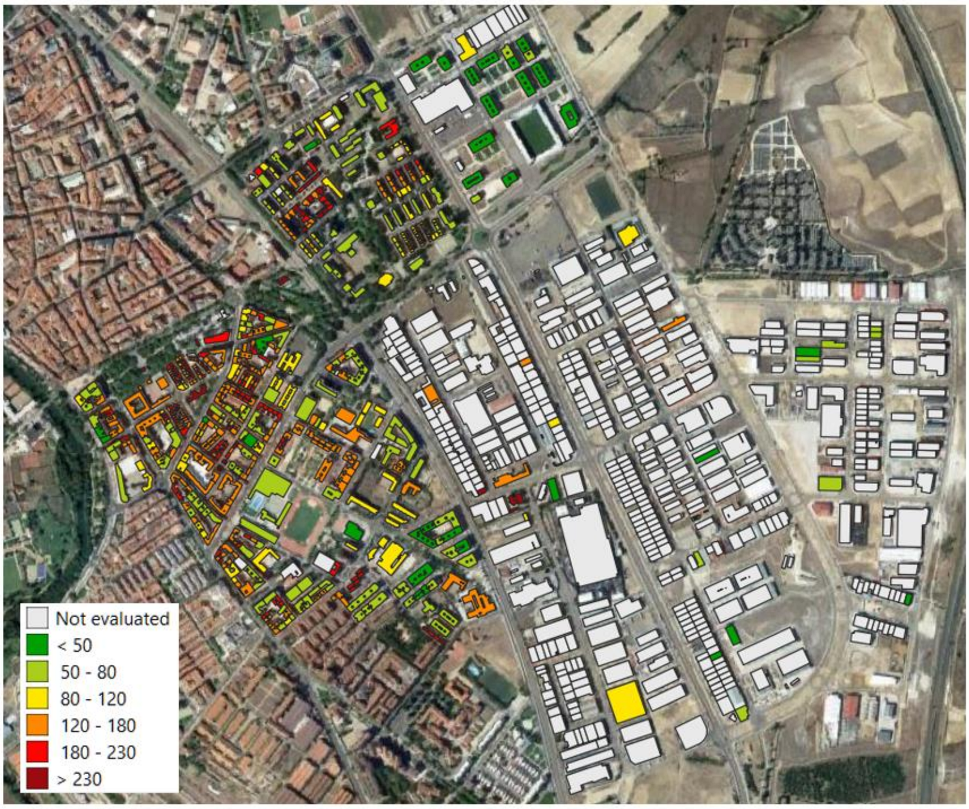

Figure 29. Heating demand (kWh/m2) of the district selected in Palencia.

From this analysis it is estimated extent of the city which will be covered by the district heating by 2050. Therefore, the replication scenario considers that this part of the energy demand of the city is covered by the district heating system which replaces the current systems improving the overall energy generation performance. Besides, the scenario considers that almost 75% of the demand is covered by biomass and the rest by natural gas.

The following figure shows the effect of this intervention.

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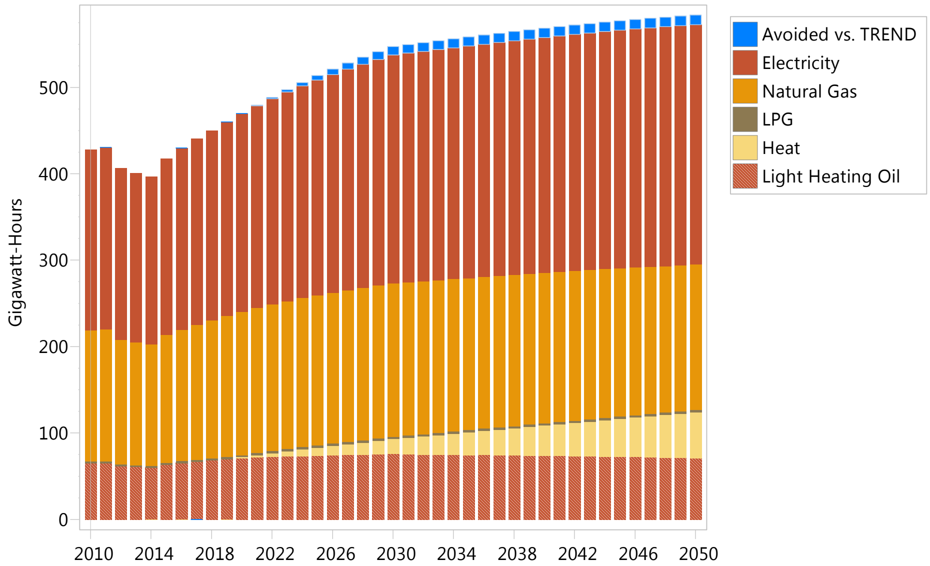

Figure 30. Effect of the replication of the intervention of district heating in Palencia

- <u>Intervention 2. Electric Vehicles for fleet municipality services:</u>

The action corresponds to increase the use of sustainable vehicles in the city of Palencia. The municipality has as objective to replace the current fleet of municipal vehicles by EV vehicles. With this action, the municipality assumes an exemplary role in the adoption and purchase of electric vehicles.

Taking into account this initial information provided by the city, the replication scenario considers that the 50% of the municipal fleet will be electric by 2030 and extending this tendency in the following years. Besides, the buses will also be 100% electric by 2030. Finally, it is also modelled the effect of the change in the private vehicles to electric vehicles by replacing before 2050 all gasoil cars by electric cars. The following figure shows the effect of this intervention in the bus fleet.

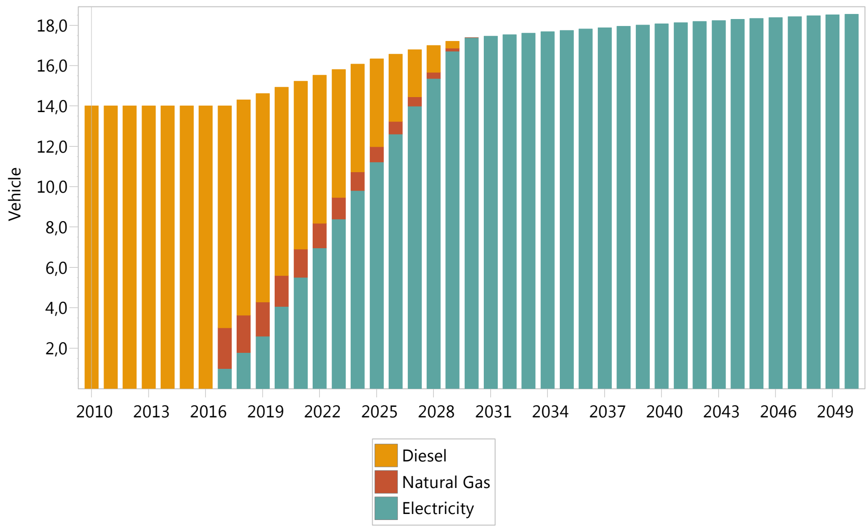

Figure 31. Effect of the replication of the intervention of Electric Vehicles in Palencia

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- Intervention 3. Energy Monitoring of Public Buildings:

The action corresponds to the implementation of energy monitoring systems in public buildings. For the replication scenario is it considered that due to the monitoring and management of buildings 6% of energy savings can be obtained (in both the heating and the electric uses). This intervention is extended to the entire public building sector. This intervention starts in the first simulation year and considers that before 2030 all the public buildings will have these systems implemented.

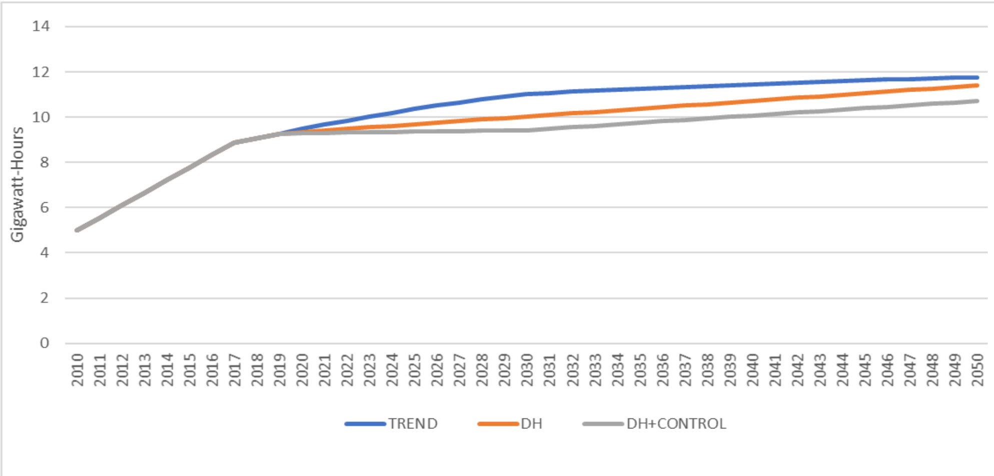

Figure 32. Effect of the replication of the intervention of Energy Monitoring of Public Buildings in Palencia

- Intervention 4: Public lighting LED:

This action is not included in the final selection of the city carried out in the PESTEL analysis. However, the city has expressed their interest in it and this is the reason why it has been included in the replication scenario analysis. More precisely, the scenario considers the substitution of all the lamps with the current technologies to LED technology by 2030.

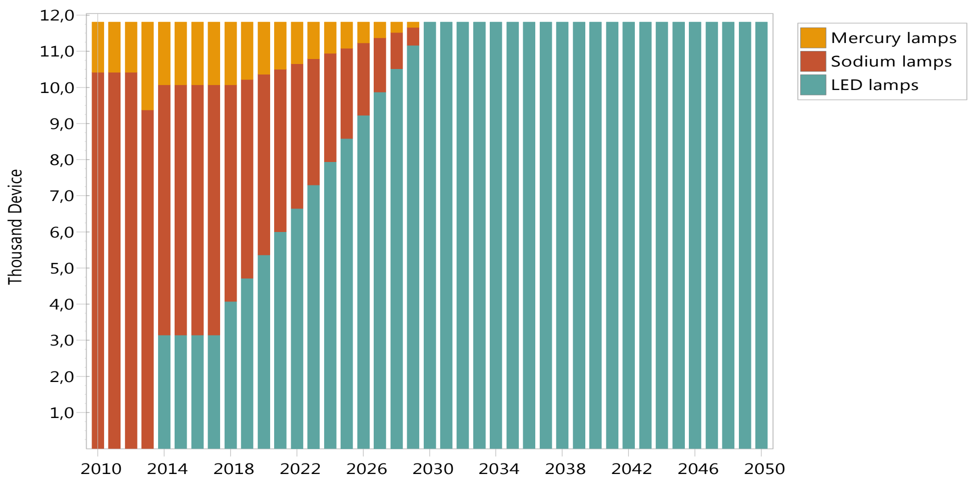

Figure 33. Effect of the replication of the intervention of Public lighting LED in Palencia

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- <u>Intervention 5: New heating systems in public buildings</u>

As in the previous case, this action is not included in the final selection of the city carried out in the PESTEL analysis. Nevertheless, due to the initial interest of the city in it and this is the reason why it has been included in the replication scenario analysis.

The intervention is focused on the substitution of the existing heating systems in the public buildings of the city with new boilers. The intervention applies to the part of the city which is not covered by the new district heating system proposed. Therefore, the replication scenario considers the change of the current energy mix of these buildings to a new energy mix with 50% natural gas, 30% electricity and 20% biomass.

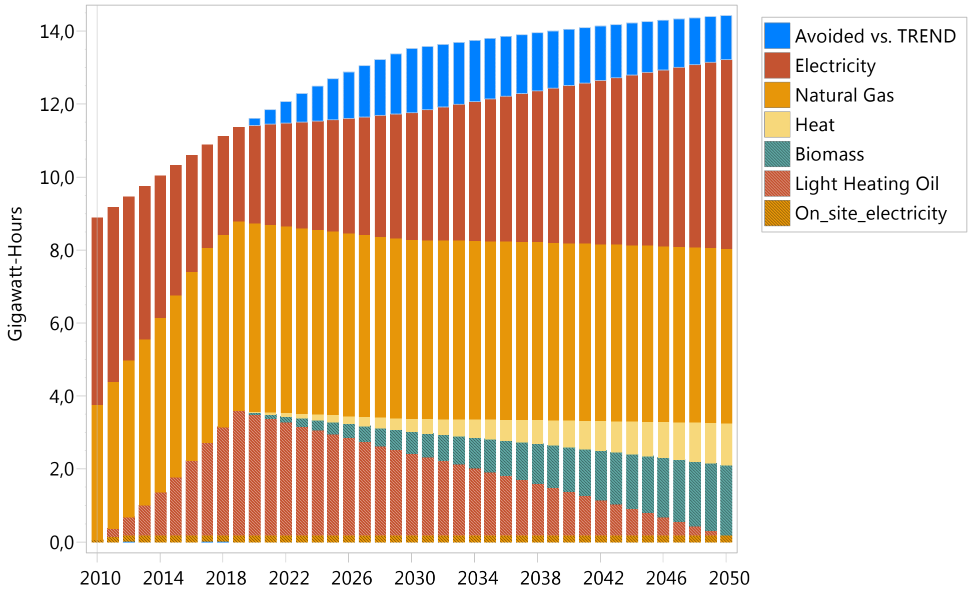

Figure 34. Effect of the replication of the intervention of New heating systems in public buildings in Palencia

Replication scenario for Palencia

All above-mentioned interventions are included in the replication scenario. This scenario manages to save 46,49 GWh (final energy), which represents a 3% savings in relation to the BaU scenario in the final year.

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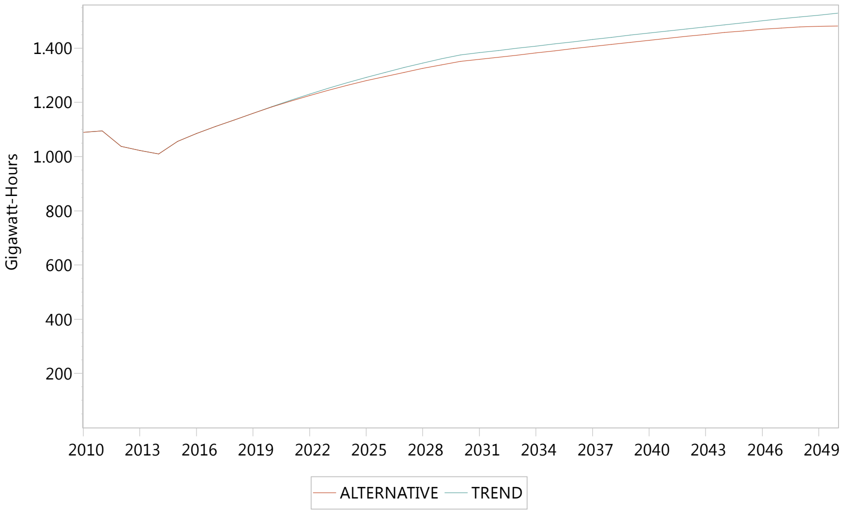

Figure 35. Total final energy consumption comparison of the end-use sectors in Palencia (BaU scenario vs replication scenario)

Concerning the fuel savings and fuel mix changes, a 1,89% and 4,28% savings are achieved in the residential and tertiary sectors respectively, while the greatest energy consumption reduction is performed in the transport sector: 17,36% less consumed energy respecting the BaU scenario in the final year. Greater reductions could be made in the first two sectors, if refurbishment interventions were carried out. Also, natural gas and light heating oil final consumptions are reduced at the expense of an increase of heat consumption in the building sector (it should be noted that part of the heat comes from the combustion of natural gas burned in the District Heating's boilers). Although electricity is intensively consumed in the replication scenario in the public and part of the private transport fleet, its consumption is reduced 1,66% respect the BaU scenario. Efforts should be made, however, in the private freight transport fleet in order to reduce diesel consumption as only 11,82 GWh are saved in the replication scenario in relation to the BaU scenario in 2050.

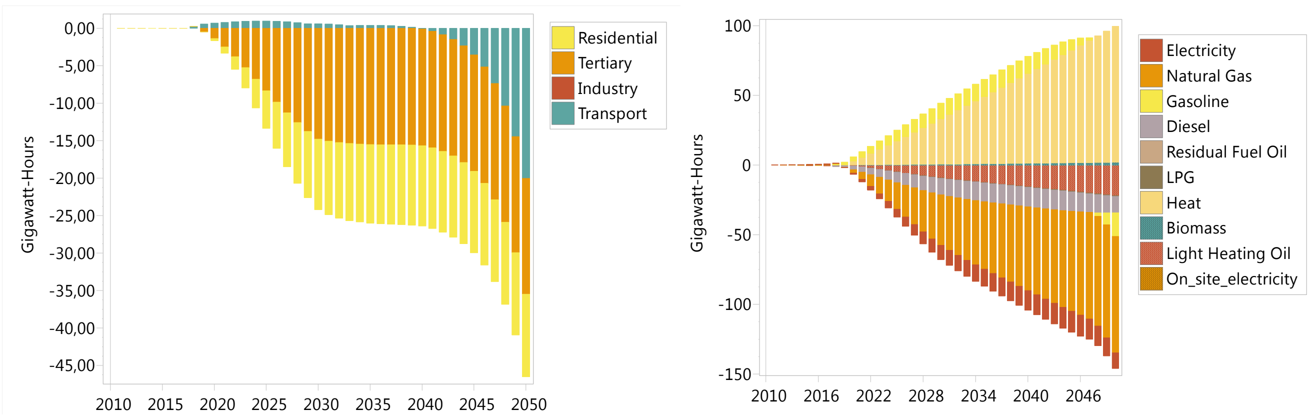

Figure 36. Energy savings by end-use sector (left) and fuel mix in Palencia (BaU vs replication scenario)

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6.2 Scenario analysis for Rijeka

In the case of Rijeka, the energy model created covers for the entire city considering the different energy consumptions of each sector of the city, as well as the different energy supply systems. This section focuses on the projections generated for the energy consumption and generation of the city for the following decades.

6.2.1 BaU scenario for Rijeka

As in the case of Palencia, the first step of the BaU's construction in Rijeka is to establish the relationship between a driver and the energy consumption of a specific sector. However, energy historical data was unavailable and only socioeconomic historical data could be found:

- Wikipedia [24]: regional GDP and GDP per capita for the Primorje Gorski county where Rijeka is located was extracted from the web
- Croatian Bureau of Statistics [25]: regional data about vehicles fleet, households and completed buildings, and population was issued from the statistical yearbooks of the Croatian national bureau of statistics

6.2.1.1 Driver selection for the definition of the BaU Scenario

As historical energy consumption was not accessible, the link with the drivers could not be made through statistical analysis and drivers were allocated to specific sectors through the modeller's criteria based on the conclusions obtained from the WP1 in which the same process was carried out for the three lighthouse cities. For each driver their evolution was assumed in order to project their associated sector's consumption.

- Residential sector:

For the energy consumption in the residential sector, the evolution marked by the Croatian Energy Strategy BAU has been considered [26]. That is an average increase of 0,26% per year since 2014 (as it will be explained later in this document, consumption from 2008 to 2014, will evolve in a manner that data supplied by the city for that year was respected). In fact, the future consumption projected by the BAU's national energy strategy is a straight line with a 1,74 slope.

- Tertiary sector:

Energy consumption in the tertiary sector (both private and public services) evolves as the regional GDP per capita. Real evolution values have been followed from 2014 until 2018 (as for the case of the residential sector, consumption from 2008 to 2014, evolved in a manner that data supplied by the city for that year was respected), when a yearly 1,13% average growth has been considered which is the mean increase of this parameter from 2009 to 2018.

- Mobility sector:

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Due to the transport sector modelling approach, the number of vehicles has been chosen as the driver, which will guide the sector's consumption. Considering that the energy intensity remains constant (excepting municipal fleet and LPG cars), the evolution of vehicles characterizes the change in the transport sector's consumption. As in the case of the tertiary sector in Rijeka, the number of each vehicle type in the city evolves in the same way as the real number of vehicles in the Primorje-Gorski county from 2014 to 2017. Since 2018 the following growth values have been considered:

Table 27. Vehicles yearly growth in Rijeka (2018 in advance)

Type of vehicle		Yearly growth
Two wheels	Gasoline	0,66%
Private cars	Gasoline	1,28%
	Diesel	0,75%
	LPG	0,11%
Duty vehicles	Gasoline	2,53%
	Diesel	2,53%

These growth values are taken from the average increase of vehicles between 2015 and 2017. In the case of private cars, it has been assumed that 60% of the absolute growth of this type of vehicles (2,14%) corresponds to the increase of gasoline cars, while 35% and 5% are for the diesel and LPG cars respectively.

For the municipal fleet and public transport, regional GDP per capita is used as driver which guides the final consumption of these sectors. More precisely, it has been considered that in the case of the public buses, the number of the new natural gas fuelled buses evolves as the mentioned driver, while the number of vehicles in the rest of buses categories remain unchanged.

6.2.1.2 BaU modelling

The main characteristic of the Rijeka's BaU is that the city supplied an updated consumption inventory for the year 2014. Data of the generated energy in the year 2017 was given too. This data has been therefore included in the city's BaU scenario.

In order to respect these values, fuel shares were recalculated for the year 2014 and consumption data in the end-use sectors was interpolated from 2008 to 2014. After that date consumption evolves as explained in the previous section.

In the case of the residential and tertiary buildings, the decreasing of the electricity consumption has been distributed between heating uses and lighting and appliances uses. That is, instead of assuming the same decline for both uses, electricity consumed in the lighting and appliances changes the same way as the

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sectors' floor space, while the electricity used in heating applications unfolds in a way that the global reduction (2008-2014) of the electric consumption is fulfilled.

Table 28. Electric consumption evolution (2008-2014) in the residential and tertiary buildings

Parameter	Residential buildings	Private services buildings	Public services buildings
Total electric change (2008-2014)	-7,74%	-7,74%	-7,74%
Electric change (heating)	-21,84%	-17%	-44,29%
Electric change (lighting and appliances)	11,6%	0%	21,02%

On the other hand, the consumption share of heat in the residential and tertiary buildings was also recalculated between the years 2015 and 2017 in order to respect the heat generated data (2017) as it is assumed that heat is not imported neither exported in Rijeka. Total consumption evolves as is it described previously, however from 2015 to 2017 the heat share in these sectors evolves as is indicated in the following table. It should be noted that the share of the rest of fuels must change too in order to respect the total consumption change of the corresponding sectors defined previously (0,26% average increase per year for the residential's total energy consumption).

Table 29. Heat consumption share evolution (2015-2017) in the residential and the tertiary sectors where it is consumed

Sector/Subsector	Fuel	2014	2015	2016	2017
Residential	DH	11,21%	10,92%	10,64%	10,36%
	Electricity	34,62%	34,73%	34,84%	34,95%
	Natural Gas	13,14%	13,18%	13,22%	13,27%
	Light Heating Oil	12,43%	12,47%	12,51%	12,55%
	Biomass	28,61%	28,70%	28,79%	28,88%
Private services	DH	3,00%	2,88%	2,69%	2,53%
	Electricity	26,64%	26,68%	26,73%	26,77%
	Natural Gas	59,81%	59,89%	60,01%	60,10%
	Light Heating Oil	10,54%	10,56%	10,58%	10,59%
Education	DH	17,78%	17,07%	15,92%	15,02%
	Electricity	0,68%	0,68%	0,69%	0,70%
	Natural Gas	5,80%	5,85%	5,93%	6,00%
	Light Heating Oil	75,72%	76,37%	77,43%	78,26%
	On_site_electricity	0,02%	0,02%	0,02%	0,02%
City administration	DH	3,37%	3,24%	3,02%	2,85%
	Electricity	14,87%	14,89%	14,92%	14,95%
	Natural Gas	76,84%	76,95%	77,12%	77,26%
	Light Heating Oil	4,91%	4,92%	4,93%	4,94%

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Technical culture. Sports	DH	13,23%	12,70%	11,85%	11,18%
	Electricity	1,91%	1,92%	1,94%	1,96%
	Natural Gas	72,47%	72,91%	73,62%	74,18%
	Light Heating Oil	12,39%	12,47%	12,59%	12,68%
City owned homes and business premises	DH	12,44%	11,95%	11,14%	10,52%
	Electricity	27,40%	27,55%	27,81%	28,00%
	Natural Gas	14,59%	14,67%	14,81%	14,91%
	Light Heating Oil	13,80%	13,88%	14,01%	14,11%
	Biomass	31,76%	31,94%	32,24%	32,46%

In the transport sector, data was supplied by the city concerning the city's vehicle fleet and consumption in 2014. Concerning the number of vehicles, the municipal fleet went from 591 to 377 vehicles in 2014, while in the public transport fleet it was assumed that a number of conventional buses was substituted by natural gas buses (21). The total number of buses in 2014 is 173, against 186 in 2008. In the case of the private fleet each vehicle type suffered a 16,44% decrease in the number of vehicles changing from a total of 73848 private vehicles in 2008 to 61711 in 2014.

Table 30. Change in the transport fleet in Rijeka (2008-2014)

Subsector	Type of vehicle		2008	2014
Public vehicles. Municipal fleet	-		591	377
Public vehicles. Public transport	Buses	Conventional (Diesel)	79	45
		Euro I (Diesel)	26	26
		Euro II (Diesel)	30	30
		Euro III (Diesel)	28	28
		Euro IV (Diesel)	23	23
		Natural gas	0	21
Private vehicles	Two wheels	Gasoline	8314	6948
	Private cars	Gasoline	39138	32706
		Diesel	19587	16368
		LPG	880	735
	Duty vehicles	Gasoline	1283	1072
		Diesel	4646	3882

In order to respect the sector's total final energy consumption in 2014 the energy intensity of the LPG vehicles was modified (6 MWh/veh in 2008 to 6,7 MWh/veh in 2017). Fuel shares and energy intensity in the municipal fleet were changed too.

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Table 31. Specific changes in the municipal fleet in Rijeka (2008-2014)

	2008	2014
Diesel consumption share	97,15%	64,51%
Gasoline consumption share	2,85%	35,49%
Energy intensity (MWh/veh)	92,54	52,6

After 2014, consumption in the transport evolves as indicated in the previous section.

Outdoor lighting also suffered modifications between 2008 and 2014 as it is shown in the next table. The number of street lamps and their energy intensity were interpolated between these dates in order to fulfil the values in 2014. However, after that date, no more changes have been considered.

Table 32. Changes in the outdoor lighting in Rijeka (2008-2014)

	2008	2014
Nº lamps	12695	15083
Energy intensity (MWh/lamp)	0,66	0,54

Regarding the supply side, heat generation plants work in order to cover the heat demand defined in 2014 and in the rest of the years. On the other hand, availability of the heat only boiler plants was modified in the year 2017 with the purpose of respecting the generation values of each plant that were given by the city for that specific year. After that year, maximum operating hours values are considered the same as in the baseline year’s values.

Finally, from 2011 to 2014, solar PV facilities were installed in educational buildings. Installed capacity was interpolated through these years until achieving a total installed capacity of 0,09 MW. Availability of these facilities has been extracted from the JRC PVGIS data for an optimized installation (considering 19% system losses) and is estimated as 13,01% of the total yearly hours. PV facilities integrated in buildings have been modelled as for the case of Palencia: electricity generated in these systems is in consumed in the sectors where they are located.

As a conclusion for this section, evolution of the final energy consumption in in Rijeka in the BaU scenario is shown in the next figure.

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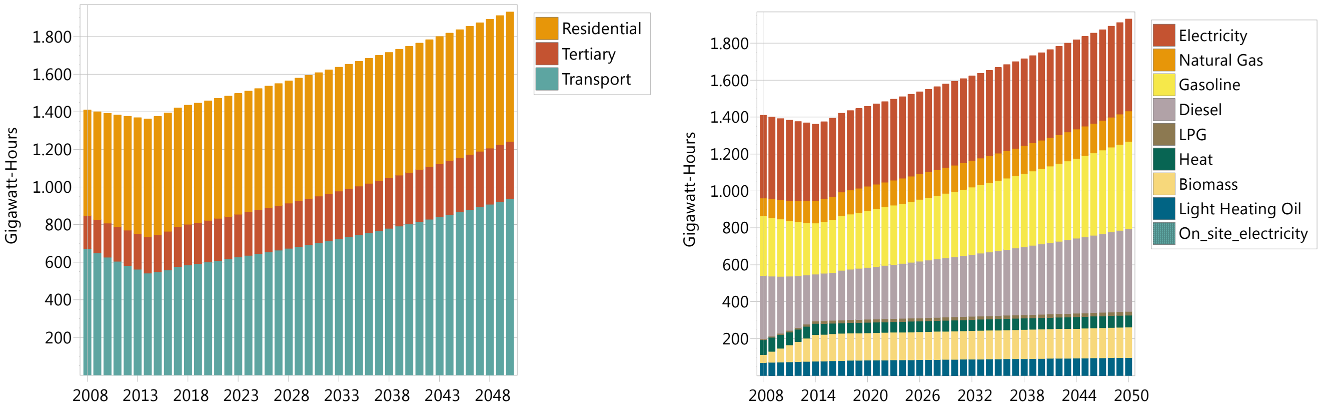

Figure 37. Sectoral final energy consumption (left) and fuel consumption (right) in Rijeka for the BaU scenario

Besides, as a picture of the final year, final energy consumption disaggregated by fuel and sector can be seen in the next figure.

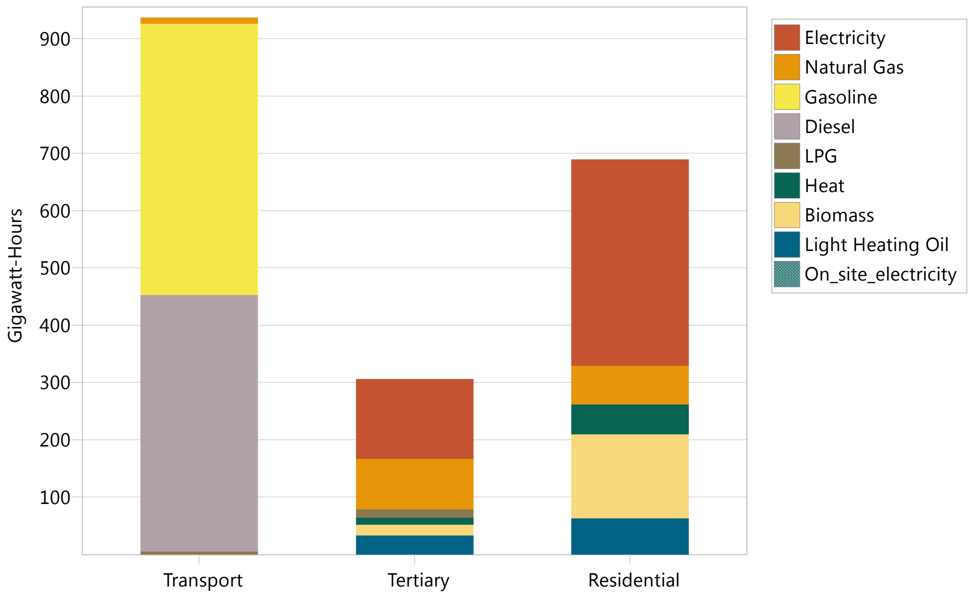

Figure 38. Energy consumption disaggregated by fuel and sector in Rijeka for the BaU scenario in the year 2050

Regarding energy generation in the BaU scenario, PV panels (on-site electricity generation) start working in 2011, reaching its maximum installed capacity in 2014 with a production of 102,6 MWh, which remains constant through the years. On the other hand, heat generation starts to increase in 2018 after a period of steady decrease since 2008. This production increase comes along with a consumption increase of the fuels consumed in the heat only boilers plants (production and therefore consumption in the CHP plant is considered to remain the same all along the simulation years).

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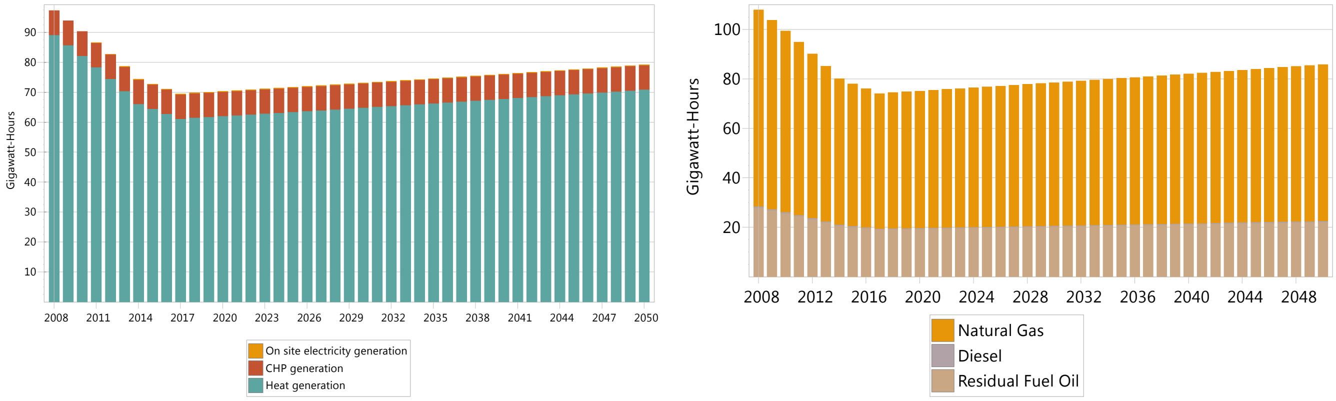

Figure 39. Energy generation (left) and consumption in the heat only boiler plants (right) in Rijeka for the BaU scenario

6.2.2 Alternative scenarios for Rijeka

This subsection describes the replication scenario developed for Rijeka. This scenario takes into account the implementation of the interventions that have been selected by the city for its replication. The following subsections describe the type of interventions considered, their level of deployment and the influence of these interventions in the entire city.

6.2.2.1 Analysis of the interventions to be replicated in city and replication scenario modelling

The scenario is based on the interventions that can be replicated in the city, which have been selected and evaluated in detail through the PESTEL analysis carried out in previous studies of WP6. The figure below shows the general overview of the pros and cons of each intervention for the dimensions considered in the PESTEL analysis.

The results obtained here have been considered as general criteria for the definition of the replication potential of each intervention in the replication scenario.

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Figure 40. Synthesis of PESTEL analysis for the interventions selected in Rijaka.

- <u>Intervention 1. Smart bus-stations and smart traffic platform:</u>

This action aims to build a smart bus-station network for public transport supported with innovative systems for integrated traffic management in the urban area. The central information system for traffic management will collect, process and make accessible all available information related to the public transport system. This action will contribute to implement energy efficiency measures in public transport upon monitoring and coordinating traffic actions, in order to reduce greenhouse gases emissions in the city area.

Therefore, for the modelling of this intervention in the BaU scenario of Rijeka, it needs to be taken into account that the limits of the system considered for the transport sector apply to the subsector defined in the model as public transport (buses), in which the effect of the implementation of this action have been reflected as a reduction of the average energy intensity of the vehicles. Due to the lack of specific data for the potential improvement of this action in Rijeka, several information sources have been consulted which reflect the actual potential improvement obtained in other cities [27]. This reference shows different levels

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of improvement; 13% in UK, 3,6% in Finland, 8,3%-13,8% in Italy and 5% in UE. For this study, an average value of improvement of 11% has been considered.

The replication scenario considers that the implementation of the intervention starts in 2020 and that in the year 2030 this intervention has already been extended in the city so that it covers the entire road public transport sector (buses).

The following figure shows the specific influence of this intervention in the city of Rijeka.

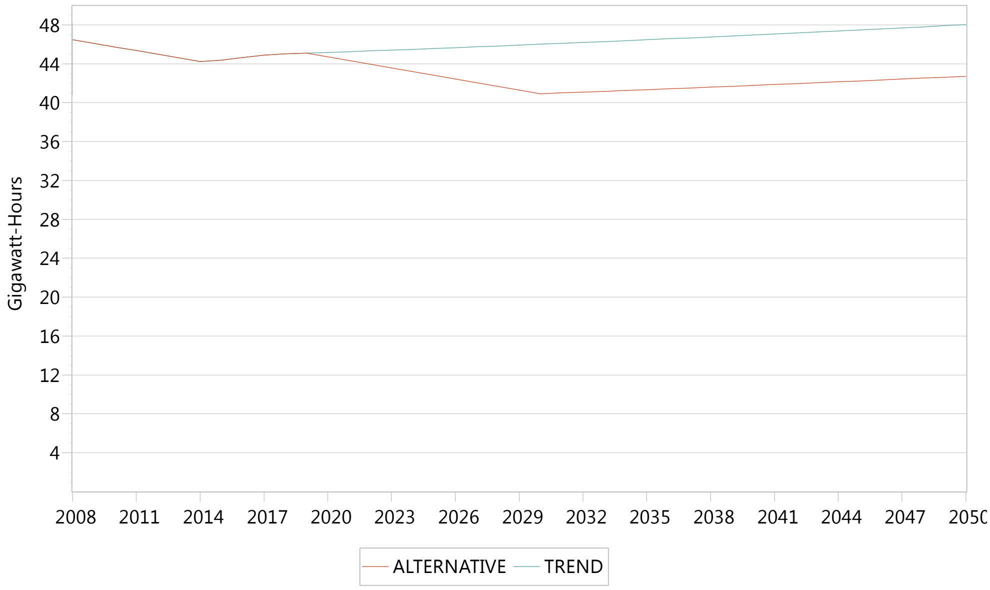

Figure 41. Effect of the replication of the intervention of Smart bus-stations and smart traffic platform in Rijeka.

- <u>Intervention 2. Smart Public Lighting:</u>

The action corresponds to the implementation of a smart lighting system which presumes the possibility of remote control and management (lighting/turning off/strength regulation) of every particular lamp in the system. Also, smart lighting can be upgraded by adding additional sensors (temperature, humidity…) which could then be used by other systems for increasing the quality of living for all citizens. As described in the deliverable D6.3, for the Rijeka public lighting system it would mean replacing all existing lamps (app.15.500) with new LED lamps, which have the possibilities mentioned above. The available technologies of the smart public lighting systems mostly use wireless GPRS technology.

Therefore, the replication scenario takes into account that all the lamps of the city will be replaced to LED technology before 2040. This will reduce gradually the average energy intensity per lamp in the city. At the end of the period, the average energy intensity per lamp in the city is considered 0,078 MWh/lamp.

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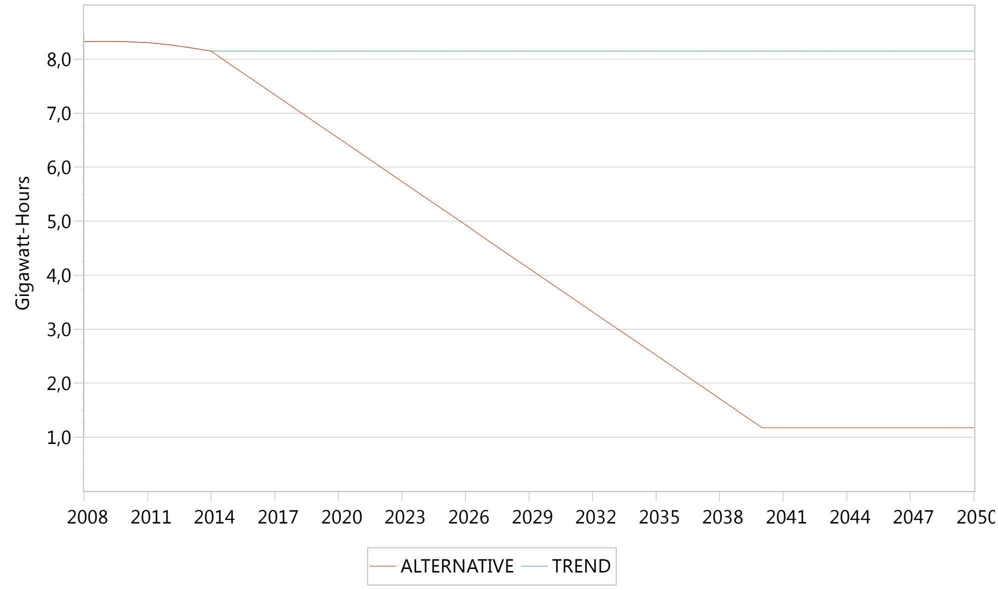

Figure 42. Effect of the replication of the intervention of Smart Public Lighting in Rijeka

- Intervention 3. Smart metering and Smart Meter data management:

The action corresponds to the installation of smart meters in the City of Rijeka owned public buildings. Smart metering system is monitoring several parameters, depending of the object purpose: electricity consumption, gas consumption, electricity production (when PV/solar-thermal are installed), gas distribution (gas stations), thermal energy consumption, thermal energy production (heating plants), water consumption, and heating oil consumption.

For the modelling of the replication scenario it is considered that the monitoring and management of the energy consumption of buildings will contribute to a reduction of the energy consumption of these buildings. This energy consumptions reduction is estimated in 6% which is applied to both the thermal and the electrical uses. In the scenario the replication potential of the intervention is considered to cover by 2030 all the city administration buildings and city owned homes and businesses. In a second level of deployment of the intervention the scenario considers the effect of implementing it in all the buildings of the public sector by 2050.

As it can be observed in the following figure, the savings obtained by this replication scenario is expected to be 3% respect to the total energy consumption of the sector by 2030 and near 6% by 2050.

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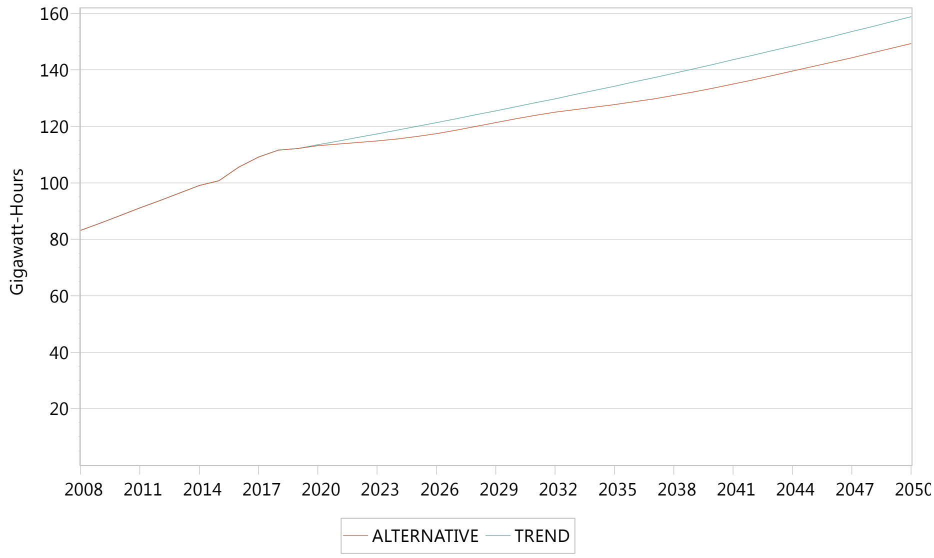

Figure 43. Effect of the replication of the intervention of Smart metering and Smart Meter data management in Rijeka

- Intervention 4. RES integration – PV panels: energy storage and sharing:

The action corresponds to the implementation of an energy-sharing concept joining neighbouring buildings in sharing electricity generated by PV panels. The replication scenario aims to evaluate the effect of replicating this intervention in the tertiary/public buildings.

The scenario considers that 15% of roof area of the buildings of the sector could be covered by solar PV technology (0,62kW/m2) [28] by 2050. This area has been estimated considering the analysis carried out for the city in the ST6.2.1 related energy characterization and the CityGML generation for the city, where all the building stock of the city was evaluated.

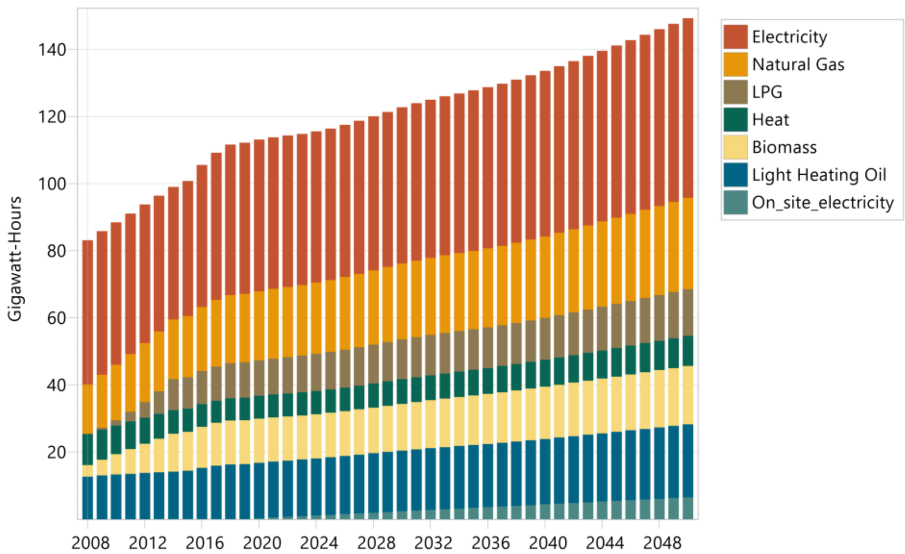

Figure 44. Effect of the replication of the intervention of RES integration – PV panels in Rijeka

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Finally, it needs to be remarked that the interventions related to Citizen involvement/participation in energy savings and open data and GIS platform have not been included in the modelling due to the difficulties to assign specific energy reductions to this type of non-technical interventions.

Replication scenario for Rijeka

Replication scenario in Rijeka manages to save 1,13% final energy consumption in relation to the BaU scenario in 2050.

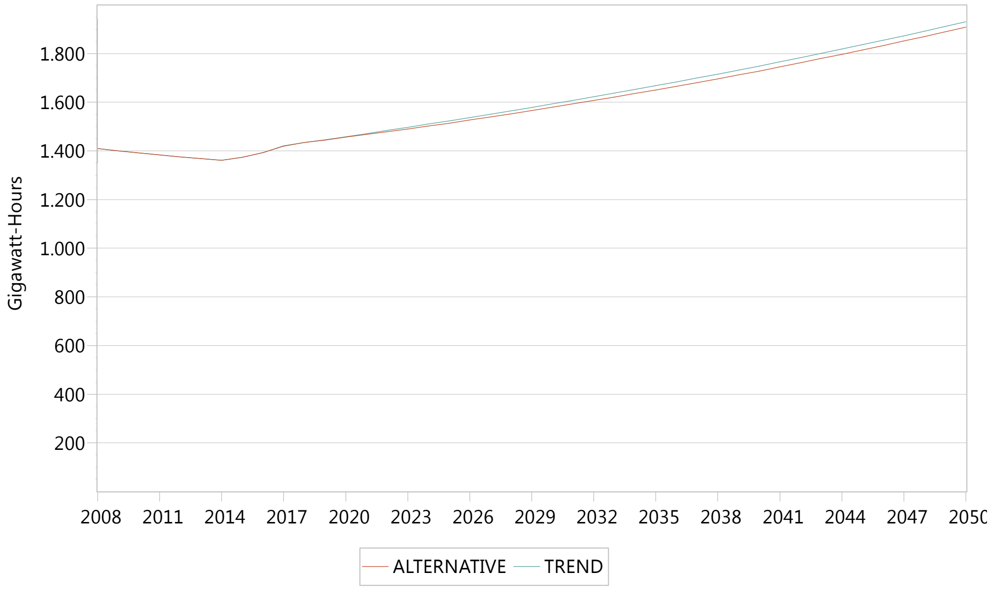

Figure 45. Total final energy consumption comparison of the end-use sectors in Rijeka (BaU scenario vs replication scenario)

As no interventions are implemented in the residential sector no final energy consumption reduction is performed in this sector. Savings are, however, achieved in tertiary (only public services) and transport sector. Interventions 2 and 3 manage to save 16,5 GWh in the latter, while intervention 1 saves 5,31 GWh in the former with respect to the BaU scenario in 2050. Changes in the fuel mix are presented in the figure below. Greater reductions are achieved in the electricity consumption, in part because the electricity coming from the grid is substituted by the electricity generated in the installed PV panels.

As a general conclusion, it can be mentioned that in the case of Rijeka, other interventions could be also considered in order to attain higher levels of energy consumption reduction: actions such as the ones contemplated in the PESTEL analysis; buildings refurbishment or public fleet substitution by e-vehicles (instead of natural gas buses for example) obtain greater savings as seen in the lighthouse cities and the rest of follower cities. Further analysis related to the implementation of these type of interventions should be therefore considered in the future.

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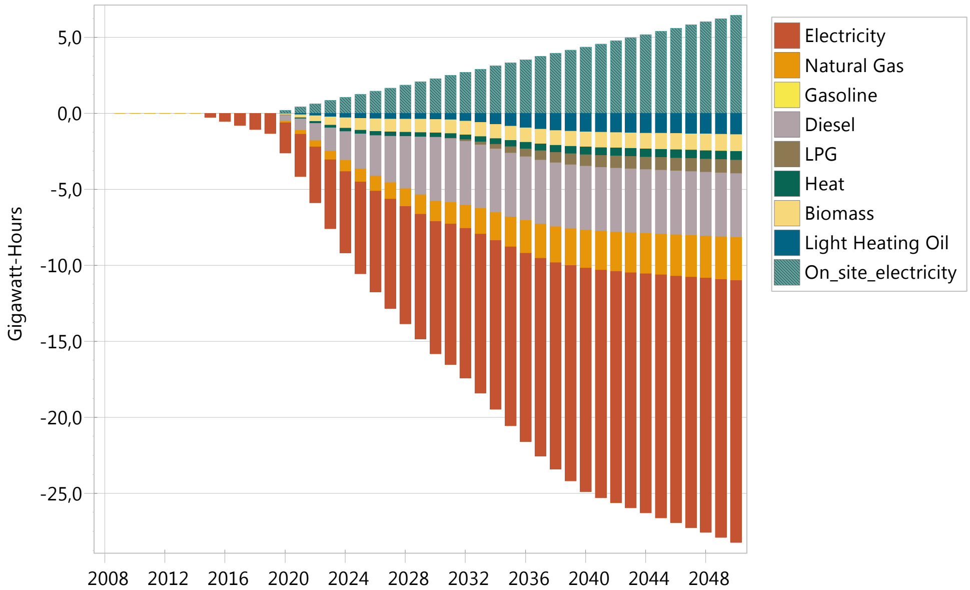

Figure 46. Fuel mix differences in the end-use sectors in Rijeka (BaU scenario vs replication scenario)

Finally, reductions in the consumption of the District Heating boilers are also accomplished due to the reduction of the heat demand in the end-use sectors. However, the fuel savings only represent 0,97% with respect to the BaU scenario in 2050.

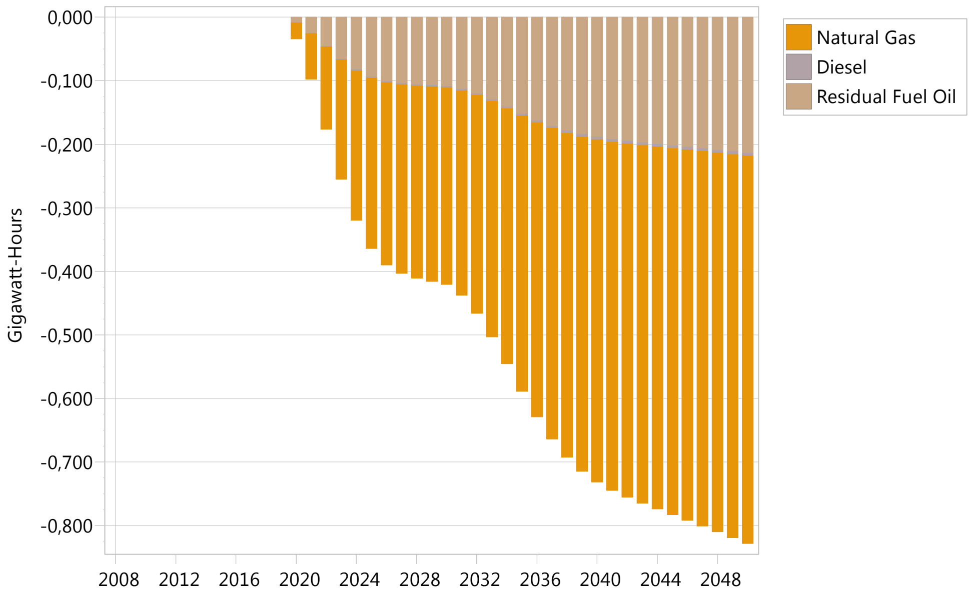

Figure 47. Fuel consumption differences in the District Heating boilers in Rijeka (BaU scenario vs replication scenario)

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6.3 Scenario analysis for Bydgoszcz

In the case of Bydgoszcz, the energy model created covers for the entire city considering the different energy consumptions of each sector of the city, as well as the different energy supply systems. This section focuses on the projections generated for the energy consumption and generation of the city for the following decades.

6.3.1 BaU scenario for Bydgoszcz

For the case of Bydgoszcz, the following information sources have been consulted in order to define the drivers, which will guide the energy consumption in the coming years:

- Statistics Poland [29]: projection of the number of households is issued from the national statistical office of Poland
- Municipality data: population data and projections supplied by the city have been considered
- PRIMES model [30]: Poland's national GDP growth considerations in the PRIMES energy model have been used in the city model

6.3.1.1 Driver selection for the definition of the BaU Scenario

As for the previous cases, historical information was very limited and incomplete at city scale.

- Residential sector:

For the energy consumption in the residential sector in Bydgoszcz the number of households has been chosen as the main driver. Projected values of this parameter were available and have been used in the model.

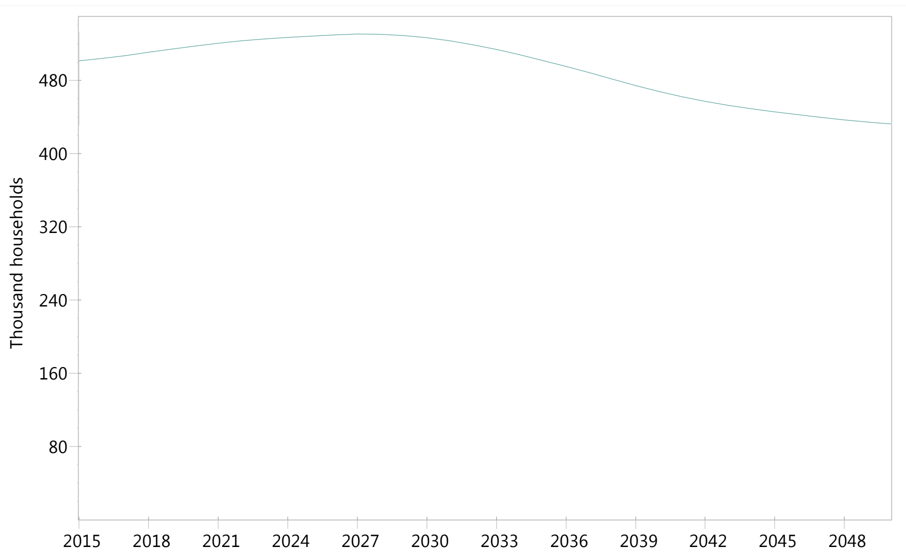

Figure 48. Number of household evolution in Bydgoszcz for the BaU scenario

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- <u>Tertiary sector:</u>

In the tertiary sector private and public subsectors have been distinguished, and each one of them evolves based on a specific driver. While it has been assumed that private tertiary subsector changes as the GDP, public tertiary subsector evolves as the GDP per capita. Regional GDP (Bydgosko-Torunski region) data has been found and is supposed to change as the national GDP which is extracted from the PRIMES model: 2,88% yearly change until 2020; 2,37% until 2030; and 1,22% until 2050. On the other hand, the population projection of the city was given by the municipality. This data was adapted to regional level in order to be compared with the GDP data scale available. Regional GDP per capita was then calculated. It should be noted that a decoupling factor of 0,7 has been considered in order to attenuate the GDP per capita growth as the population in Bydgoszcz is ageing like in the case of Palencia.

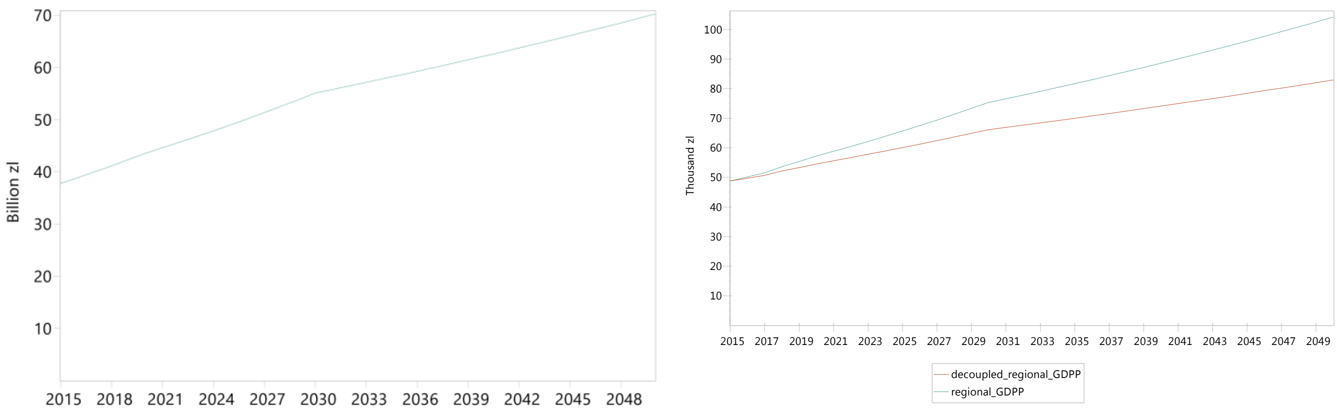

Figure 49. GDP (left) and GDP per capita (right) evolution in Bydgoszcz for the BaU scenario

- <u>Industrial sector:</u>

For the energy consumption in the industrial sector it has been supposed that it follows the evolution of the GDP, as in the case of the private tertiary subsector.

- <u>Mobility sector:</u>

Energy consumption in the transport sector has been assumed to evolve as the GDP, which changes as it has been explained before.

6.3.1.2 BaU modelling

Considering the base year energy balance and the tendencies described in the previous subsection that are used to project the energy consumption of Bydgoszcz, the BaU scenario is modelled in LEAP.

For the city’s demand side, the energy consumption evolution is shown in the figure below.

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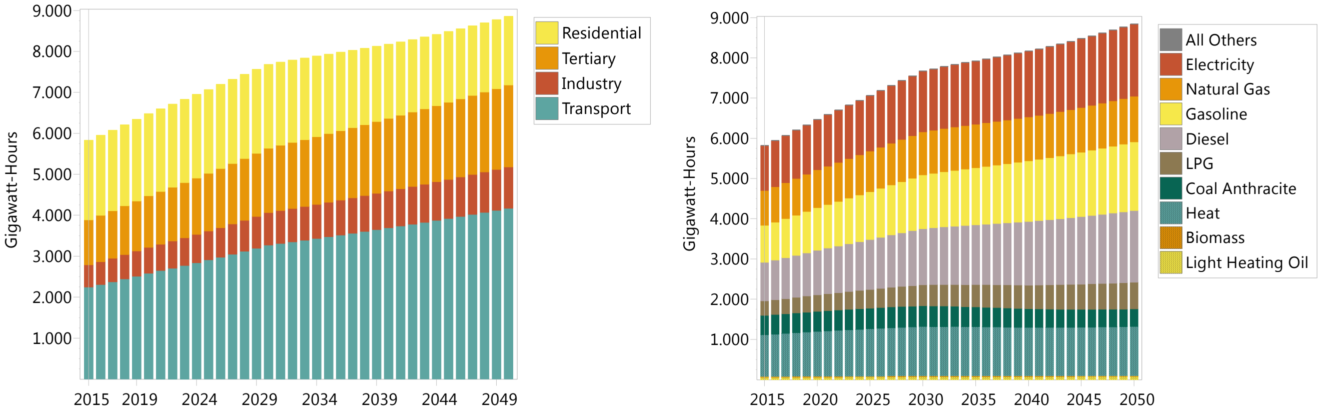

Figure 50. Projection of the sectoral final energy (left) and fuel consumption (right) in Bydgoszcz for the BaU scenario

Fuel consumption by sector in 2050 is shown in the next figure.

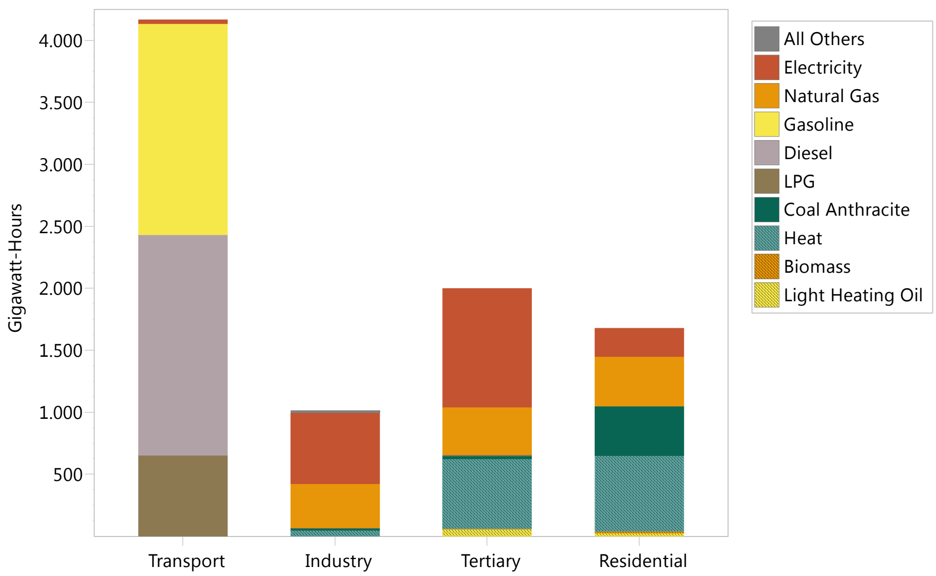

Figure 51. Energy consumption disaggregated by fuel and sector in Bydgoszcz for the BaU scenario in 2050

In the case of the city's supply side, as no capacity is added and as the maximum operating hours are supposed to remain constant, renewable electricity generation processes and heat only boiler plants produce (and consume) the same amount of energy as the baseline year. Energy produced in the CHP plants on the other hand varies in order to cover the heat demand of the city through the years.

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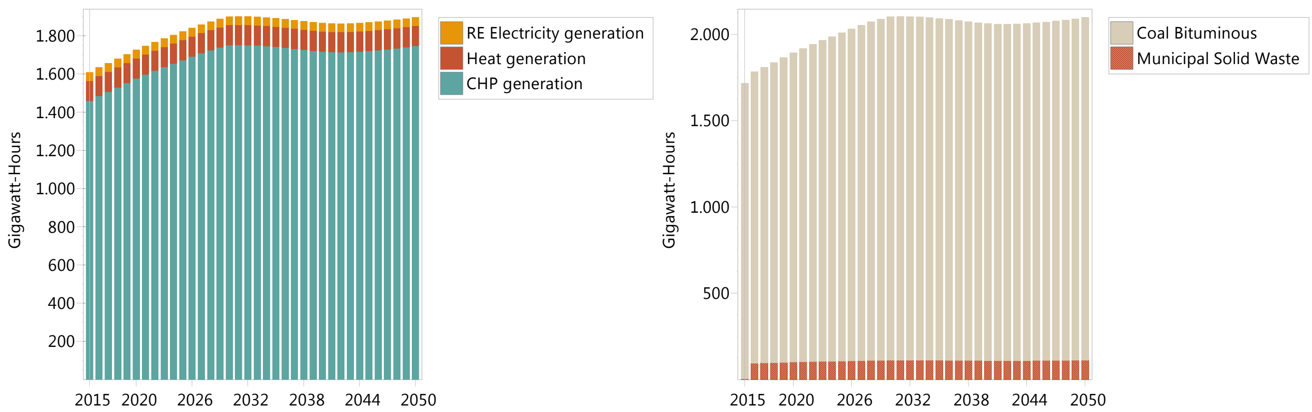

Figure 52. Energy generation (left) and consumption in the CHP plants (right) in Bydgoszcz for the BaU scenario

6.3.2 Alternative scenarios for Bydgoszcz

This subsection describes the replication scenario developed for Bydgoszcz.

6.3.2.1 Analysis of the interventions to be replicated in city and replication scenario modelling

The scenario is based on the interventions that can be replicated in the city, which have been selected and evaluated in detail through the PESTEL analysis carried out in previous studies carried out in the WP6.

The figure below shows the general overview of the pros and cons of each intervention for the dimensions considered in the PESTEL analysis.

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Figure 53. Synthesis of PESTEL analysis for the interventions selected in Bydgoszcz.

- <u>Intervention 1. E-mobility in Bydgoszcz:</u>

The action corresponds to a complex cross-sectoral action focused on development of electro-mobility in Bydgoszcz. It can be divided into the following sub-actions;

a) Electric buses – introduction of electric buses in public transport in Bydgoszcz (purchase of e-buses as well as supporting infrastructure);

b) E-mobility development strategy

c) Analysis and implementation of public charging stations network in Bydgoszcz

d) Introduction of electric vehicles in city's fleet

The replication scenario developed for the city considers that the public transport will be 100% electric by 2050. This has been modelled by replacing the current vehicle fleet, as well as the future fleet defined in the BaU scenario by e-vehicles and decreasing accordingly the total energy intensity of the fleet.

The figure below shows the effect of this intervention.

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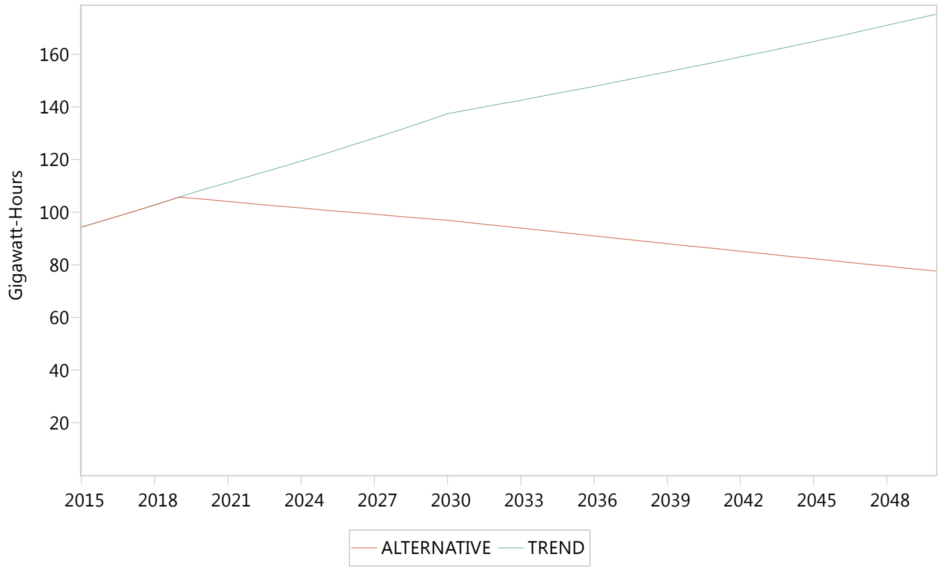

Figure 54. Effect of the replication of the intervention of E-mobility in Bydgoszcz.

- Intervention 2. PV on public buildings:

The action corresponds to the implementation of PV installations on public buildings (schools and office buildings) with a capacity ranging between 5 - 40 kW. As described in the PESTEL analysis, in most cases the deployment of the PV will be made within thermal refurbishment of the building. These installations will be designed to cover buildings' electricity demand – most of the modules will be off-grid, but some also will be grid connected, which would allow two-way transfer of the electricity.

The replication scenario considers that the deployment of PV systems will be linked in many cases to building refurbishment. The implementation of PV systems in the scenario starts in 2020 and considers that by 2050 the 20% of the electricity consumption of all the public buildings of the city will be covered by electricity generated by PV panels. Besides, the scenario also considers that all the new public buildings constructed after 2020 will have a minimum of 20% of electricity consumption covered by renewable electricity produced by PV systems. The figure below shows the effect of this intervention.

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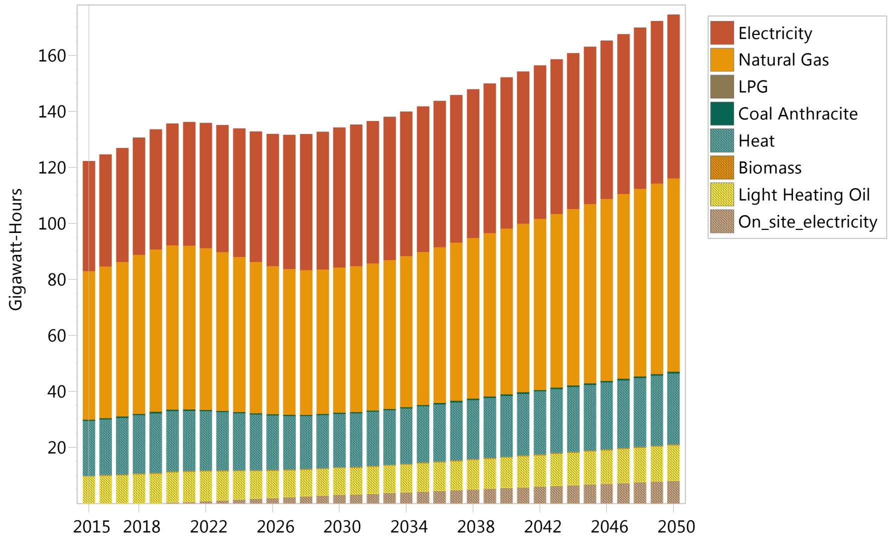

Figure 55. Effect of the replication of the intervention of PV on public buildings in Bydgoszcz.

- Intervention 3. Smart lighting system:

The action corresponds to the modernization of the lighting of the city. This modernization has only been partially modernized over recent years. As evaluated in the PESTEL analysis, this is due to complicated ownership situation – large part of the lighting (ca. 80%) is owned and managed by the energy operator company and the city cannot do any investment on this part of lighting. However, Bydgoszcz plans to take control over this part of lighting system in coming years. On the municipally owned lighting there has already been investment made in the smart lighting: 7309 lamps have been modernized (LED lighting) and steering system has been implemented at the cost of ca. 5M EUR.

Therefore, the Smart lighting system intervention in Bydgoszcz project will cover the modernization of old lighting (implementation of LED lighting system) and the enhancement of smart steering of public lighting (telematics, smart controls).

This is modelled in the replication scenario as a substitution of the current lighting systems to new LED systems. It is considered that the intervention starts in 2020 and that by 2040 all the public lighting of the city will be LED.

The figure below shows the effect of this intervention.

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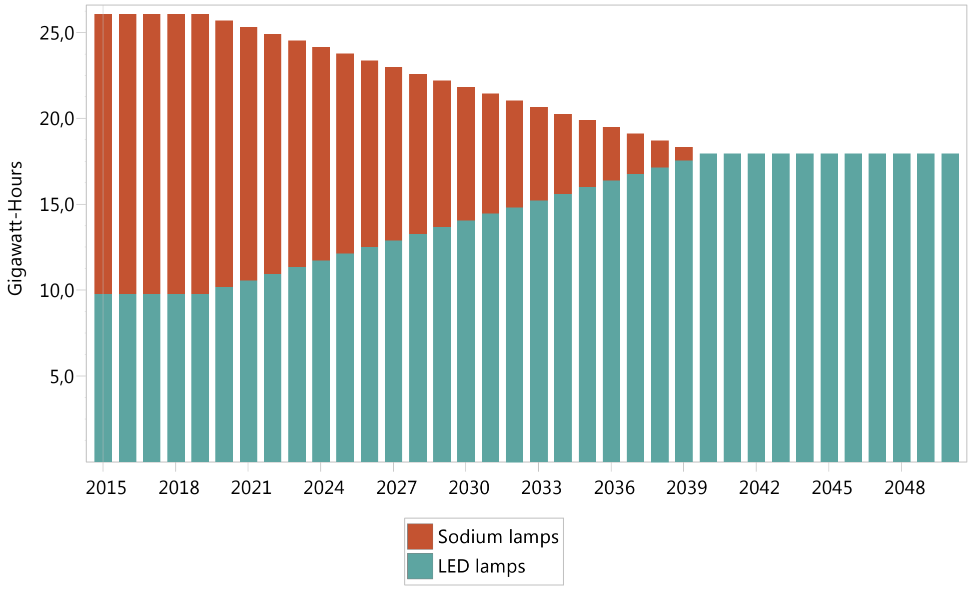

Figure 56. Effect of the replication of the intervention of Smart lighting system in Bydgoszcz.

- Intervention 4. Public building refurbishment:

The action is not included in the final selection of the city. However, it is mentioned and linked in many cases to the intervention related to the PV systems. Besides, the city has expressed their interest in this action and it is considered that it would be interesting to evaluate its potential effect in the city. This is the reason why it has been included in this section.

The replication scenario considers that the improvement of the envelope of buildings is applied in all the public buildings by 2050. For the estimation of the average energy saving potential of this intervention the results of the ST 6.2.1 have been used.

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Figure 57. Heating demand (kWh/m2) in Bydgoszcz.

Here, evaluating the age of the buildings and the differences between energy consumption of the current building stock of the city and the energy consumption of new buildings the average energy saving potential is estimated in 40% (of the fossil fuel consumption in the baseline year). Modelling this deployment level of the interventions, the figure below shows the effect of this intervention.

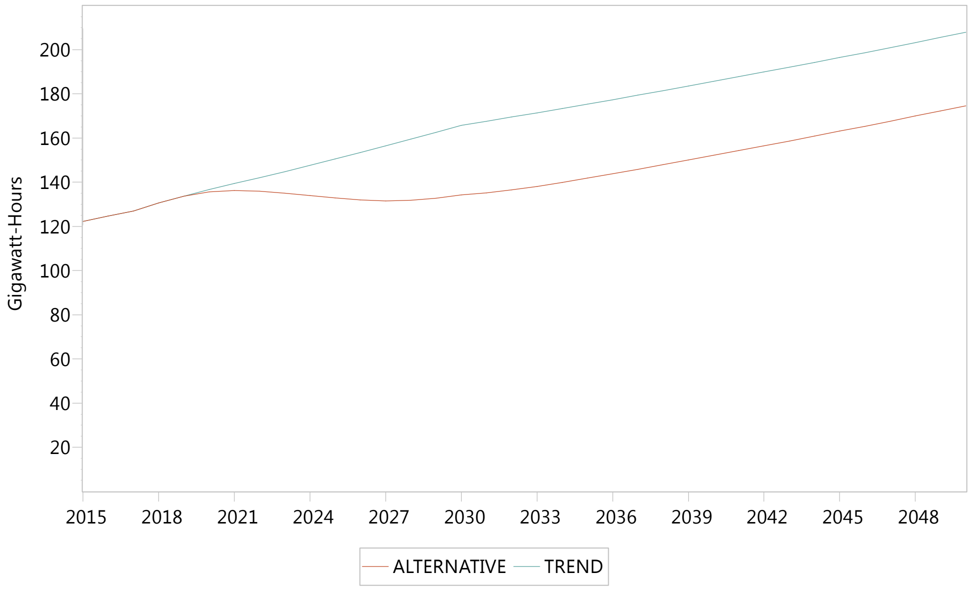

Figure 58. Effect of the replication of the intervention of public building refurbishment in Bydgoszcz.

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Finally, it needs to be remarked that the interventions related to open data GIS portal and smart rainwater system have not been included in the modelling due to the difficulties to assign specific energy reductions to this type of non-technical interventions.

Replication scenario for Bydgoszcz

All interventions taken into account, the replication scenario in Bydgoszcz manages to save 138,88 GWh, which represents 1,57% with respect to the BaU scenario.

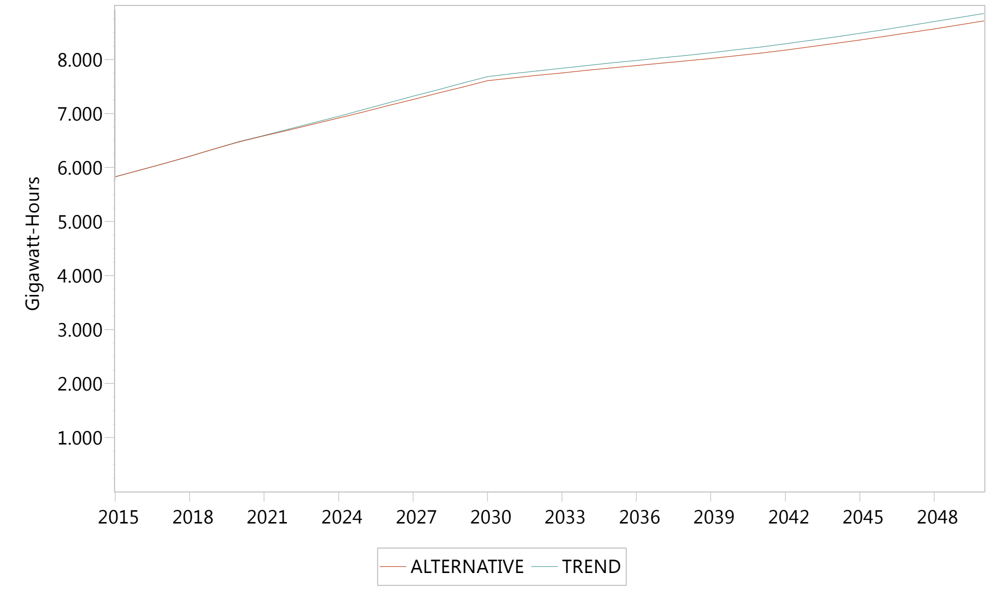

Figure 59. Total final energy consumption comparison of the end-use sectors in Bydgoszcz (BaU scenario vs replication scenario)

As in the case of Rijeka, no interventions are carried out in the residential sector. Savings are mainly obtained in the tertiary (41,38 GWh reduction) and transport (97,51 GWh) sectors. It should be noted that consumption reductions only take place in the public branches of these sectors and therefore represent only 2,07% and 2,34% of the sector's total consumptions respectively. Replication of interventions 1 and 4 in the respective private branches of the transport and tertiary sectors could achieve important savings as integration of e-vehicles in the public fleet represents a 55,69% consumption reduction and public buildings refurbishment saves 16% energy with respect to the BaU scenario in 2050. The last intervention could be also replicated in the residential sector.

The next figure shows the evolution of the differences in the fuel mix between the BaU and replication scenarios. As it can be seen, on-site produced electricity growths due to intervention 2, while electricity, natural gas and diesel decreases. The former two due to interventions in public buildings, the latter because of the public fleet substitution by e-vehicles.

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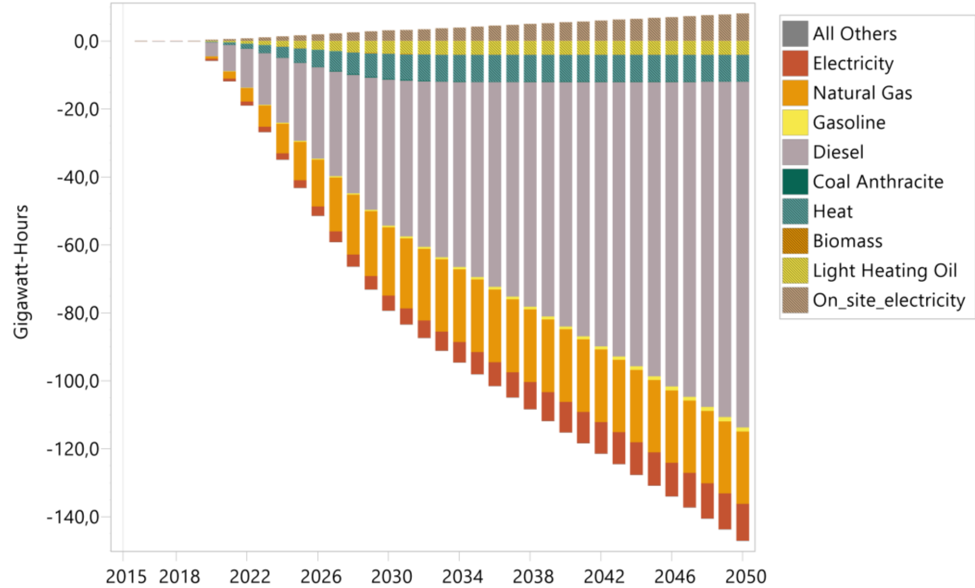

Figure 60. Fuel mix differences in the end-use sectors in Bydgoszcz (BaU scenario vs replication scenario)

Finally, coal and municipal solid waste consumed in the CHP plants of the District Heating also decrease due to the heat demand reduction in the end-use sectors. However, this diminution only represents 0,69% energy reduction with respect to the BaU scenario in 2050.

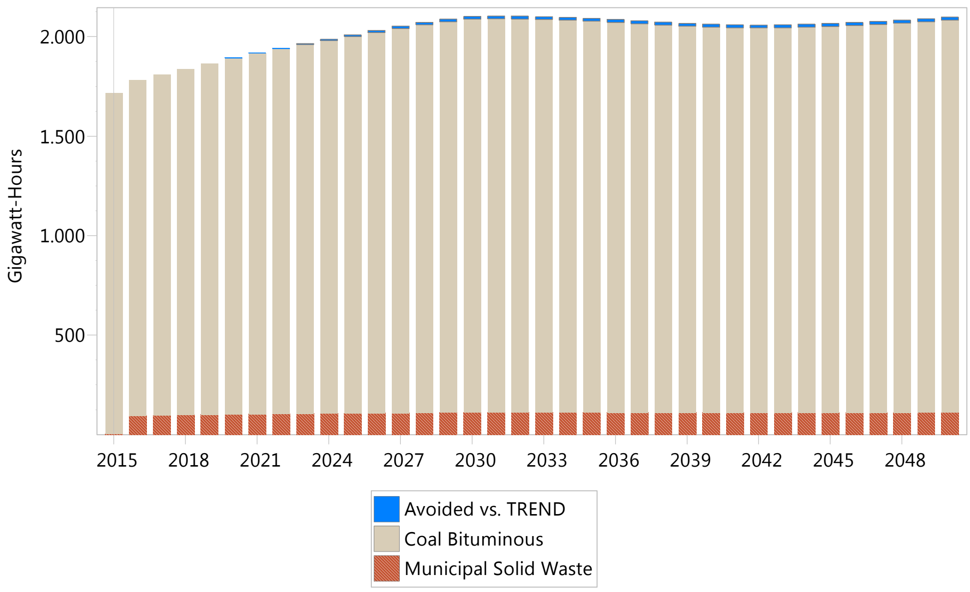

Figure 61. Fuel consumption differences in the CHP plants of the DH in Bydgoszcz (BaU vs replication scenario)

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7. Conclusions

This deliverable includes a description of the work carried out in the mySMARTLife project related to the energy scenario modelling for the three follower cities. The work carried out provides a solid basis for the long-term city energy modelling, which will allow the replication of the analysis in other cities out of the scope of the project. The methodological description provided in the initial sections is in line with the methodology developed for the case of lighthouse cities. This methodology allows a good understanding of the way to approach long-term energy modelling at city scale, which in most of the cases is carried out partially.

In terms of the analysis carried out, it can be concluded that the first steps followed from the base year modelling to the BaU scenario modelling have followed the same procedure as in the case of the analysis carried out with lighthouse cities. Similar difficulties have been identified in both cases. The difficulties are mainly linked to the data gathering phase for the base year modelling, which is a critic step since the level of detail and flexibility of the scenario developments will depend on it. On the other hand, during the BaU scenario modelling, it needs to be mentioned that the previous work carried out in WP1 with regard to the selection of specific drivers for each sector and subsector of cities has facilitated this part of the work in the case of follower cities. One of the main conclusions was that similar drivers can be considered in the case of all the cities for each sector. Here, the lack of data related to the historic energy consumptions of cities, as well as the lack of data (specific at city scale) related to the potential tendencies of the main drivers selected for each case has been one of the main difficulties faced in the process. As occurred in the case of some lighthouse cities, the tendencies of the main socioeconomic parameters have been adapted from their corresponding regions in each case.

The main difference of the methodology used in this case respect to the process followed with lighthouse cities has occurred during the alternative scenario modelling. In the case of lighthouse cities, specific interventions were already planned, and the alternative scenarios evaluated the effect of the scaling-up of these interventions in the rest of the city areas. However, in the case of the follower cities, the alternative scenario is directly the replication scenario, which explores the potential effect of replicating some of the interventions carried out in lighthouse cities in their specific case. The main difficulty here has been that no specific data of the interventions exist for the follower cities. Therefore, the main conclusions obtained from the lighthouses have been particularized to their case.

Finally, it is concluded that scenario analysis in general and the use of specific tools, such as the one selected for mySMARTLife project (LEAP), is a powerful approach that needs to be used in city energy planning, especially in the definition phase, when comparing the potential effects of different alternative interventions for the city.

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