Nantes | Hamburg | Helsinki

my SMART Life

Deliverable due date: M23 – October 2018

D1.13 COMPILATION OF ENERGY SYSTEM SCENARIOS FOR EACH LIGHTHOUSE CITY

WP1, Task 1.4

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	D1.13 Compilation of energy system scenarios for each lighthouse city	
Diss. Level	PU	
Status		Working
		Verified by other WPs
	■	**Final version**
Due date	31/10/2018	
Work Package	WP1	
Lead beneficiary	TECNALIA	
Contributing beneficiary(ies)	NAN, HAM, HEL, VTT, FVH, NBK, ESA, CAR	
Task description	Task 1.4 is related to evaluating impacts in lighthouse (NAN, HAM, HEL) and follower cities (BYD, RIJ, PAL) from the social, economy and environmental field to understand the interaction of the different interventions as a system. These will be clear indicators for the cities to make decisions. These results, combined with their own SEAPs, their sustainable mobility plans, their open data strategy, and related tasks in this WP1 and with WP2, WP3, WP4 and WP6 will serve to develop the integrated urban plans of these cities as an application of the methodology that later will be replicated in the followers. Subtask 1.4.2: 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
01/03/2018	0.1	Eneko Arrizabalaga (TEC) Contributions of lighthouse cities of mySMARTLife partners	Interim Version
11/05/2018	0.2	Eneko Arrizabalaga (TEC) Contributions of lighthouse cities of mySMARTLife partners	Initial structure and content
01/07/2018	0.3	Eneko Arrizabalaga (TEC) Contributions of lighthouse cities of mySMARTLife partners	Advanced version with the general content of all the sections
15/10/2018	0.4	Eneko Arrizabalaga and Iñigo Muñoz (TEC) Contributions of lighthouse cities of mySMARTLife partners	Advanced version sent to the reviewer

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24/10/2018	0.5	Eneko Arrizabalaga and Iñigo Muñoz (TEC) Contributions of lighthouse cities of mySMARTLife project and contributions from the reviewers (ENH, CER)	Final version

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Abbreviations and Acronyms

Acronym	Description
BaU	Business as usual
CHP	Combined Heat and power
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 D1.13 aims to describe the energy scenarios developed for the next 10-20 years for the three lighthouse 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 1.4, which is related to evaluating impacts in lighthouse cities (NAN, HAM, HEL) from the social, economic and environmental field 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 1.12:** This deliverable is related to the subtask 1.4.1 and is focused on the description of 3D models for each pilot 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 so that 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 1.4.2.
- **Deliverable 1.13:** This deliverable is related to the subtask 1.4.2 which is focused on the energy scenario development at city scale. The outcome of the subtask that is described in the Deliverable 1.12 will be used for the definition of scenarios.
- **Deliverable 1.14:** This deliverable is related to the subtask 1.4.3 which is focused on the techno-economic assessment of the interventions that will be implemented in the lighthouse cities.
- **Deliverable 1.15 and 1.16:** These deliverables are related to the subtask 1.4.4 which is focused on the impact assessment and the comparative analysis of all interventions. Here, the outputs described in both deliverables D1.13 and D1.14 will be completed with an energy and environmental assessment which will provide extra indicators and criteria that will be used for the prioritization of interventions in each lighthouse city.

Moreover, all the subtask and outputs described in the mentioned deliverables (focused on the lighthouse cities) will serve as a starting point for the replication plan for the follower cities. Based on the experience gained, the entire process will be replicated in the Task 6.2 of the WP6 for the follower cities of mySMARTLife project.

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 lighthouse cities and the relation with the replication in the follower cities.

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Chapter 4: Provides an introduction with the methodological approach to the city energy characterization and scenario modelling of the three lighthouse 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 pocess as well as the modelling of the base year in LEAP energy scenario modelling software. This section distinguishes the case of the three lighthouse cities.

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 pocess as well as the modelling of the base Business as Usual (BaU) scenario and alternative scenarios in LEAP energy scenario modelling software. This section distinguishes the case of the three lighthouse cities.

Chapter 7: Describes de main conclusions obtained from the work carried out in the subtask 1.4.2.

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
HEL	Contribution (data provision) to the sections 5 and 6
HAM	Contribution (data provision) to the sections 5 and 6
NAN	Contribution (data provision) to the sections 5 and 6
VTT	Contribution–support to HEL in data gathering for sections 5 and 6
FVH	Contribution (data provision) to the sections 5 and 6
ENH	Overall review of the deliverable
CER	Overall review of the deliverable

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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
D2.1	This deliverable provides the baseline information of Nantes demonstrator area
D3.1	This deliverable provides the baseline information of Hamburg demonstrator area
D4.1	This deliverable provides the baseline information of Helsinki demonstrator area
D1.12	This deliverable provides the compilation of the 3D models and energy demand calculation of the pilots of the three lighthouse cities
D1.14	This deliverable provides the techno-economic analysis of each intervention per pilot which in part will depend on the results of this deliverable
D1.15	This deliverable provides comparative analysis of interventions based on impacts (per pilot) which will use some results of this deliverable
D6.6	This deliverable provides the compilation of energy system scenarios for each follower city which will follow the same procedure described in this deliverable

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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 subtask of the Task 1.4 of the project and how each subtask contributes to the rest with their corresponding outcomes.

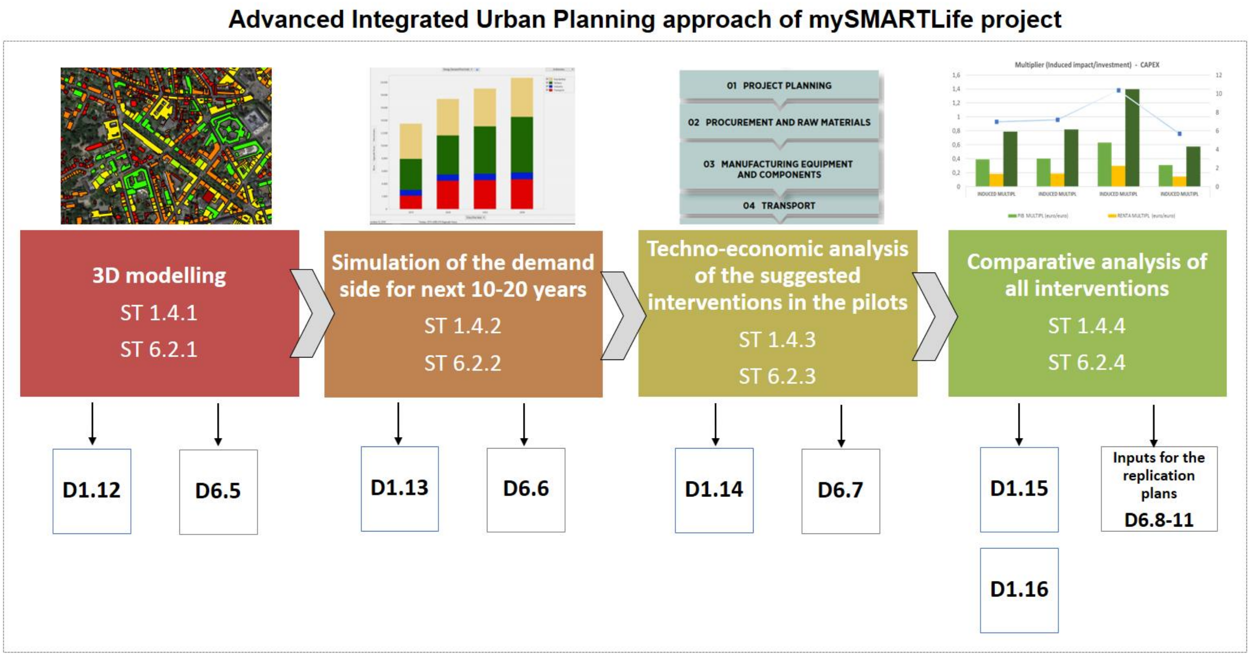

Figure 2: Methodological approach of the Advanced Integrated Urban Planning in mySMARTLife project.

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 lighthouse 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.

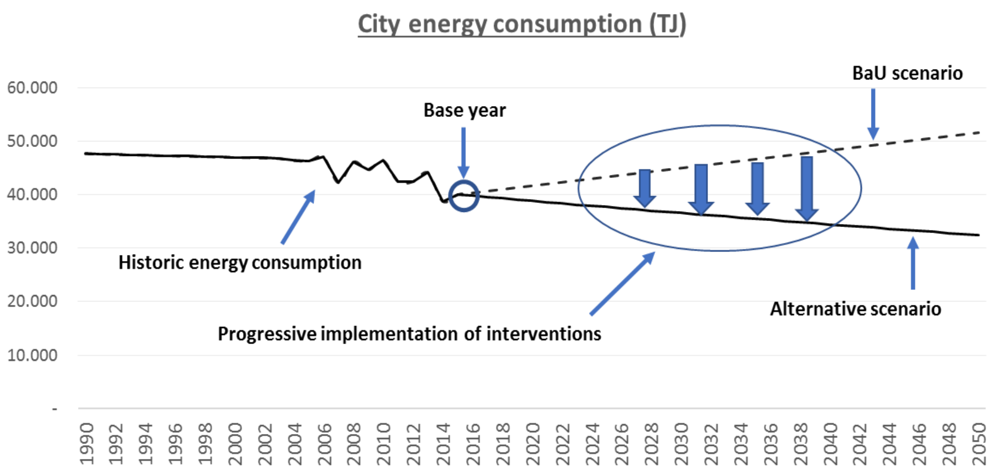

Figure 3: Scenario modelling in mySMARTLife project.

The methodology adopted for the scenarios 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

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top-down approach through use of production functions linking economic variables to energy use. In this case the bottom-up perspective has been considered according to the 3D modelling and energy demand analysis carried out in subtask 1.4.1.

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 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

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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

<table>
<tr><th>Subsector</th><th>Final energy use</th><th>Technology</th><th>Fuel</th></tr>
<tr><td rowspan="8">Apartment block</td><td rowspan="4">Heating and DHW</td><td>Boiler</td><td>Natural gas</td></tr>
<tr><td>District Heating</td><td>Heat</td></tr>
<tr><td>Heat pump</td><td>Electricity</td></tr>
<tr><td>Electric heater</td><td>Electricity</td></tr>
<tr><td rowspan="2">Lighting</td><td>Conventional lamps</td><td>Electricity</td></tr>
<tr><td>LED lamps</td><td>Electricity</td></tr>
<tr><td rowspan="2">Home appliances</td><td>TV</td><td>Electricity</td></tr>
<tr><td>Dishwasher</td><td>Electricity</td></tr>
</table>

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:

- <u>Electricity generation processes:</u> PV plants, hydro plants, wind farms, other non-renewable processes for electricity production, etc.

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- 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.
- 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

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evaluate an endless number of modeler's assumptions and judgements to explore the effect of these implementation in the development of the city.

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

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

In this 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 and 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 lighthouse cities

5.1 Common aspects and procedures

The three lighthouse 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 lighthouse 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 Nantes

5.2.1 General considerations

Nantes is the sixth-large city in France and the main north-western French metropolis. The model is divided in two: the city of Nantes itself and the remaining 23 communes which form the "Nantes Metropole" with the latter. Although the two regions share a common structure, each one of them has their own specific consumptions and transformation plants. Thus, it can be seen how and for which uses each territory consumes energy and the interaction of energy flows between the two regions. The year 2014 has been defined as the baseline year for this case.

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5.2.2 Data processing and base year modelling

5.2.2.1 Demand side

For this case the BASEMIS database was accessible. Performed by the AIR PAYS DE LA LOIRE organization [3], it includes energy consumption/production and GHG emissions data from 2008 to 2014 (v4 version) for each one of the 24 communes of "Nantes Metropole". For each year and commune the information is disaggregated by sector, subsector, usage and fuel.

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

Table 4: Nantes Metropole demand side disaggregation

Sector	Subsectors		Final uses
Residential	Housing block		Heating, Cooling, Cooking, DHW, Lighting and appliances
	Single family house		Heating, Cooling, Cooking, DHW, Lighting and appliances
	Special machinery		-
Tertiary	Non-Commercial	Education	Heating, Cooling, Cooking, DHW, Lighting and appliances, Other uses
		Community	Heating, Cooling, Cooking, DHW, Lighting and appliances, Other uses
		Sports, leisure & culture	Heating, Cooling, Cooking, DHW, Lighting and appliances, Other uses
		Health	Heating, Cooling, Cooking, DHW, Lighting and appliances, Other uses
		Transport	Heating, Cooling, Cooking, DHW, Lighting and appliances, Other uses
	Commercial	Offices	Heating, Cooling, Cooking, DHW, Lighting and appliances, Other uses
		Hotels & restaurants	Heating, Cooling, Cooking, DHW, Lighting and appliances, Other uses
		Commercial businesses	Heating, Cooling, Cooking, DHW, Lighting and appliances, Other uses
Industry	No data was available about subsectors or uses, only final energy consumption by fuel has been introduced		
Transport	Non- energy		Walking, Bicycle
	Road	Passenger	Two wheels, Buses, Private cars
		Freight	Heavy weights, Light utility vehicles
	Rail	Passenger	Tramway
		Freight	Train

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	Air & Sea	River, Sea, Air
Agriculture	-	Combustion, Machinery
Public lighting	The public lighting has been divided between conventional and LED lamps	

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

For the case of Nantes, an “Activity Level” has been defined for the residential sector. The activity level is defined in LEAP as “a measure of the social or economic activity for which energy is consumed” [4]. In the Nantes model, the consumption in the residential sector is affected by the number and type (housing block or single-family house) of the residential buildings. This kind of data has been extracted from the French national statistical institution INSEE [5] and is summarized in the next table:

Table 5: Residential activity level in Nantes Metropole

Region	Residential buildings area (m^2)	Housing block share
Nantes city	11.230.294	78,5%
Nantes Metropole w/o Nantes city	13.481.625	32,82%

The use of the activity level is here helpful since the future energy consumption in the residential sector in Nantes will be calculated through the growth of m2 in the city as it will be explained in the following sections of the deliverable.

Residential final consumption distributions by use and by fuel are presented in the next figures for the base year. As it can be seen, natural gas and electricity (including pv electricity) are the most consumed fuels in the sector, representing respectively 52,53% and 36,29% of the total consumption of 3183,88,28 GWh in Nantes Metropole. Although its minimal contribution towards final consumption, on site generated electricity manages to cover 1,02 GWh in the Nantes city region and 9,41 GWh in the Nantes Metropole w/o Nantes city region. Heat generated on solar collectors covers 4,31 GWh (Nantes city region) and 4,42 GWh (Nantes Metropole w/o Nantes city region) of the final energy consumption.

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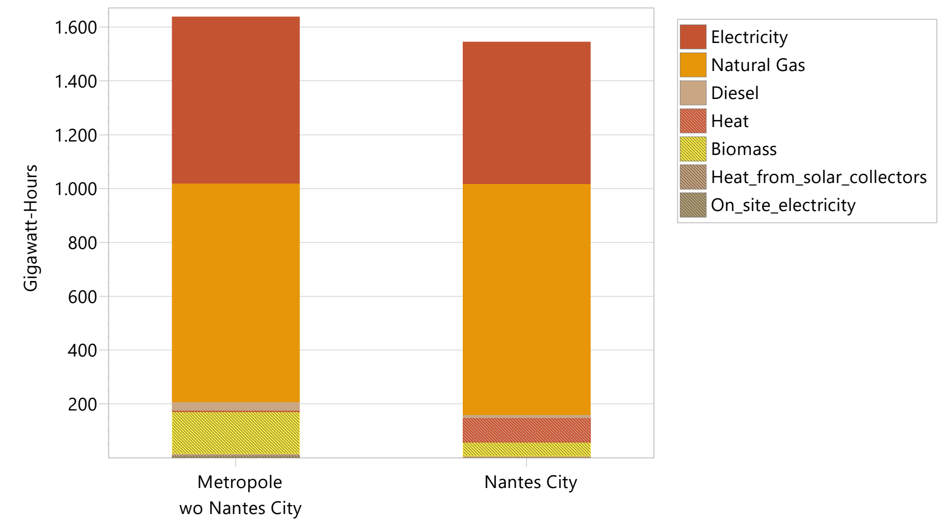

Figure 4: Residential sector consumption by fuel in Nantes Metropole

As showed in the next two figures “Heating” and “lighting and home appliances” are the most-consuming uses in both housing blocks and single-family houses, followed by DHW, cooking and cooling uses.

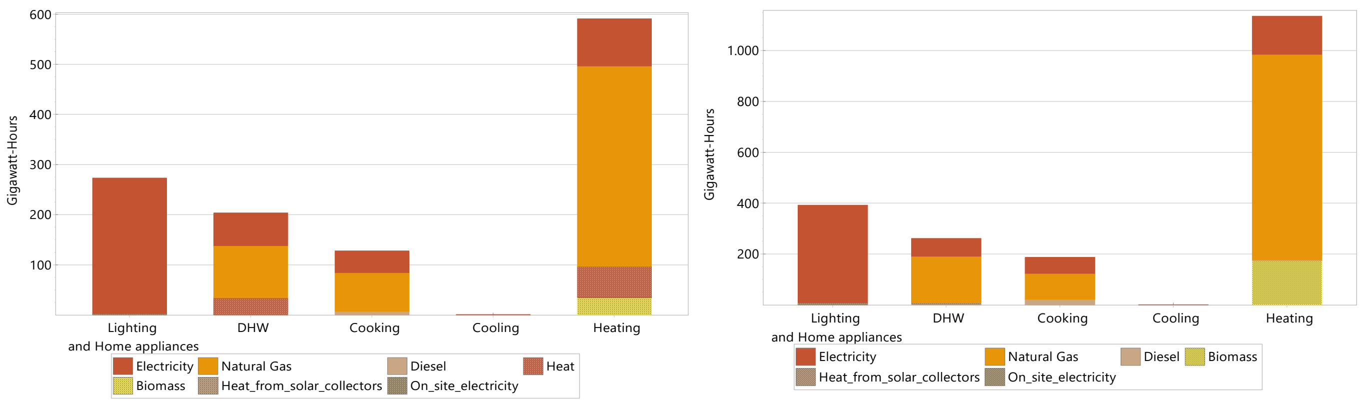

Figure 5: Housing blocks (left) and single family houses (right) consumption by use and fuel in Nantes Métropole

For the rest of sectors, the model has been completed including directly the data from BASEMIS as no activity level was defined. The final consumption in the tertiary sector is described in the following figures for the baseline year. As for the residential sector, natural gas and electricity are the most consumed fuels in the tertiary sector. In this case however, electricity (including pv electricity) accounts for the greatest share with 52,16%, while natural gas represents 29,25% of the total consumption of 2754,27 GWh in Nantes Metropole. Offices and commercial businesses are the most consuming sectors, followed by sports/leisure/culture buildings, hotel and restaurants, education, health, community, and finally, transport related buildings.

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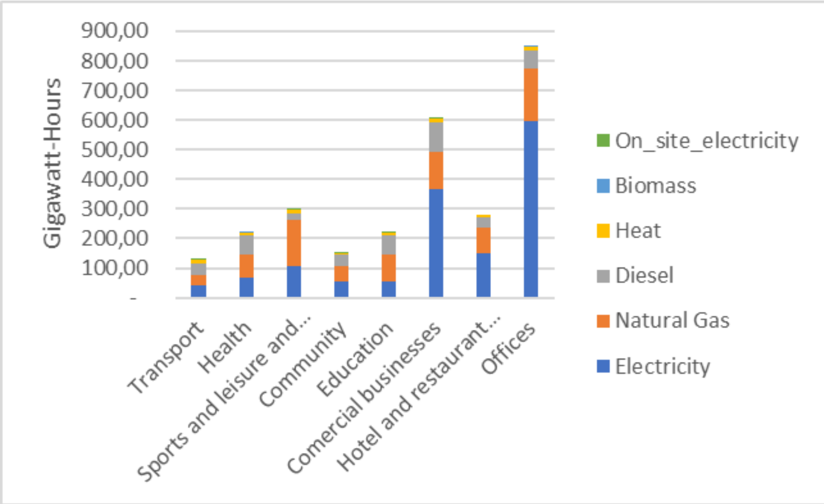

Figure 6: Tertiary consumption by fuel and subsector in Nantes Metropole

For transportation, consumption of electric and hybrid vehicles has been included in the “Passengers cars” section. Given the average travelled distance and number of vehicles by fuel type indicated in the city’s baseline assessment (Deliverable 2.1), and assuming an average fuel efficiency, the oil consumption displayed in the BASEMIS database has been disaggregated into diesel and gasoline cars. The consumption of electric and hybrid vehicles has been added, and the final consumption shares recalculated:

Table 6: Nantes Metropole car fleet energy disaggregation

Fuel	Average travelled distance (km/journey)	Average fuel efficiency	Nº vehicles	Final consumption share
Diesel	6,75	6,4 l/100 km	460776	36,21625%
Gasoline	6,75	7,8 l/100 km	214774	63,75247%
Natural gas	-	-	-	0,03112 %
Electricity	6,75	20,08 kWh/100 km	201	0,00001%
Hybrid	6,75	18,9 kWh/100 km	2380	0,00015%

It has been considered that all the electric and hybrid vehicles travel within the Nantes City region where the charging points are settled. In addition, the energy consumption related to the “Air & Sea” subsector is assumed to occur inside the borders of “Nantes Metropole” as is explained in the methodological guide of the BASEMIS database [6].

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For the base year, the transport sector is characterized in the following figures. Road transport is the most consuming sector in Nantes with 93,84% share of the total consumption of 4218 ,41 GWh. Private cars represent 93,54% of the total road consumption in Nantes Metropole.

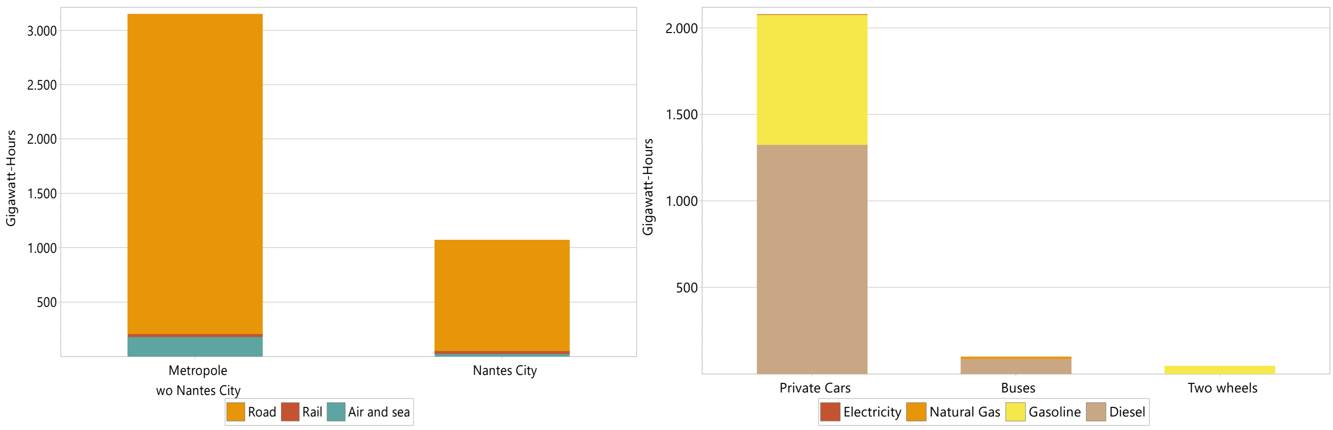

Figure 7: Transport sector consumption by region (left) and road passenger transport consumotion by type of vehicle and fuel (right) in Nantes Métropole

The area of Nantes Metropole accounts for several solar photovoltaic systems integrated in buildings. The electricity generation of these photovoltaic panels is assumed to cover part of the electricity consumed in the buildings of the residential and tertiary sectors for the "Lighting and appliances" final use. In this regard, the final energy consumption for these sectors and specific use corresponds to the value given by BASEMIS. However, with the introduction of the self-consumption modelling solution described above, part of this consumption comes from the electricity generated in the panels instead of fully coming from the grid. 19% losses due to AC/DC conversion and electric distribution have been considered reducing the consumption share covered by the electricity coming from the panels.

Electricity generation from PV systems has been allocated depending on where the panels were installed: residential buildings, education buildings, commercial buildings, etc. For the case of residential buildings, the distribution of the electric generation between housing blocks and single-family houses has been made based on the electric consumption of each subsector in the base year:

Table 7: Electric consumption distribution in the residential sector

Region	Residential subsector	Electric consumption share
Nantes city	Housing blocks	64,71%
	Single family houses	80,57%
Nantes Metropole w/o Nantes city	Housing blocks	19,43%
	Single family houses	80,57%

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Finally, heat generated in solar collectors has been included too. The production of these systems has been allocated as an extra-consumption in single family houses for DHW use. As this consumption was not included in the BASEMIS database, it must have been added and the rest of the fuel shares recalculated.

The allocation and characteristics of these kind of systems are described with more detail in the following section.

5.2.2.2 Supply side

The supply side of Nantes is formed by:

- On site electric generation processes: photovoltaic panels
- On site solar heat generation processes: solar collector panels
- DH networks: supplied by conventional boilers, micro-CHP systems, and heat recovery from waste incineration processes

5.2.2.2.1 On site electric generation processes

The photovoltaic panels integrated in buildings are the main on site electric generation processes. These systems are distributed across different buildings types and across the two defined regions of Nantes Metropole. The specific location of the systems and their installed capacity have been extracted from the city's 2015 energy summary [7]. The maximum operating hours of the PV systems installed in tertiary or agriculture buildings has been calculated from the kWh/kWp relationship issued from the JRC PVGIS web of the European Commission [8]. For the PV systems installed in residential buildings, their historical production has been calculated in accordance with the total production given in the BASEMIS database. Assuming the maximum operating hours obtained from the aggregate production in BASEMIS and knowing the production share for the two regions, the installed capacity for both regions has been determined.

Table 8: Photovoltaic systems' installed capacity and maximum operating hours in Nantes Métropole

Region	Sector	Installed capacity (kW)	Maximum operating hours
Nantes city	Tertiary	1134,48	16,1%
	Agriculture	-	-
	Residential	1024,53	13,99%
Nantes Metropole w/o Nantes city	Tertiary	184,13	16,1%
	Agriculture	63,36	16,1%
	Residential	9475,47	13,99%

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5.2.2.2.2 Solar collectors

Solar collectors systems have been modelled in a similar way to the photovoltaic ones. The installed capacities for these systems in both regions are presented in the next table:

Table 9: Solar collectors systems' installed capacity and maximum operating hoursin Nantes Metropole

Region	Sector	Installed capacity (kW)	Maximum operating hours
Nantes city	Residential	5076,93	9,69%
Nantes Metropole w/o Nantes city	Residential	5212,01	9,69%

5.2.2.2.3 District Heating networks

Nantes Metropole accounted for six District Heating networks in 2014, distributed in the two defined regions of the model:

Table 10: District Heating networks in Nantes Metropole

<table>
<tr><th>Region</th><th>Network</th></tr>
<tr><td rowspan="3">Nantes city</td><td>Centre Loire</td></tr>
<tr><td>Bellevue</td></tr>
<tr><td>La Chantrerie</td></tr>
<tr><td rowspan="3">Nantes Metropole w/o Nantes city</td><td>ZAC de la Minais</td></tr>
<tr><td>ZAC de la Noë</td></tr>
<tr><td>Rezé</td></tr>
</table>

The characteristics for each one of the networks are presented below:

Table 11: District Heating networks' characteristics in Nantes city region

<table>
<tr><th>Process/Plant name</th><th>Input fuel</th><th>Fuel share</th><th>Installed capacity (MW)</th><th>Max. operating hours</th><th>Historical production (MWh) (2014)</th><th>Process technical efficiency</th></tr>
<tr><td rowspan="4">Centre Loire [9], [10]</td><td>Heat from UIOM Alcea</td><td>79,7%</td><td rowspan="4">123</td><td rowspan="4">15,85%</td><td rowspan="4">149713</td><td rowspan="4">94,97%</td></tr>
<tr><td>Natural gas</td><td>18,2%</td></tr>
<tr><td>Diesel</td><td>2,1%</td></tr>
<tr><td>Biomass</td><td>0%</td></tr>
<tr><td rowspan="3">Bellevue [11], [10]</td><td>Biomass</td><td>51%</td><td rowspan="3">58,3</td><td rowspan="3">15,13%</td><td rowspan="3">60514,5</td><td rowspan="3">86,43%</td></tr>
<tr><td>Natural gas</td><td>48,8%</td></tr>
<tr><td>Diesel</td><td>0,2%</td></tr>
</table>

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La Chantrerie [12], [13]	Biomass	72%	10	19,4%	260,313	86,4%
	Natural gas	28%				

Table 12: District Heating networks' characteristics in Nantes Metropole w/o Nantes city region

Process/Plant name	Input fuel	Fuel share	Installed capacity (MW)	Max. operating hours	Historical production (MWh) (2014)	Process technical efficiency
ZAC de la Minais [14], [10]	Biomass	0%	5,5	5,18%	1930,01	89,11%
	Natural gas	100%				
ZAC de la Noë [15]	Biomass	80%	1,3	98,33%	414,54	86%
	Natural gas	20%				
Rezé [16]	Biomass	85%	18	14,66%	5739,75	85,75%
	Natural gas	15%				

When data was unavailable the following assumptions have been made:

- Feedstock shares: when historical data was unavailable, design data has been considered
- Maximum operating hours: the higher from historical data has been chosen. When historical data was unavailable operating hoursavailability has been calculated through design data
- Process technical efficiency: when data was unavailable, 90% technical efficiency for natural gas boilers and 85% technical efficiency for biomass boilers [17] has been considered
- Historical production (2014): for the baseline year, when production data was unavailable, the heat generation has been calculated assuming the heat losses for each region and the final heat consumption given by BASEMIS for 2014. This is the case for Chantrerie, ZAC de la Noë and Rezé networks. Heat losses have been calculated as the average of the networks' losses for which data was available:

Table 13: District Heating networks' losses by region

Region	Heat losses
Nantes city	16,75%
Nantes Metropole w/o Nantes city	11,53%

Altogether, 218,57 GWh of heat are produced in Nantes (222,17 GWh including the micro-CHP presented below). This generation comes from the consumption of 237,31 GWh of fuels (245,24 GWh including the micro-CHP presented below), which are distributed as follows:

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- Heat from UIOM Alcea (waste incineration): 52,94%
- Natural gas: 27,91%
- Biomass: 17,7%
- Diesel: 1,45%

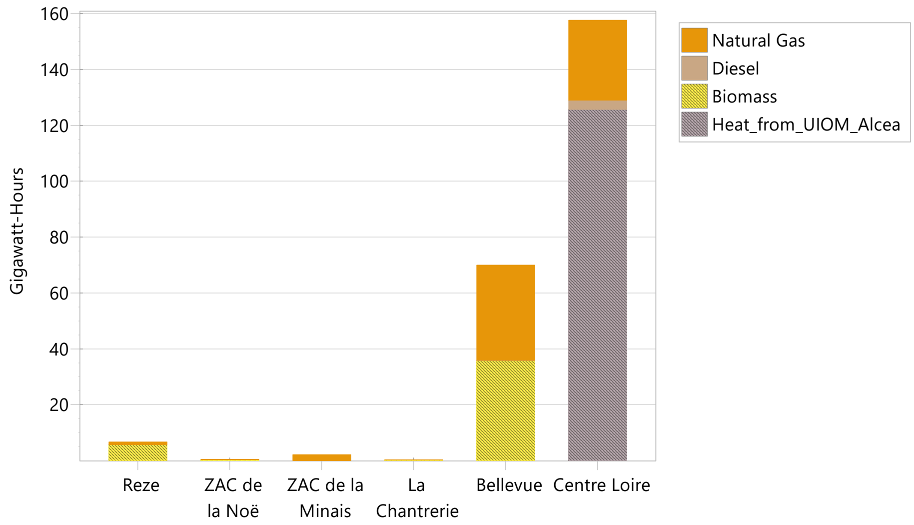

Figure 8: Fuel consumption by district heating network in Nantes Metropole

Apart from the boilers system, the Bellevue network has a micro-CHP plant:

Table 14: Bellevue micro-CHP plant's characteristics

Process/Plant name	Input fuel	Electric installed capacity (MW)	Heat installed capacity (MW)	Max. operating hours	Electric historical production (MWh) (2014)	Electric technical efficiency	Heat technical efficiency
CHP Bellevue [11], [10]	Natural gas	7,8	8,4	0,075%	51,081	38,09%	29,08%

The rest of the District Heating networks system is completed by the sewage treatment plant "Petite Californie" and the waste incineration plant "Alcea". The former has a micro-CHP to produce heat and electricity through biogas consumption, while the latter supplies with heat the "Centre Loire" network through heat recovery in a heat exchanger. Due to the lack of information for this plant a maximum operating hours of 79,91% (7000 working hours) has been considered. The historical production of this plant has been assumed the same as the input for the related District Heating network, that is, no distribution losses have been considered.

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Table 15: STEP Petite Californie plant's characteristics

Process/Plant name	Input fuel	Electric installed capacity (MW)	Heat installed capacity (MW)	Max. operating hours	Electric historical production (MWh) (2014)	Electric technical efficiency	Heat technical efficiency
STEP Petite Californie [6]	Biogas	0,373	0,401	90,71%	2964	38%	45,6%

Table 16: UIOM Alcea plant's characteristics

Process/Plant name	Input fuel	Installed capacity (MW)	Max. operating hours	Historical production (MWh) (2014)	Process technical efficiency
UIOM Alcea [6]	Municipal solid waste	125618/7000	79,91%	125618	41,33%

5.2.2.3 Resources

The potential of available resources like biomass or municipal solid waste has been extracted from the city's baseline (Deliverable 2.1).

It has been assumed that all the biomass comes from the "Nantes Metropole w/o Nantes city" region, while the municipal solid waste is proportional to the number of inhabitants. The model considers that only 50% of the municipal solid waste generated within the city is used in the waste incineration plants or energy generation purposes.

Table 17: Biomass and municipal solid waste potentials in Nantes Metropole

Region	Resource	Potential (ton/year)
Nantes city	Biomass	0
	Municipal solid waste	75342
Nantes Metropole w/o Nantes city	Biomass	26000
	Municipal solid waste	81202

5.2.3 Base year summary

A review of the energy consumption in Nantes Metropole for the baseline year can be shown through the next figure. Total consumption in the end-use sectors in Nantes accounts for 12614,41 GWh. Transport and residential are the most consuming sectors (33,44% and 25,24% respectively), followed by tertiary

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and industry. Moreover, diesel is the most consumed fuel (28,94%). Electricity (including PV electricity) and natural gas come next with respectively 28,55% 27,95% of the total share.

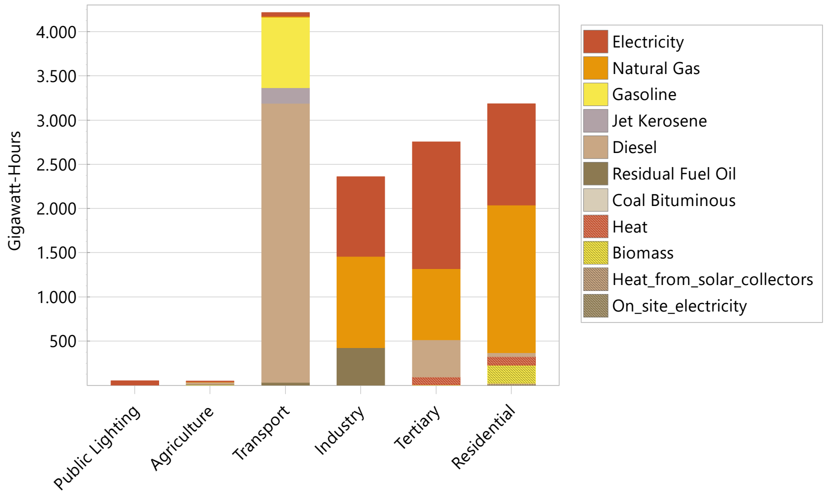
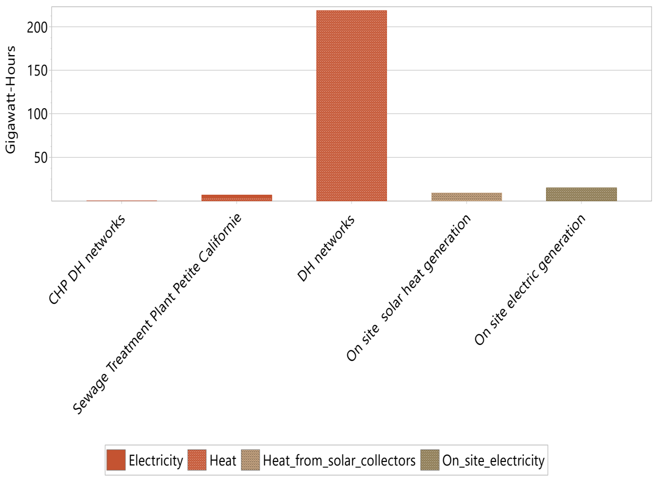


Figure 9: Energy consumption by fuel and sector in Nantes Métropole

For the supply side, consumption and energy production are presented in the figures below for the baseline year. Municipal solid waste is the most consumed fuel for energy generation (303,89 GWh), followed by natural gas (66,58 GWh). Municipal solid waste is consumed in the UIOM Alcea to generate "Heat_from_UIOM_Alcea" (125,62 GWh) which in turn is used in the DH networks. DH networks generate a total of 218,57 GWh (222,17 GWh including micro-CHP plants). On site electricity represents 83,07% of the total electricity generation in Nantes Metropole (17,84 GWh), while heat generated on solar collectors reach a production of 8,73 GWh.



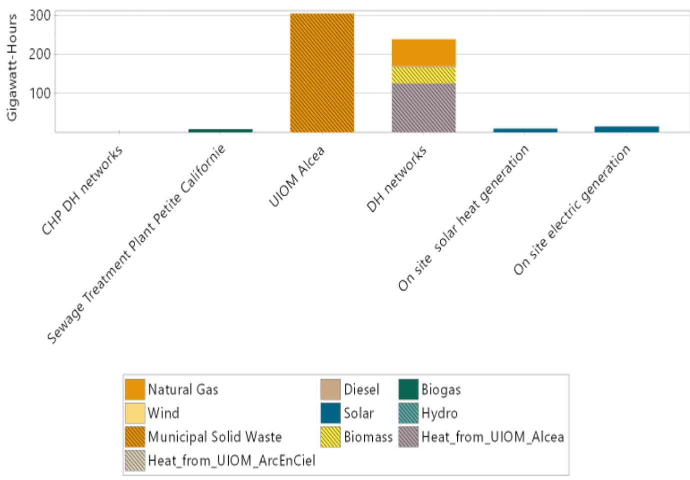


Figure 10: Energy generation (left) and energy consumption in transformation processes (right) in Nantes Métropole

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Finally, the Sankey diagram presented below shows the distribution of the fuel consumption and their allocation to the end-use sectors.

As it can be seen, all the fossil fuels (natural gas, diesel, gasoline, etc.) are imported. While natural gas is consumed in the residential, tertiary and industry sectors, diesel and gasoline are mostly used in the transport sector.

Excluding the electricity produced in on-site generation systems (PV panels systems) and in CHP plants, the electricity consumed in Nantes is imported in its clear majority. Like natural gas, electricity is used in residential, tertiary and industry applications. Lastly, heat generated in the district heating networks, comes from incineration of municipal solid waste, natural gas, biomass and diesel, and is consumed in the residential and tertiary sectors.

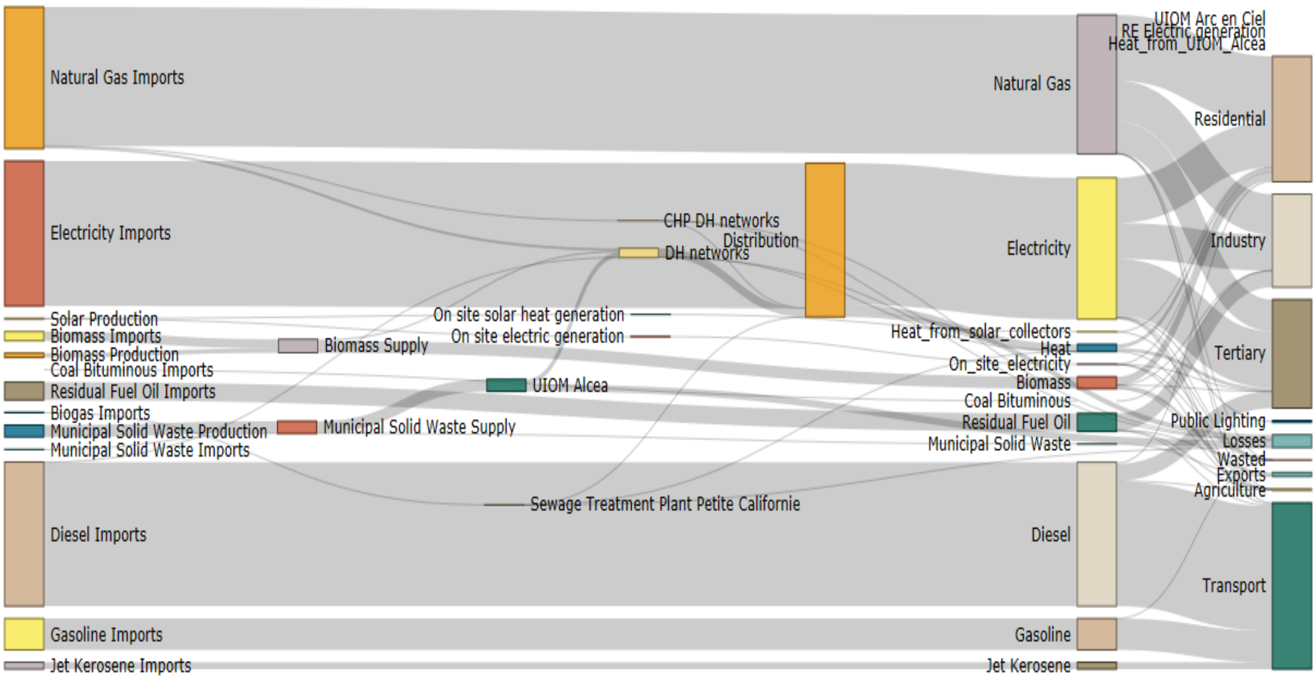

Figure 11: Sankey diagram. Nantes Métropole. 2014

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5.3 Case of Hamburg

5.3.1 General considerations

The “Freie und Hansestadt Hamburg” (Free and Hanseatic City of Hamburg) is one of the 16 German states or “Bundesländer”. Hence the city can be considered as a region in administrative terms. The city is shaped and 2015 has been defined as the baseline year.

5.3.2 Data processing and base year modelling

5.3.2.1 Demand side

For this case the *Hamburg energy and CO_2 summary* for 2015 [18] has been used. Although the fuel share is highly detailed, the sectoral and usage consumptions in the demand side are poorly disaggregated. Therefore, information (energy intensities and fuel shares in residential and tertiary uses) from the ODYSSEE database [19] has been required in order to allocate the different fuels consumptions to sectors and energy uses. It must be said that in the case of the ODYSSEE database national data has been extrapolated to a regional scale.

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

Table 18: Hamburg demand side disaggregation

<table>
<tr><th>Sector</th><th>Subsectors</th><th>Final uses</th></tr>
<tr><td>Residential</td><td>-</td><td>Space heating, Water heating, Cooking, Lighting, Appliances Cooling</td></tr>
<tr><td rowspan="6">Services</td><td>Hotels and restaurants</td><td>Space heating, Water heating, Cooking, Lighting, Appliances Cooling</td></tr>
<tr><td>Trade</td><td>Space heating, Water heating, Cooking, Lighting, Appliances Cooling</td></tr>
<tr><td>Private offices</td><td>Space heating, Water heating, Cooking, Lighting, Appliances Cooling</td></tr>
<tr><td>Health</td><td>Space heating, Water heating, Cooking, Lighting, Appliances Cooling</td></tr>
<tr><td>Education</td><td>Space heating, Water heating, Cooking, Lighting, Appliances Cooling</td></tr>
<tr><td>Public offices. Administration</td><td>Space heating, Water heating, Cooking, Lighting, Appliances Cooling</td></tr>
<tr><td>Agriculture</td><td colspan="2">No data was available about subsectors or uses, only final energy consumption by fuel has been introduced</td></tr>
<tr><td rowspan="4">Industry</td><td>Food and beverages</td><td>No data was available about uses, only final energy consumption by fuel has been introduced</td></tr>
<tr><td>Information and communication</td><td>No data was available about uses, only final energy consumption by fuel has been introduced</td></tr>
<tr><td>Chemical and pharmaceutical</td><td>No data was available about uses, only final energy consumption by fuel has been introduced</td></tr>
<tr><td>Other materials</td><td>No data was available about uses, only final energy consumption by fuel has been introduced</td></tr>
</table>

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	Iron and steel industry		No data was available about uses, only final energy consumption by fuel has been introduced
	Electronic equipment		No data was available about uses, only final energy consumption by fuel has been introduced
	Machinery		No data was available about uses, only final energy consumption by fuel has been introduced
	Automobiles		No data was available about uses, only final energy consumption by fuel has been introduced
	Other industries		No data was available about uses, only final energy consumption by fuel has been introduced
Transport	Non- energy		Walking, Bicycle
	Road	Passenger	Motorcycles, Cars, Buses
		Freight	Trucks
	Rail	Passenger	Tramway, Metro, Train
		Freight	Freight train
	Air		No data was available about uses, only final energy consumption by fuel has been introduced
	River and sea		No data was available about uses, only final energy consumption by fuel has been introduced

Additionally, two more “sectors” have been created: “Auxiliary fuels in other transformation processes” and “Non-energy consumption”. These categories don’t represent any end-use sector, but stand for energy consumptions that occur but can’t be allocated in any sector.

For each final use, consumption of one or more fuels is defined filling up the final energy consumption for this specific use. As explained above, national data has been used to disaggregate the residential consumption. First, electricity has been divided between heat uses (space heating, water heating, cooking) and electric uses (appliances, lighting, cooling):

Table 19: Residential electricity consumption distribution by uses (disaggregated from national level data [19])

General use	Share	Specific use	Specific share
Heat uses	39,55%	Space heating	8,85%
		Water heating	14,02%
		Cooking	16,68%
Electric uses	60,45%	Appliances	51,28%
		Lighting	7,84%

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		Cooling	1,33%

Secondly, for the heat uses, the consumption has been disaggregated by fuel (including fossil fuels) and uses, also following national level data:

Table 20: Residential heat uses fuels distribution (disaggregated from national level data [19])

Fuel	Space heating	Water heating	Cooking
Coal	100,00%	0,00%	0,00%
Oil	91,25%	8,64%	0,10%
Gas	82,84%	15,13%	2,03%
Heat	89,18%	10,82%	0,00%
Wood	35,67%	64,33%	0,00%
Electricity	22,38%	35,46%	42,16%

Therefore, the data provided by the Hamburg energy and CO2 summary is disaggregated following these shares.

The final energy consumption by fuel and use in the residential sector is shown below for the baseline year. Residential uses consume 11128,03 GWh, for which 63,16% accounts for space heating, 15% for appliances, 13,56% for water heating, 5,6% for cooking, 2,3% for lighting and 0,38% for cooling. Natural gas and electricity (including pv electricity) are the most consumed fuels with respectively 34,8% and 29,24% of the final consumption.

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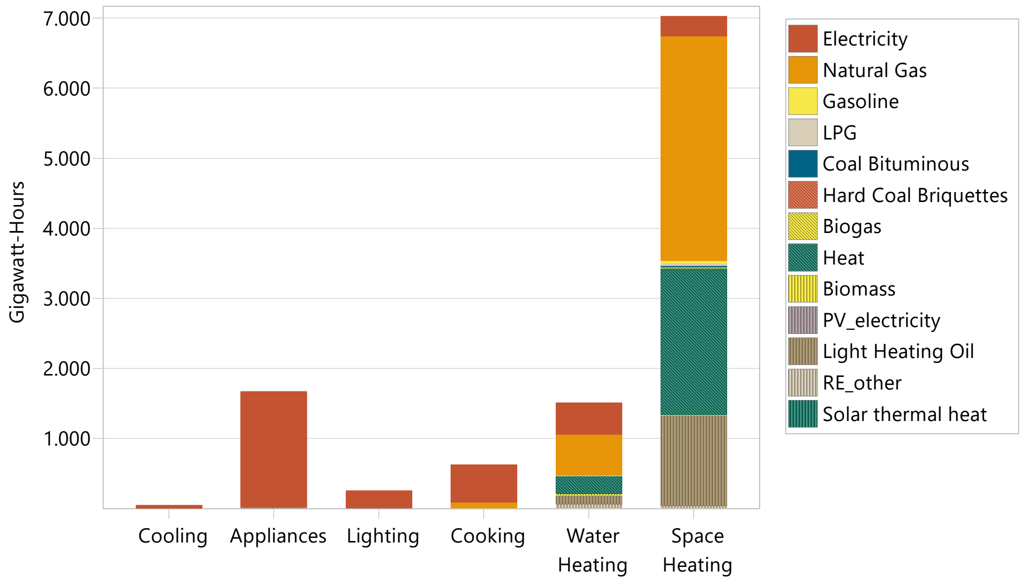

Figure 12: Residential sector consumption by fuel and use in Hamburg

The services sector has been disaggregated using national level data too. In this case, energy intensities have been used to allocate the energy consumption to the different subsectors. The consumption shares are calculated and applied to the data from the *Hamburg energy and CO_2 summary*.

Table 21: Services consumption disaggregation (disaggregated from national level data [19])

Sectors	Energy intensity (koe/€2010)	VA Hamburg 2015 (M€2010) (disaggregated from national data)	Calculated consumption share
Agriculture	0,2723	47	0,87%
Hotels and restaurants	0,1487	3507	37,16%
Trade	0,0198	25718	34,77%
Private offices	0,0076	29862	15,52%
Health	0,0082	6557	3,69%
Education	0,0159	3746	4,01%
Public offices. Administration	0,0108	5308	3,98

For each sector the uses and fuels distribution are calculated like in the residential case, with the same following shares for all the sectors:

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Table 22: Services electricity consumption distribution by uses (disaggregated from national level data [19])

General use	Share	Specific use	Specific share
Heat uses	12,30%	Space heating	3,45%
		Water heating	3,82%
		Cooking	5,03%
Electric uses	87,70%	Appliances	49,71%
		Lighting	35,94%
		Cooling	2,05%

Table 23: Services heat uses fuels distribution (disaggregated from national level data [19])

Fuel	Space heating	Water heating	Cooking
Coal	93,71%	6,29%	0,00%
Oil	93,71%	6,29%	0,00%
Gas	79,79%	5,35%	14,86%
Heat	90,84%	9,16%	0,00%
Wood	100,00%	0,00%	0,00%
Electricity	28,01%	31,07%	40,92%

The energy consumption of the service sector is 11669,9 GWh. Natural gas is the most consumed fuel with 43,15% of the total share, followed by electricity with 32,33% (including PV electricity). The next figure shows the consumption distribution between the services' subsectors for the baseline year in Hamburg:

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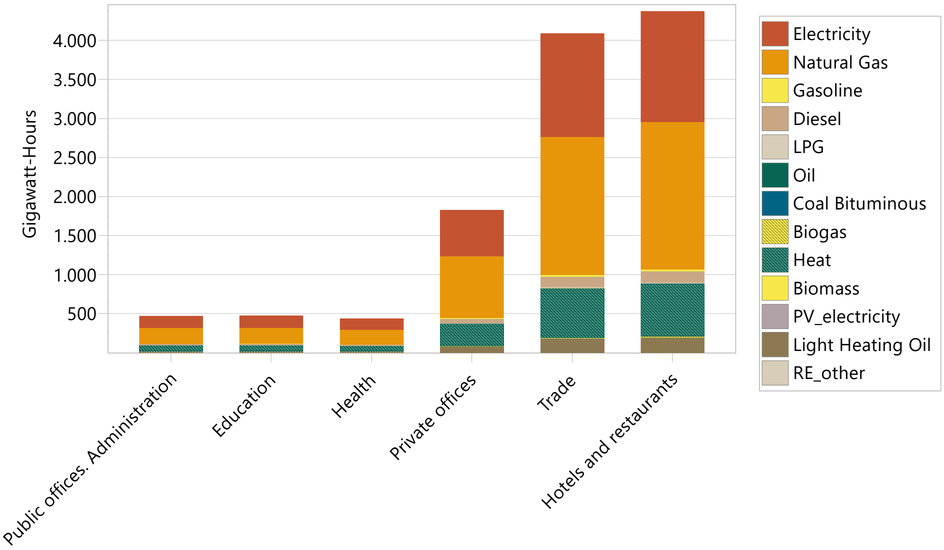

Figure 13: Services sector consumption by fuel and subsector in Hamburg

For the transport sector, gasoline and diesel consumption in road transport has been disaggregated using average efficiency and average distance values to allocate the data given by the *Hamburg energy and CO_2 summary* to the different vehicle types.

Table 24: Gasoline vehicles disaggregation

Type of vehicle	Average travelled distance (km/day) [20]	Average fuel efficiency (l/100 km) [21]	Nº vehicles [19], [22]	Final consumption share
Motorcycle	36	5,4023	52128	6,87%
Car	36	7,7152	493550	92,91%
Car (Hybrid)	36	4,0554	2264	0,22%

Table 25: Diesel vehicles disaggregation

Type of vehicle	Average travelled distance (km/day)	Average fuel efficiency (l/100 km) [19], [21]	Nº vehicles [22]	Final consumption share
Car	36	6,8017	247383	48%
Buses	36	37,3356	1663	2%
Trucks	36	35,4239	50243	20%

Other fuels like LPG, ethanol, or natural gas have been allocated directly to cars' consumption. In the case of rail transport, electricity consumption for passenger and freight transport has been distributed using local passenger-km data and national level rail passenger transport intensity values.

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The next figures show the road and rail transport consumption in Hamburg for the baseline year. Cars are the most consuming mean of transport. In the road transport diesel is the most consumed fuel (66,6%), while electricity represents 76,74% of the total consumption in the rail transport.

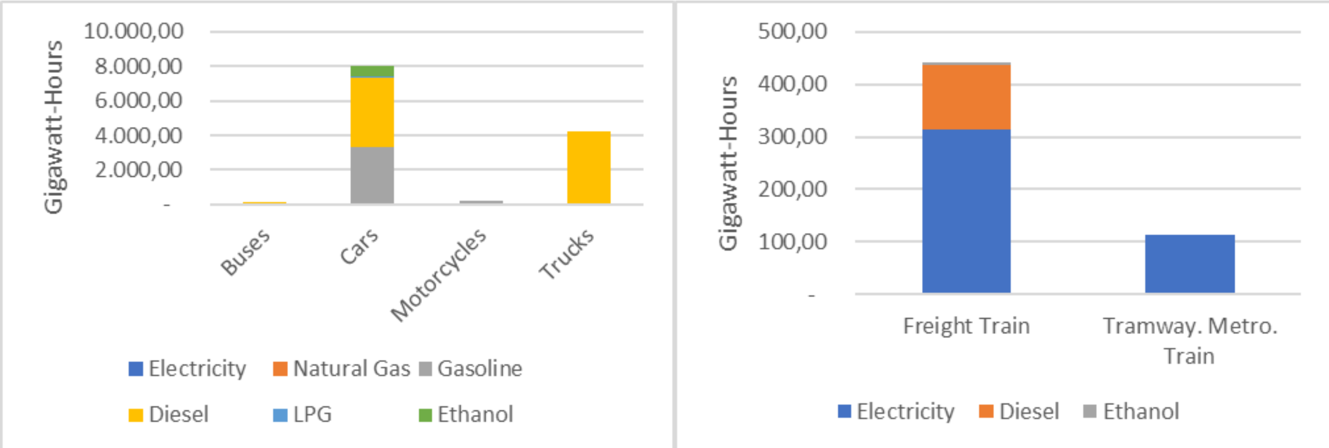

Figure 14: Road transport by fuel and vehicle (left) and rail transport consumption by fuel and vehicle (right) in Hamburg

Like in Nantes, Hamburg accounts for several solar photovoltaic systems integrated in buildings which have been included in the model. The electricity produced by these systems has been allocated as a final consumption in the residential and services sectors. The distribution of the PV electricity consumption in the residential sector by use is shown in the table below and has been made based on the electric consumption for each use in the base year:

Table 26: PV electricity distribution in the residential sector in Hamburg

Use	Share
Space heating	8,85%
Water heating	14,02%
Cooking	16,68%
Appliances	51,28%
Lighting	7,84%
Cooling	1,33%

The PV electricity generated in the different subsectors of the services sector has been disaggregated following the electric consumption of these subsectors in the base year. Each subsector has then a specific share of the PV electricity for each use.

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Table 27: PV electricity consumption distribution in the agriculture and services sectors in Hamburg

Sector/Subsector	Share
Agriculture	0,87%
Hotels and restaurants	37,16%
Trade	34,77%
Private offices	15,52%
Health	3,69%
Education	4,01%
Public offices. Administration	3,98%

The characteristics of these kind of systems are described with more detail in the following section.

5.3.2.2 Supply side

The supply side of Hamburg is formed by:

- On site electric generation processes: photovoltaic panels
- Renewable electricity generation processes: wind, hydro, biomass, pv plants, etc.
- Conventional electricity generation processes: thermal plants
- Heat only generation processes: mainly boilers plants
- CHP processes

Some general assumptions for the transformation processes have been made:

- Production and consumption of the different plants were available on the Hamburg energy and CO2 summary. Efficiencies have been calculated for all the plants from there. For biomass and biogas electric generation plants, efficiencies [23] of respectively 45% and 35% have been assumed.
- Excluding the PV, hydro and wind plants, there was no information available on installed capacities. A maximum operating hours of 79,91% (7000 working hours) has been adopted. Therefore, the capacities have been estimated.
- Some auxiliary consumptions have been allocated to specific plants. This data is indicated on the Hamburg energy and CO2 summary. When this data had to be distributed between different plants, disaggregation following installed capacity has been done.

The following distribution losses have been considered:

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Table 28: Fuel distribution losses in Hamburg

Fuel	Losses
Natural gas	0,0019%
Biogas	13,79%
Electricity	1,3%
Heat	11,5%

5.3.2.2.1 On site electric generation processes

These processes correspond to the photovoltaic panels installed in buildings. The information for the modelling of these systems has been extracted from the “Final Energy Consumption” section of the *Hamburg energy and CO_2 summary*. The consumption of electricity coming from PV systems appears disaggregated between residential and services consumptions. The rest of the electricity produced in photovoltaic panels which appears in the “Transformation” section of the *Hamburg energy and CO_2 summary* has been assumed to come from large-scale photovoltaic plants and is explained in the next section. A 907 kWh/kWp relationship issued from the JRC PVGIS web of the European Commission has been used to estimate the maximum operating hours and installed capacity of these systems. This relationship considers already 19% losses. The consumption between services’ sectors is then distributed as explained in the previous section.

Table 29: Photovoltaic systems’ installed capacity and maximum availability in Hamburg

Sector	Installed capacity (MW)	Maximum operating hours
Residential	36,38	10,35%
Services	2,21	10,35%

5.3.2.2.2 Renewable electricity generation processes

The renewable electricity generation processes in Hamburg regroup:

- Hydro plants
- Wind farms
- Photovoltaic plants
- Biogas plants
- Biomass plants

Information for the electricity coming from renewable sources has been extracted from the Hamburg energy and CO_2 summary and completed with the Energieportal Hamburg [24].

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Table 30: Renewable electricity generation processes' characteristics in Hamburg

Process/Plant name	Installed capacity (MW)	Max. operating hours	Historical production (GWh) (2015)
Biogas	9,42	79,91%	65,95
Hydro	0,11	47,77%	0,46
Wind	65,347	18,64%	106,73
Solar	30,49	10,35%	27,66
Biomass	14,94	79,91%	104,55

For the solar PV plants, the installed capacity and historical production corresponds to the electricity generated which appears in the “Transformation” section of the *Hamburg energy and CO_2 summary*. The same kWh/kWp relationship as for the building-integrated pv systems of the previous section has been chosen to calculate the installed capacity and maximum operating hours of these systems.

5.3.2.2.3 Conventional electricity generation, heat only generation, and CHP processes

For these processes, the information from the “Transformation” section of the *Hamburg energy and CO_2 summary* has been used. When data was missing, the general assumptions explained above have been considered.

The production and consumption of these processes are presented with renewable energy production in the summary section.

5.3.2.3 Resources

The potential energy resources of the city of Hamburg are extracted from the *Hamburg energy and CO_2 summary* and are summarized in the next table:

Table 31: Energy resources in Hamburg

Fuel	Potential/Reserves (TJ)
Natural gas	9
Crude oil	561
Biomass	21674
Re_other	360
Municipal solid waste	5107

5.3.3 Base year summary

In 2015, 48152,41 GWh were consumed in the end-use sectors in Hamburg. Transport is the most consuming sector (35,43%) followed by services (24,24%) and residential (23,11%). Electricity (including pv electricity) is the most consumed fuel accounting for 25,75% of the fuel share. Natural gas (25,02%) and diesel (19,7%) come after.

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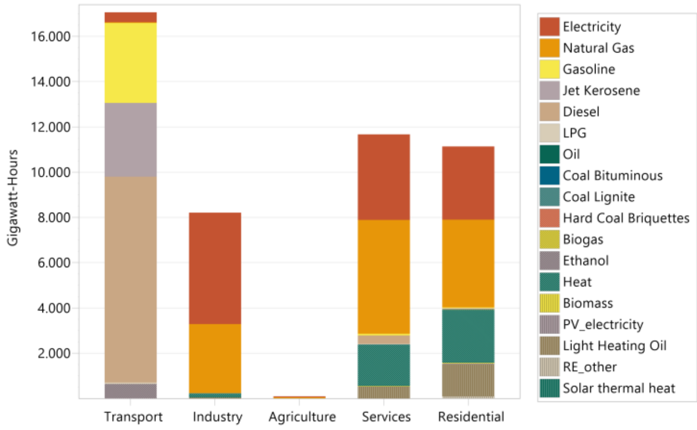

Figure 15: Energy consumption by fuel and sector in Hamburg

Meanwhile, in the transformation processes, 24886,01 GWh were consumed, being coal (62,62%) and natural gas (9,7%) the most-used fuels for energy generation. 8571,45 GWh (including on-site production) of electricity were produced (only 8,04% coming from renewable sources. 9,52% if municipal solid waste is considered as a renewable fuel), while 5118,86 GWh of heat were generated in Hamburg in the baseline year.

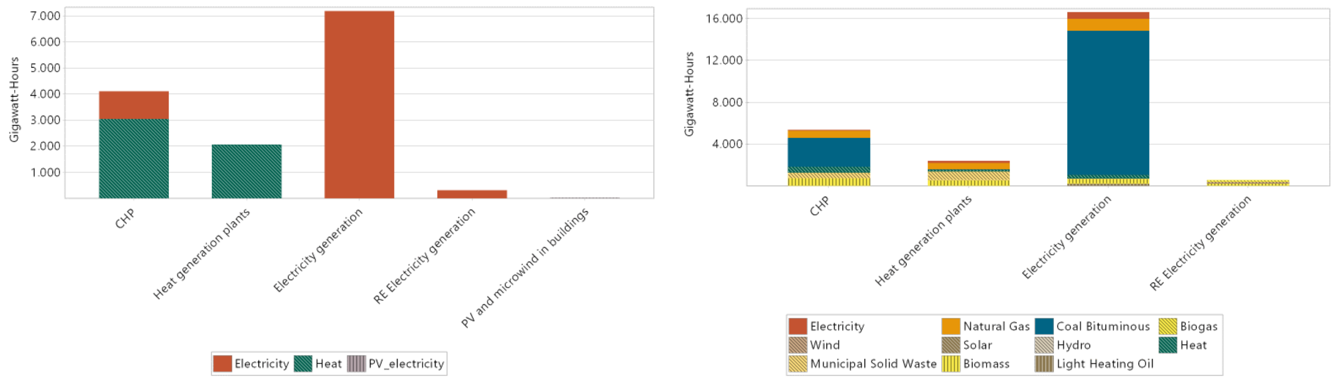

Figure 16: Energy generation (left) and energy consumption in transformation processes (right) in Hamburg

Finally, in the Sankey diagram below, the fuel consumption and its allocation can be observed. For simplicity, fuels have been grouped. Final oil products like diesel or gasoline are produced in refineries and consumed in the transport sector, or exported in its majority. Electricity generation is mainly based on solid fuels (coal and others) which are imported. End-use sectors are mainly supplied by electricity, natural gas, heat and oils products like diesel or gasoline. Although included in distribution, pv processes in buildings are allocated directly in the residential, services and agriculture sectors (that is because of the fuel groupings presentation).

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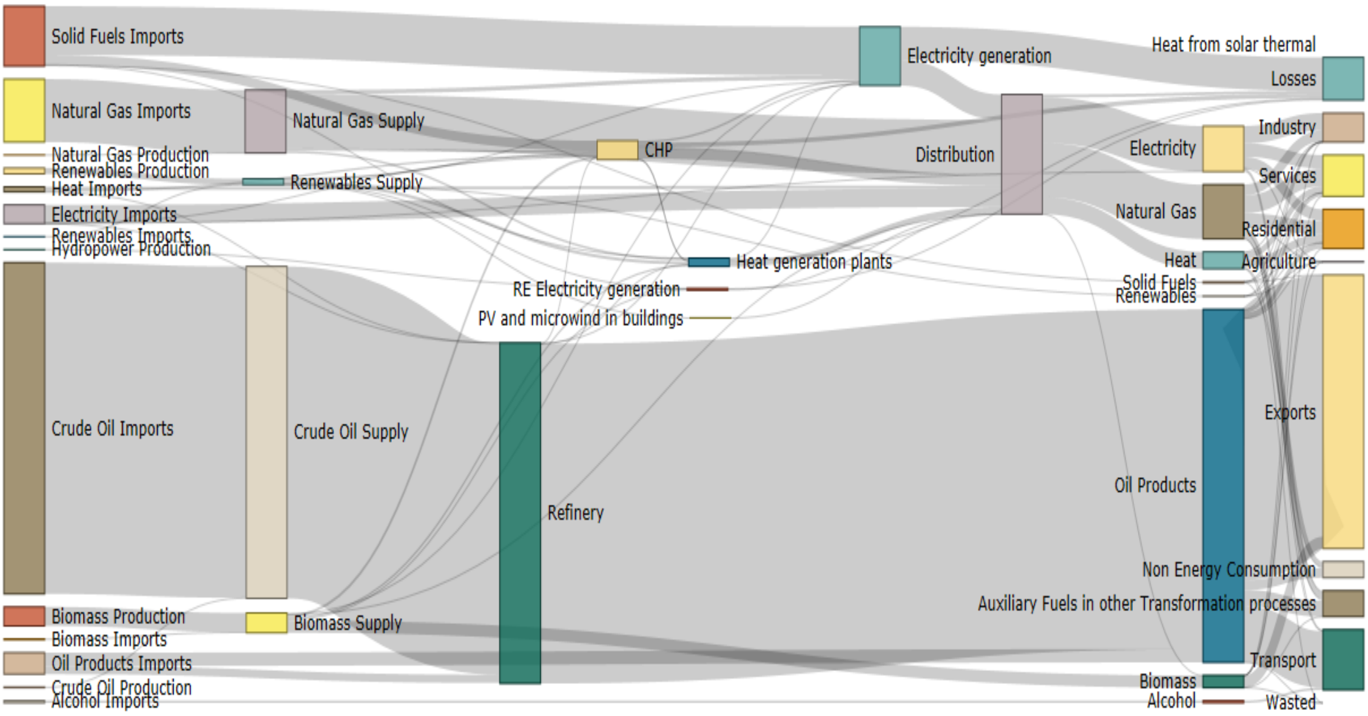

Figure 17: Sankey diagram. Hamburg. 2015

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5.4 Case of Helsinki

5.4.1 General considerations

As Finland's capital, Helsinki is the most populous city in the country and one of the most important cities in Northern Europe. The Helsinki model only accounts for the city itself and not for the metropolitan area which includes the surrounding municipalities of Espoo and Vantaa too.

5.4.2 Data processing and base year modelling

5.4.2.1 Demand side

For this case information disaggregated by sectors (residential, services (including municipality), and industry) and heating technologies (and hence fuels) was supplied by the local government for the year 2016. The non-heating electricity consumption was also given for each sector.

Table 32: Energy consumption data supplied by the city of Helsinki

2016	Residential	Services, incl. municipality	Industry	TOTAL (GWh)
District heating	4068,4	2262,9	301,5	6632,8
Oil heating[1]	154,7	38,0	43,1	235,8
Electric heating	257,0	35,2	19,5	311,7
Ground source heat pumps (electricity)	9,0	1,8	0,8	11,6
Electricity	1249,1	2527,1	232,4	4008,6
TOTAL (GWh)	5738,2	4865	597,3	11200,5

The following disaggregation has been followed for the demand side:

Table 33: Helsinki demand side disaggregation

Sector	Subsectors		Final uses
Residential	Private residences	Housing blocks	Space heating and DHW, Lighting, Appliances, Ventilation, Others, Cooling
		Single family houses	Space heating and DHW, Lighting, Appliances, Ventilation, Others, Cooling
	City owned buildings	Housing blocks	Space heating and DHW, Lighting, Appliances, Ventilation, Others, Cooling
		Single family houses	Space heating and DHW, Lighting, Appliances, Ventilation, Others, Cooling

[1] Considered as diesel consumption from now on

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Services and municipality	Offices		Space heating and DHW, Lighting, Appliances, Ventilation, Others, Cooling
	Shops and retail		Space heating and DHW, Lighting, Appliances, Ventilation, Others, Cooling
	Healthcare		Space heating and DHW, Lighting, Appliances, Ventilation, Others, Cooling
	Education		Space heating and DHW, Lighting, Appliances, Ventilation, Others, Cooling
	Convention		Space heating and DHW, Lighting, Appliances, Ventilation, Others, Cooling
	Public lighting		The public lighting has been divided between the different types of lamps in the city
Industry	-		Heat, Lighting, Appliances, Ventilation, Others, Cooling
Transport	Non- energy		Walking, Bicycle
	Passenger	Road	Two wheels, Cars, Bus, Mop autos
		Rail	Tramway, Metro, Regional commuter train
	Freight	Road	Trucks, Light utility vehicles
		Rail	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.

To disaggregate the data supplied by the city by usage and subsectors, the database of the City Performance Tool [25] developed by Siemens has been consulted.

First, the residential and services consumption has been disaggregated by subsector. In the residential sector, the final consumption has been distributed between private residences (84%) and city owned buildings (16%). The energy demand values for the residential buildings have been recalculated and completed with an external source [26]. For services buildings, the energy demand values have been calculated with data from the City Performance Tool database. The consumption disaggregation of both sectors is presented in the following tables:

Table 34: Energy consumption disaggregation in the residential sector in Helsinki

Subsector	Area (m^2)	Energy demand (kW/m^2)	Consumption share
Apartment blocks	27748858,81	136,42	74,45%
Single family houses	7054676,64	184,12	25,55%

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Table 35: Energy consumption disaggregation in the services sector in Helsinki

Subsector	Area (m^2)	Energy demand (kW/m^2)	Consumption share
Offices	7974371,86	205,61	36,00%
Shops and retail	6418287,10	210,63	29,68%
Healthcare	1649522,32	369,36	13,38%
Education	2264504,85	241,31	12,00%
Convention	1504086,26	271,10	8,95%

Second, for all the sectors, the consumption for heat uses was disaggregated by fuel following the data given by the city, while the electricity consumption (for electric uses only) was disaggregated by use using the information in the *City Performance Tool* database.

Table 36: Electricity consumption disaggregation by use and subsector in Helsinki

Use	Apartment blocks	Single family houses	Offices	Shops and retail	Healthcare	Education	Convention	Industry
Lighting	25%	24,24%	40,25%	42,75%	57,86%	39,21%	31,48%	41,18%
Appliances	60%	58,18%	0,00%	0,00%	0,00%	13,68%	0,00%	12,77%
Ventilation	9%	8,73%	15,91%	15,20%	27,00%	30,09%	21,94%	11,04%
Other	6%	5,82%	37,44%	37,05%	11,57%	8,21%	41,98%	30,91%
Cooling	0%	3,03%	6,40%	5,00%	3,57%	8,82%	4,60%	4,10%

Final energy consumption in residential accounts for 5738,2 GWh in the baseline year. Heat from the district heating network is the most used fuel with 70,9% of the total share, followed by electricity (26,4%) and diesel (2,6%).

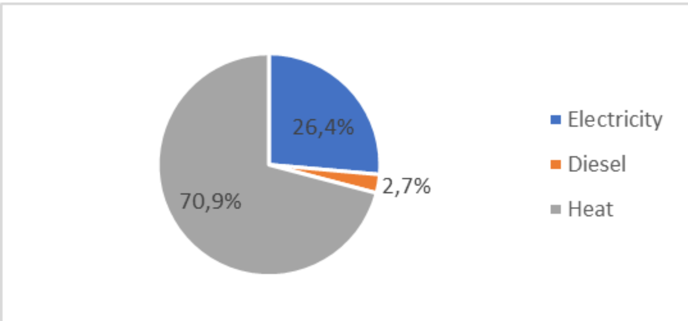

Figure 18: Fuel share in residential energy consumption

As an example, the following figure represents the energy consumption in private single-family houses by use and fuel:

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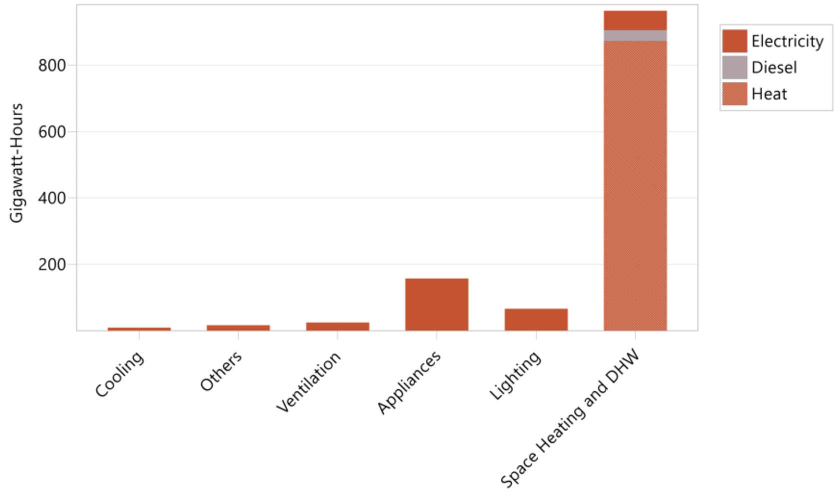

Figure 19: Energy consumption in private single-family houses by use and fuel in Helsinki

Regarding the energy consumption in the “Services and municipality” sector’s buildings, the next figure shows the disaggregation by fuel and subsector. In this case, electricity is the most consumed fuel (52,25%), followed by heat from the district heating network (46,96%) and diesel (0,79%). Offices and shops/retails are the most-consuming sectors.

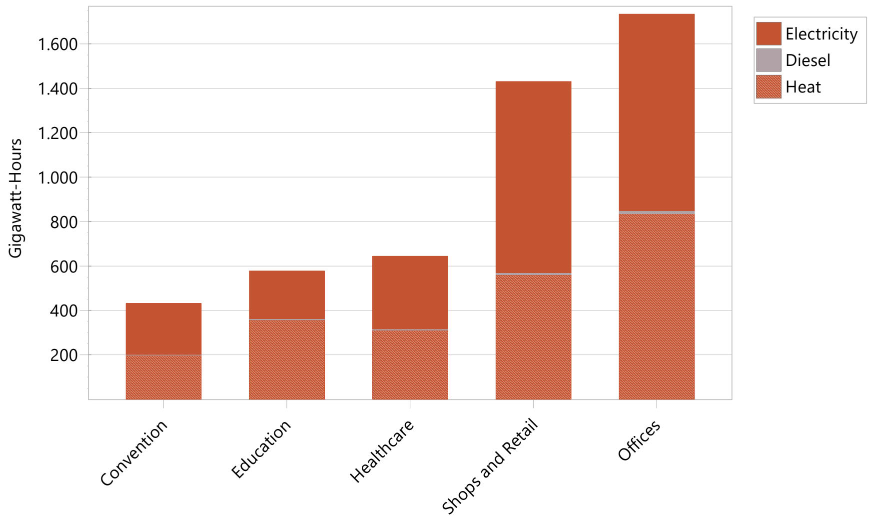

Figure 20: Energy consumption in services sector by subsector and fuel in Helsinki

Public lighting is included in the model as a subsector in “Services and municipality”. The data of total consumption was extracted from the *City Performance Tool* database, while the information used to disaggregate the consumption by type of lamp was extracted from external sources [27]. The table below shows the number of lamps of each type and its specific consumption:

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Table 37: Number and energy consumption of street lamps by type in Helsinki

Lamp type	Number of lamps	Energy consumption per lamp (MWh/device)
Mercury	13808	0,624
Sodium high pressure	51911	0,596
New sodium high pressure	6555	0,497
Xenon	404	0,037
Induction	758	0,328
Fluorescent	793	0,202
Halogen	5960	0,350
New halogen	3252	0,310
LED	924	0,297

The electricity consumption of street lighting is 46,8 GWh. The energy use by type of lamp is showed below:

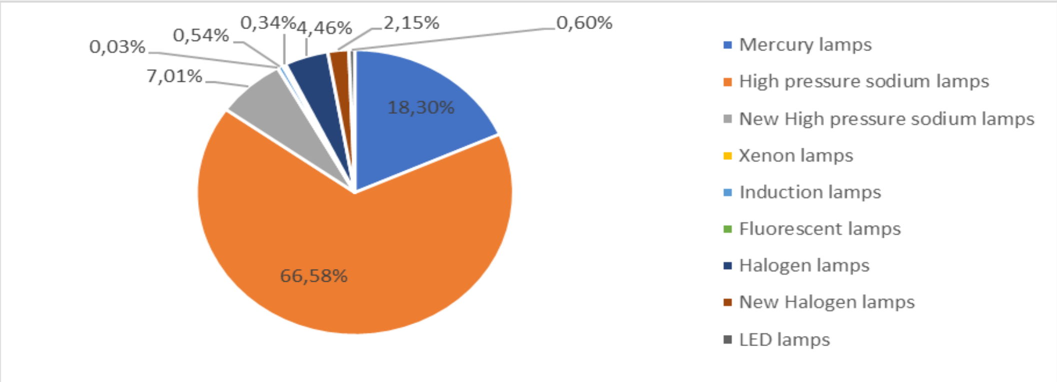

Figure 21: Public lighting consumption share by type of street lamp

For the transport sector, the final energy consumption was extracted from the city's baseline (Deliverable 4.1 of the mySMARTLife project) and disaggregated with information from the *City Performance Tool* database. The next two figures show Helsinki's transport characterization. Road total consumption sums up 2133,8 GWh, while rail transport consumption accounts for 1876,6 GWh. Cars are the most-consuming vehicle type in road transport and represent 63,79% of the energy use in this subsector. Although electricity is the most consumed fuel in all the transport sector (47,12% in opposition to 26,75% gasoline and 25,88% diesel) it only represents 0,65% in the road transport (0,9% in cars' consumption) against 50,28% gasoline and 48,61% diesel.

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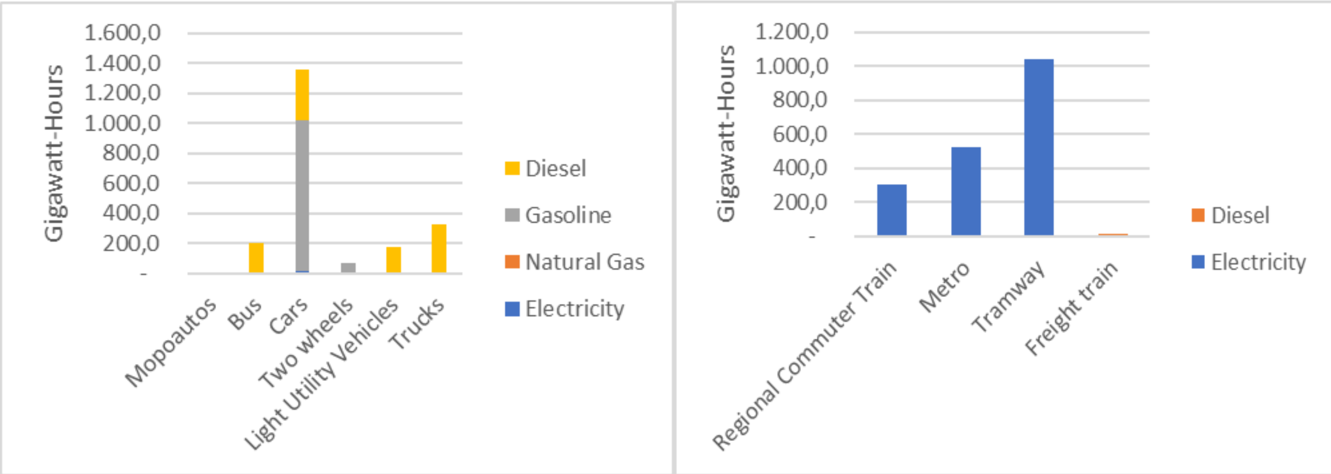

Figure 22: Road transport consumption by fuel and vehicle (left) and rail transport consumption by fuel and vehicle (right) in Helsinki

5.4.2.2 Supply side

The supply side in Helsinki is formed by:

- Electric generation processes: pv plants, hydro plants, etc.…
- District Heating network: heat only boilers and CHPs plants

5.4.2.2.1 Electric generation processes

The electric generation processes have been completed with the information contained in the city's baseline assessment. The pv plants have been completed with data from the HELEN company web [28]. 2,9% losses have been considered for the electric distribution grid. The characteristics of these plants are presented in the table below:

Table 38: Electricity generation processes' characteristics in Helsinki

Process/Plant name	Installed capacity (MW)	Max. operating hours	Historical production (GWh) (2016)
Suvilahti PV plant	0,34029	8,86%	0,26
Kivikko PV plant	0,85272	8,70%	0,65
Hydro power plants	0,4	100%	3,50
Kellosaari oil plant	120	0%	0[2]
CHP plants (electric generation part only)	1008	45,04%	3976,9

[2] Reserve plant

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It must be said that in the model the processes listed in the first 4 rows of the table 40 supply with their electricity the Katri Vala heat pump plant.

5.4.2.2.2 District Heating network

Heat produced in Helsinki's district heating network represents 92,23% of the heat consumption in the city. Therefore, the network is the key in the city's heat supply strategy.

The network heating supply is formed by the Katri Vala heat pump plant, a group of heat only boilers plants, and 3 CHP plants: Vuosaari, Hanasaari and Salmisaari.

Finland's District Heating Networks 2016 summary [29] has been used to complete the plants' characteristics and the network's losses: 6,29%

Table 39: Katri Vala and Heat Only Boilers plants' characteristics

Process/Plant name	Input fuel	Fuel share	Installed capacity (MW)	Max. operating hours	Historical production (GWh) (2016)	Process technical efficiency
Katri Vala heat pump plant	Electricity	100%	90	62,21%	490,5	394%
Heat Only Boiler plants	Light fuel oil	1,57%	2111	4,53%	838,6	91,62%
	Heavy fuel oil	17,58%				
	Hard coal and anthracite	25,48%				
	Natural gas	55,13%				
	Wood pellets	0,15%				
	Biogas	0,09%				

Due to lack of data, the three CHP's plants haven't been disaggregated and are shown as a unique process:

Table 40: Helsinki's CHP plants' characteristics

Process/Plant name	Input fuel	Fuel share	Heat installed capacity (MW)	Max. operating hours	Heat historical production (GWh) (2016)	Heat technical efficiency
CHP plants (heat generation part	Light fuel oil	0,02%	1316	49,73%	5733,2	52,33%
	Heavy fuel oil	0,32%				
	Hard coal and	60,80%				

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only)	anthracite					
	Natural gas	37,2%				
	Wood pellets	1,66%				

5.4.2.3 Resources

The potential biomass resource in Helsinki is about 4,146 PJ and was extracted from an external source [30].

5.4.3 Base year summary

Total consumption in Helsinki in 2016 accounted for 15211,26 GWh in the end-use sectors. Residential was the most consuming sector (37,77%) followed by services sector (31,98%) and transport sector (26,37%). Heat was the most used fuel with 43,6% of the total share, while electricity represented 40,9%, diesel 8,37% and gasoline 7,05%.

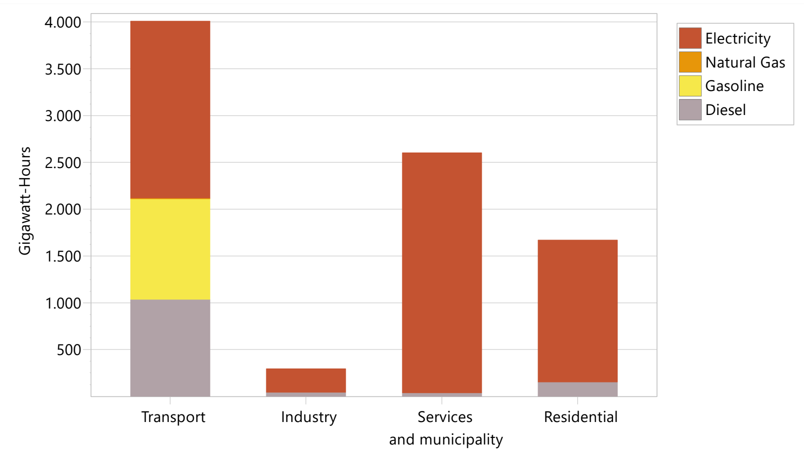

Figure 23: Energy consumption by fuel and sector in Helsinki

7061,12 GWh of heat were produced in Helsinki in the baseline year, the greatest part coming from the CHP plants. Electric production accounted for 3980,89 GWh, the clear majority coming from the CHP plants too. Electricity produced in the electric generation processes (pv and hydro plants) it's used as input fuel in the Katri Vala heat pump plant (heat generation processes module). 11994,19 GWh were consumed in the heat generation and CHP plants, being coal and natural gas the most consumed fuels (57,48% and 38,17% respectively). As a result, only 1,61%[3] of the heat generated comes from renewable energy sources.

[3] Considering that the electricity from the hydro and pv plants are used in the Katri Vala heat pump plant, and that the rest of the consumed electricity in the plant doesn't come from renewbale energy sources

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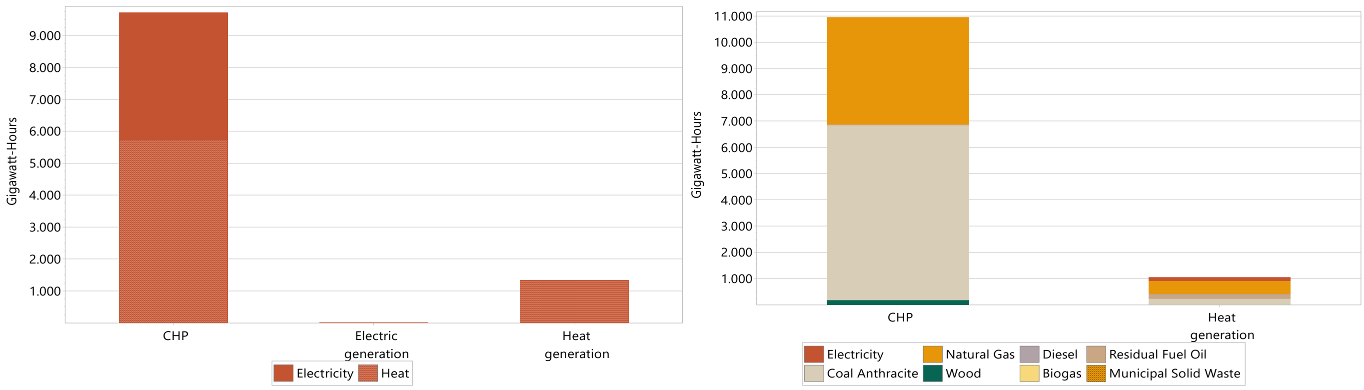

Figure 24: Energy generation (left) and energy consumption in transformation processes (right) in Helsinki

Lastly, the distribution and allocation of the energy consumption in Helsinki in the baseline year can be observed in the Sankey diagram below. Heat and electricity are the most consumed fuels in the end-use sectors in Helsinki. Almost all the consumed heat in Helsinki is produced in the CHP plants which use coal and natural gas as input fuels. Even though electricity is also produced in the CHP plants, a fraction of this fuel must be imported. A short part of electricity is also produced in other generation processes (hydro and pv plants) and used as input fuel for heat generation in Helsinki's heat pump plant.

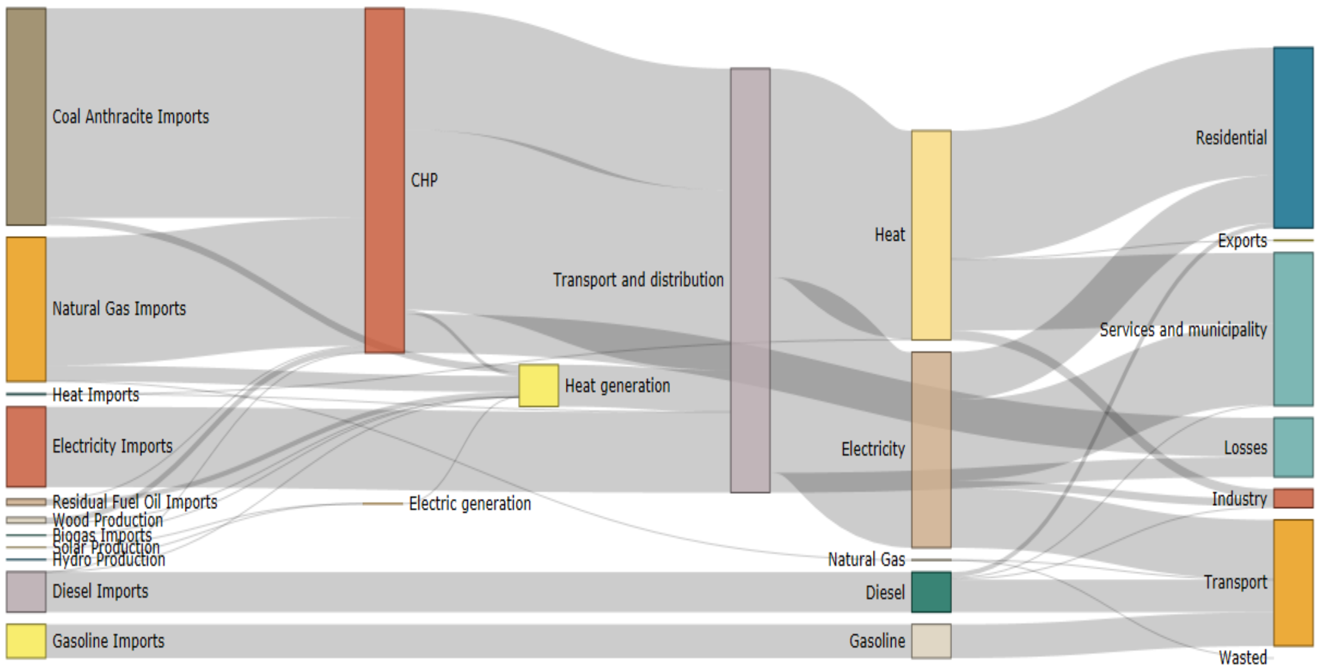

Figure 25: Sankey diagram. Helsinki. 2016

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6. Scenario modelling: Case studies

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

Besides, it needs to be taken into account that as described in section 4 different scenarios are defined by each lighthouse city (Business as Usual (BaU) scenario, mySMARTLife intervention scenario and the mySMARTLife interventions 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 number o*ne is called in this case “mySMARTLife intervention scenario” which evaluates the evolution of the city as in the case of the BaU scenario but considering that the interventions that are planned in each city in the short-term (the ones that will be implemented in the framework of the mySMARTLife project) will be implemented. This scenario considers all the interventions that will be finally implemented in each city and that are susceptible to have any effect in the energy consumptions as well as that can be modelled properly in the LEAP energy modelling software.

Finally, *the alternative scenario number two* is called in this case “mySMARTLife interventions replication scenario” which considers not only the interventions that will be implemented within the period of the project but also considers the potential of each intervention to be escalated in other areas of the city. 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 Nantes

As explained in the base year modelling section, in the case of Nantes the energy model has been created not only for the city of Nantes but also for the entire Nantes Metropole. Therefore, the projections for the scenarios need to be also considered in both cases.

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6.1.1 BaU scenario for Nantes

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.

Although the most common studies in the literature are focused on an analysis at a larger scale (regional, national) in which the driver selection is in most of the cases very linked to the variables of GDP, the population and the Value Added, as in this case the scope of the study is the city scale, the potential relation with other type of parameters such as the population, the number of households, the number of vehicles, the district heating price among other parameters has been evaluated depending on the sector evaluated.

Therefore, in the case of Nantes various data sources have been evaluated to obtain the historic evolution of these parameters and of the energy consumptions. Besides, as the analysis considers both the city scale and the scale of Nantes Metropole the analysis has been carried out specifically for each case to evaluate which are the most reliable relations.

The main data sources evaluated are the followings:

- **L'Institut national de la statistique et des études économiques [31]**: This source collects, produces, analyses and disseminates information on the French economy and society. Here, information related the population, residences, salary. Income, GDP and VA have been evaluated for the period between 1999 and 2010. The information can be obtained at the level of Pays de la Loire which is a good approach for the scale of Nantes Metropole.
- **Eurostat [32]**: Energy prices for France are available in Eurostat distinguishing between the prices for different fuels and for different final users. Besides, other information such as the GDP, the VA and the income is available also for Pays de la Loire.
- **Open data Nantes [33]**: Information related the area of the city of Nantes with different uses can be obtained in this source.
- **Basemis [6]**: As explained before in this document, this source provides data related to the historic energy consumptions at different scales (Nantes, Loire Atlantique and Pays de la Loire).
- **ORES Pays de la Loire**: Observatoire régional économique et social [34]: Socioeconomic data is available at the scale of Pays de la Loire.

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- **Urban Data Platform [35]**: This data base provides several socioeconomic parameter's historic evolution and expected projection for different European urban locations. In this case, data related the GDP/Cap, population and constructed area and average travel distances have been evaluated.

6.1.1.1 Analysis of the correlations with the energy demands and driver selection for the definition of the BaU Scenario

The key for the energy demand forecasting is the establishment of the relationship between the driver and the final energy use. It is fundamental to correctly link the driver to the energy use to accurately forecast the energy demand. This subsection includes a summary of the process followed for the analysis of this relation and the final selection of the driver or the general tendency.

- Residential sector:

Several drivers have been evaluated for the residential sector. The figure below shows an example of the relation analysis between the historic residential energy consumption of Loire Atlantique and the historic tendency of four (GDP, GDP/Cap, number of houses, population) of the many parameters evaluated. These figures have been obtained normalizing the compared values of the parameters and evaluating whether there is any linearity between them. This provides a first idea about whether they follow a similar tendency, to see if their relation is positive or negative and to start discussing whether there is any actual causal relation between them. This is evaluated comparing the resulting linear correlation index.

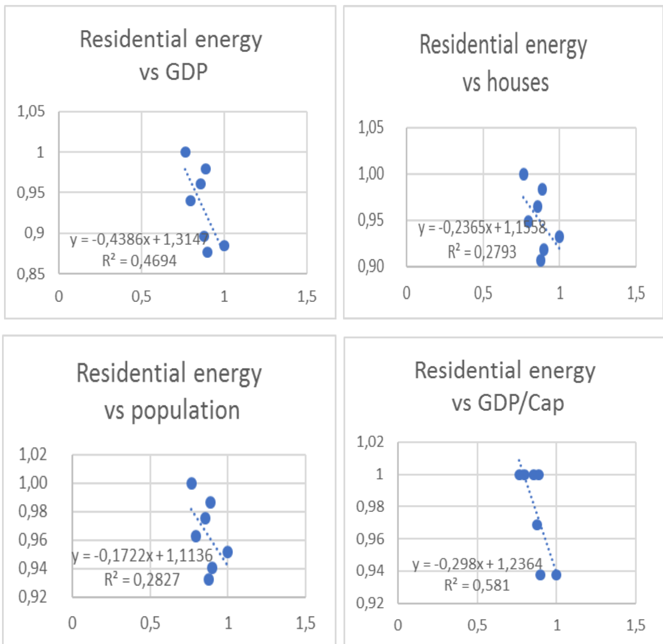

Figure 26: Analysis of the relation between the tendency of the residential sector energy consumption with the potential drivers for Loire Atlantique.

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In this case, the resulting linear correlation indexes are relatively good for the case of the GDP and the GDP/cap. However, this relation is in the figure inverse. This needs to be evaluated carefully, since based on historic developments, it cannot be justified that an increase of the GDP will drive to a lower energy consumption. This means that there is a dissociation between this driver and the energy consumption due to the many measures that have been carried out in the last years. In this case, it is recommended to find a driver which offers a causal relation, such as in the number of houses for the case of the residential sector. Therefore, to find a more causal and explicit relation, the variable of the expected new construction area in the city per inhabitant has been considered according to the projections provided in the Urban Data Platform of the European Commission. With this aim, based on the expected increase of the area per inhabitant (-0,26% until 2020, -0,34% until 2030, -0,28% until 2040 and -0,05% until 2050) and the existing projections for the population, the projection for the new construction area has been obtained.

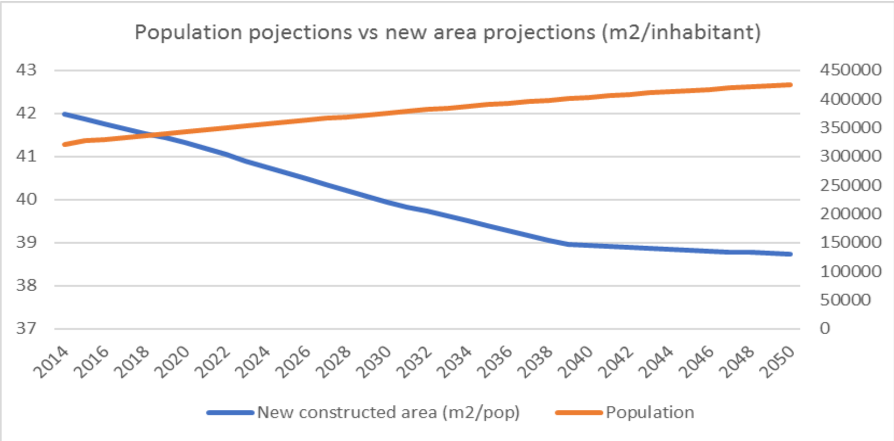

Figure 27: Relation between the projections of population and the new constructed area in Nantes.

Based on this relation and the obtained new curve for the expected new constructed are in the city, the tendency for the energy consumption of the residential sector has been defined. This new curve has been obtained considering that the energy intensity of the sector remains constant. As a result, the residential energy consumption will have a smooth increase. The same tendency has been considered (adapting to the specific values in each case) for both Nantes and Nantes Metropole.

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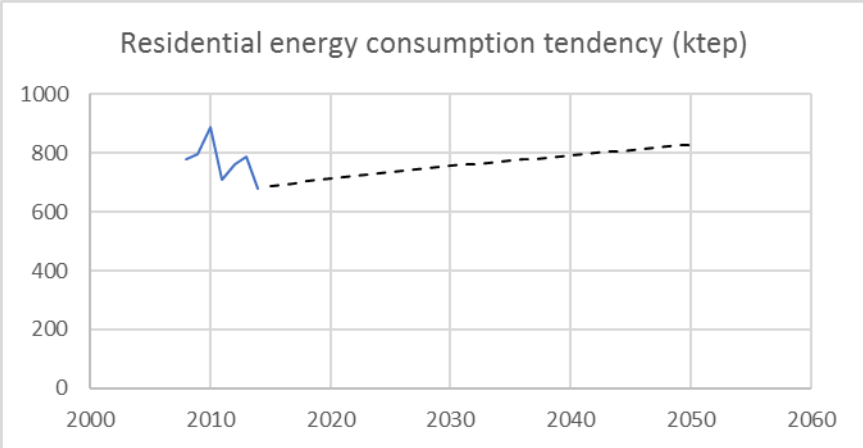

Figure 28: Projection considered for the residential sector energy consumption.

- <u>Industrial sector:</u>

Following the same procedure for the industrial sector, the main drivers evaluated are the GDP/cap and the VA of the industrial sector. As it is observed in the figure below, the best linear correlation index is obtained with the comparison of the industrial energy consumption and the value added of the industrial sector.

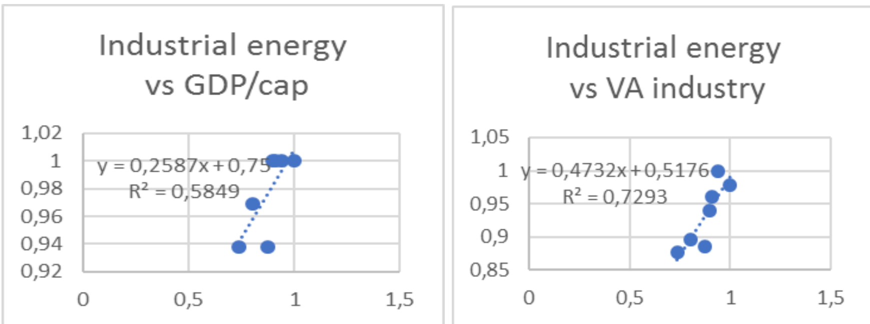

Figure 29: Analysis of the relation between the tendency of the industrial sector energy consumption with the potential drivers for Loire Atlantique.

Therefore, the energy consumption evolution in the industry of Nantes and Nantes Metropole is considered that will follow the same tendency as the calculated for Loire Atlantique which will increase with the years in the BaU scenario as the VA is expected to increase in the long-term.

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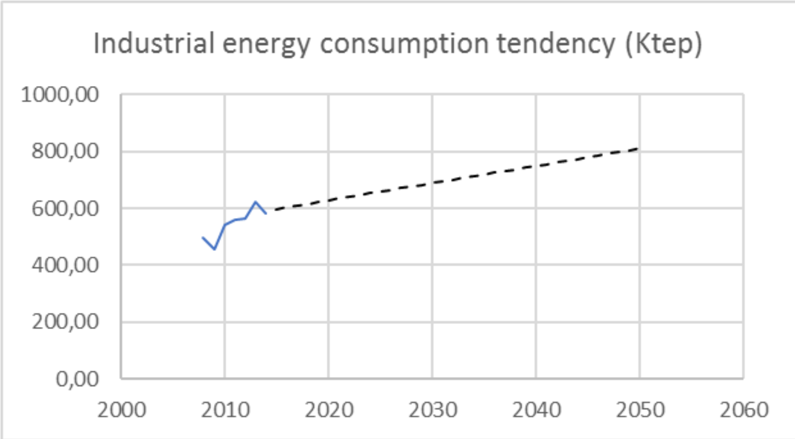

Figure 30: Projection considered for the industrial sector energy consumption.

- <u>Mobility sector:</u>

Transport sector´s projection is divided in this case into two different projections to distinguish the road and the non-road transport.

- <u>Road transport:</u>

Although the observed correlation of the energy consumption of the transport sector with the drivers GDP/Cap and population is relatively good, for the projection of the road transport of Nantes and Nantes metropole it has been finally considered the forecasts available in the PRIMES EU28: Reference scenario(REF2016) [36]. This forecast shows the increase of the number of private cars and motorcycles for France ('2000-'2010; 0,72%; ´2010-'2020;1,06%; '2020-'2030; 0,55%; '2030-'2050; 0,41%). Based on these increase rhythms the following curve is obtained.

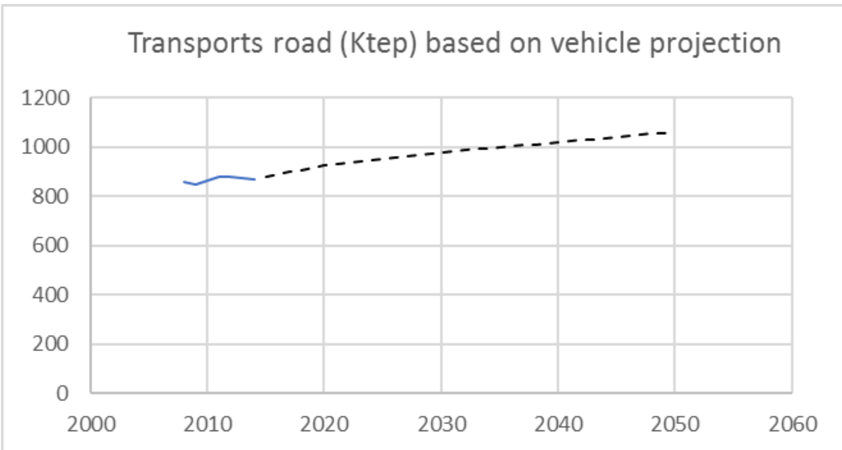

Figure 31: Projection considered for the road transport energy consumption.

- <u>Non-road transport:</u>

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For the non-road transport on the other hand the driver of GDP/Cap shows a good correlation with the energy consumption. Therefore, the base for the forecast is the population projection obtained from Eurostat combined with the projection of the GDP (3% to 2023, 2% to 204 and 1,5% to 2050). Under these considerations, the following curve is obtained.

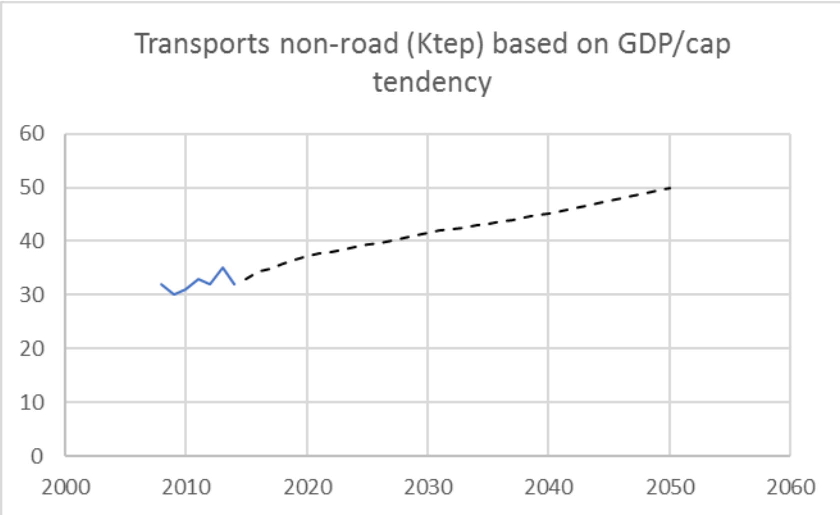

Figure 32: Projection considered for the non-road transport energy consumption.

- <u>Tertiary sector:</u>

Different drivers have been evaluated for the tertiary sector, the population, GDP, GDP/Cap, and the VA of the tertiary sector. However, in this case it cannot be stated that it exists a clear correlation with the energy consumption of the sector. Therefore, in this case the tendency of the last years has been evaluated. As it is showed in the figure below the historic tendency follows a smooth increase that in the long-term projections can be accepted as a reasonable hypothesis.

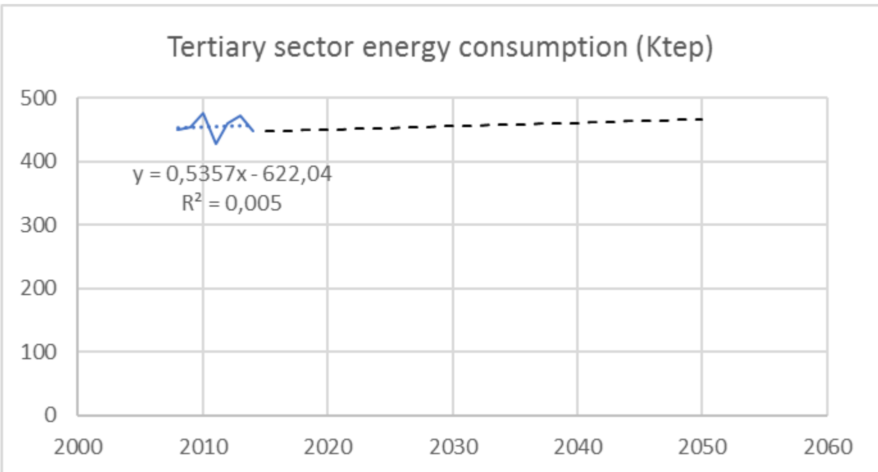

Figure 33: Projection considered for the energy consumption of the tertiary sector.

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- <u>Agriculture sector:</u>

As it occurs in the tertiary sector, it is not observed any clear correlation between the energy consumption of the sector with the VA of the agriculture sector, with the GDP or the GDP/Cap. In this case it is decided to consider the evolution of the historic energy consumption of Nantes to project the future energy consumption. This is a compromise solution that has been adopted due to the lack of correlation with specific drivers.

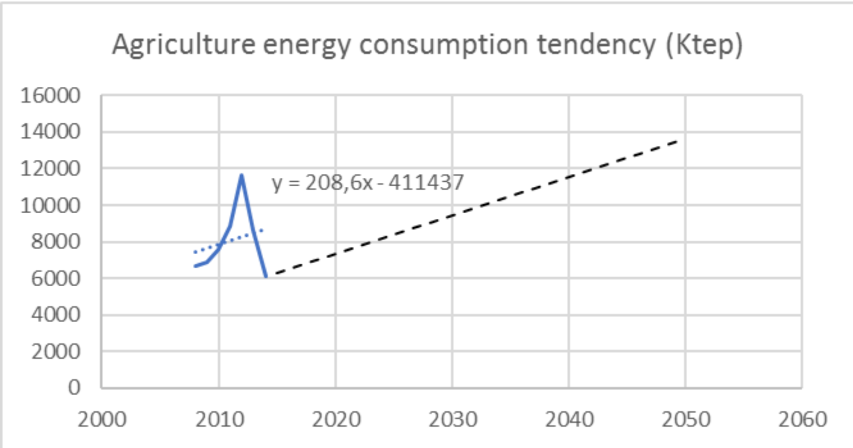

Figure 34: Projection considered for the energy consumption of the agriculture sector.

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 Nantes Metropole and Nantes, the BaU scenario is modelled in LEAP.

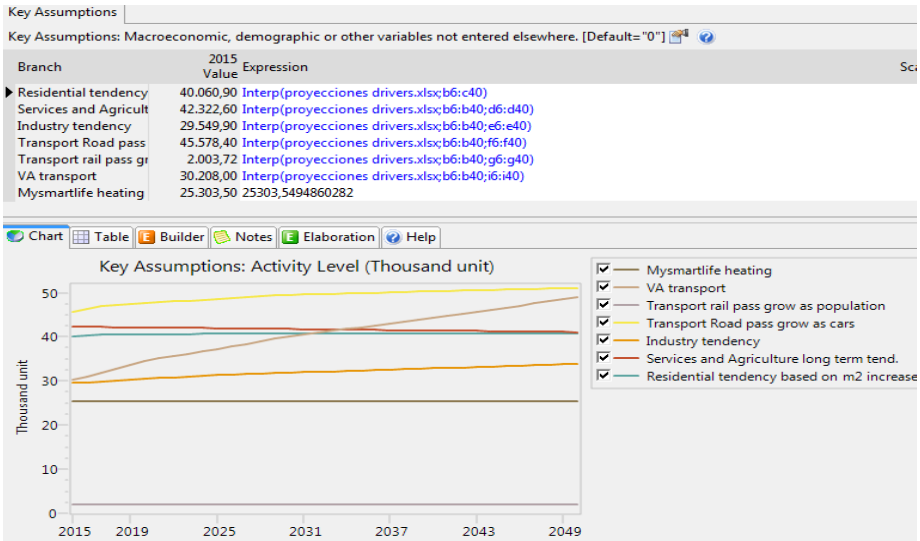

Figure 35: Driver evolution modelling in LEAP for each sector for the BaU scenario

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Based on these projections the energy consumptions of both Nantes metropole and the city of Nantes as well as the energy generation, exportation and importations are calculated in LEAP until 2050. The following figures show the expected energy consumptions and generations of the scenario in which no extra measures are considered. The figure below distinguishes the sectoral energy consumption evolution for Nantes Metropole.

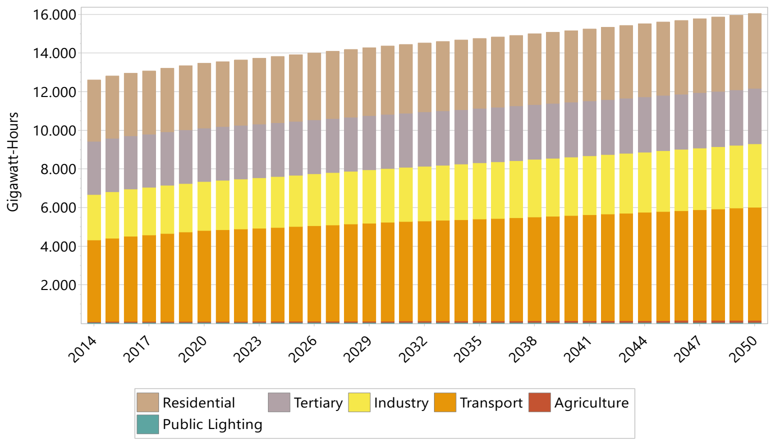

Figure 36: Projection of the sectoral energy consumption for the BaU scenario of Nantes Métropole

It is observed that all the sectors will follow a tendency to increase their energy consumption in the following years. Based on these tendencies the transport sector will continue as the main consuming sector. Evaluating the developments for the case of Nantes city, the figure below shows that an equivalent tendency is followed for Nantes where the natural gas, electricity and the fuel for transport are the most representative energy consumptions.

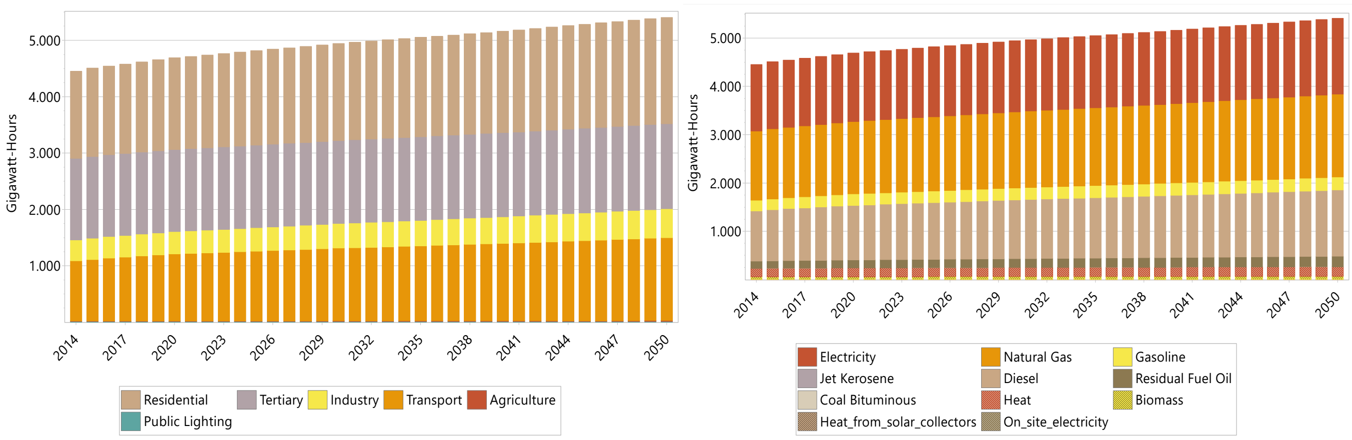

Figure 37: Projection of the sectoral energy consumption (left) and fuel consumption (right) for the BaU scenario (Nantes city region)

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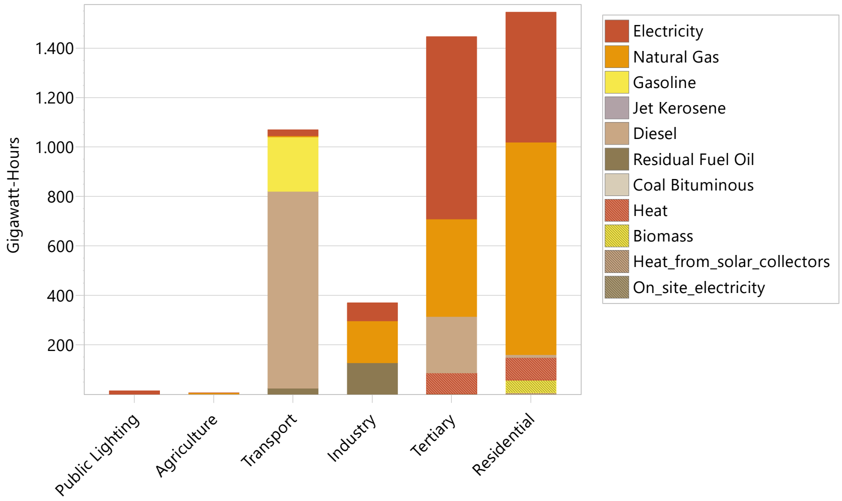

Figure 38: Energy consumption of each sector by fuel in Nantes city for the BaU scenario in the year 2050.

On the other hand, the local energy generation in the city is limited and much lower compared to the current and the future energy requirements. The figure below shows the energy generation by energy technology and generation plant only for the Nantes city region.

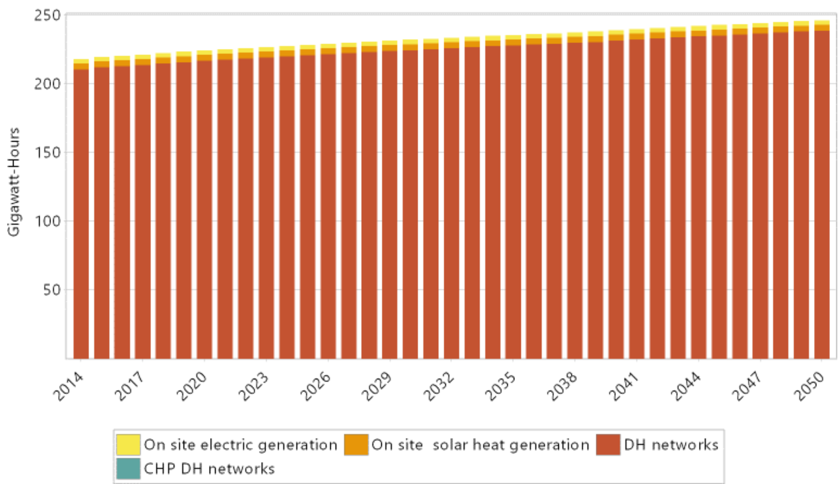

Figure 39: Projection of the local energy generation in Nantes city region BaU scenario

Also, as a picture of the BaU's last year the inputs and outputs of the different plants in the Nantes city region are shown. It should be noted that UIOM Alcea transforms municipal solid heat which is used as an input (fuel "Heat_from_UIOM_Alcea") in the District Heating networks processes. Only fuel "heat" is consumed in the end-use sectors. Also, some plants like UIOM Arc en Ciel or STEP Petite Californie doesn't appear in the figure as they aren't located in the Nantes city region. However some of them feed the District Heating networks (UIOM Arc en Ciel) and their contribution ("Heat from UIOM Arc en Ciel) is listed in the figure below.

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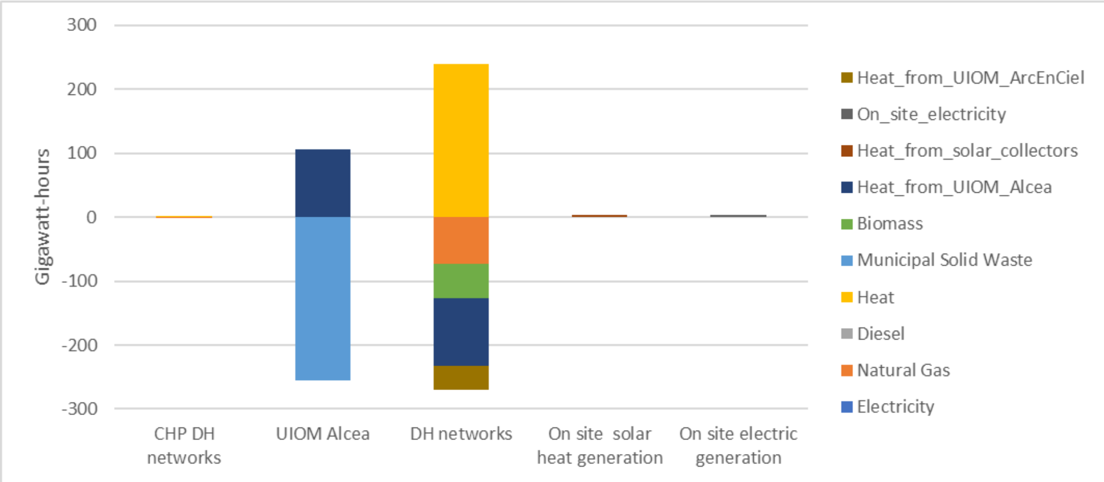

Figure 40: Energy input needed and energy generation in each of the local energy generation plants of Nantes city region for the BaU scenario in the year 2050.

The energy generation for the next decades follows the same tendency as the energy consumption and is adapted according to their current and planned capacities to supply the new demand. It needs to be mentioned that although it is the BaU scenario several changes have been considered in the generation plants: some changes in the feedstock fuels shares in the existant plants and two new plants have been considered. This is showed in the table below.

Table 41: Changes in the fuel shares in the different DH networks in Nantes and Nantes Metropole for the BaU scenario [37]

Location	Process/Plant name	Input fuel	% Fuel
Nantes city	Centre Loire	Heat from UIOM ALCEA	79,7% (2015: 77,59%;2016: 64,05%)
		Natural Gas	18,2% (2015: 19,68%;2016: 27,48%)
		Diesel	2,1% (2015:2,73%;2016: %: 0,0008043725692866%)
		Biomass	0% (2015:0%;2016: 8,47%)
	Bellevue	Biomass	51% (2015: 60,4%; 2016: 60,2%)
		Natural Gas	48,8% (2015: 39,6%; 2016: 39,8%)
		Diesel	0,2%

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			(2015: 0%; 2016: 0%)
	La Chantrerie	Biomass	72%
		Natural Gas	28%
Nantes Metropole w/o Nantes City	ZAC de la Minais	Biomass	0% (2015: 17,33%; 2016: 41,91%)
		Gas	100% (2015: 82,67%; 58,09%)
	ZAC de la Noë	Biomass	80%
		Natural Gas	20%
	Reze	Biomass	85% (2015: 51,84%; 2016: 85%)
		Gas	15% (2015: 48,16%; 2016: 15%)

In any case, it is evident that there is a large proportion of the energy consumption that needs to be covered by electricity and natural gas imports, which are not reflected in the figure.

In order to understand better the energy generation by energy plant and by fuel type (mainly to separate the heat generation and electricity generation), as well as how it corresponds to the energy consumption by sector, the Sankey diagram should be used. The following figure shows the energy balance of the city for the year 2050 in the BaU scenario. This provides a better understanding of the overall performance of the city and helps to understand the future energy import and export requirements.

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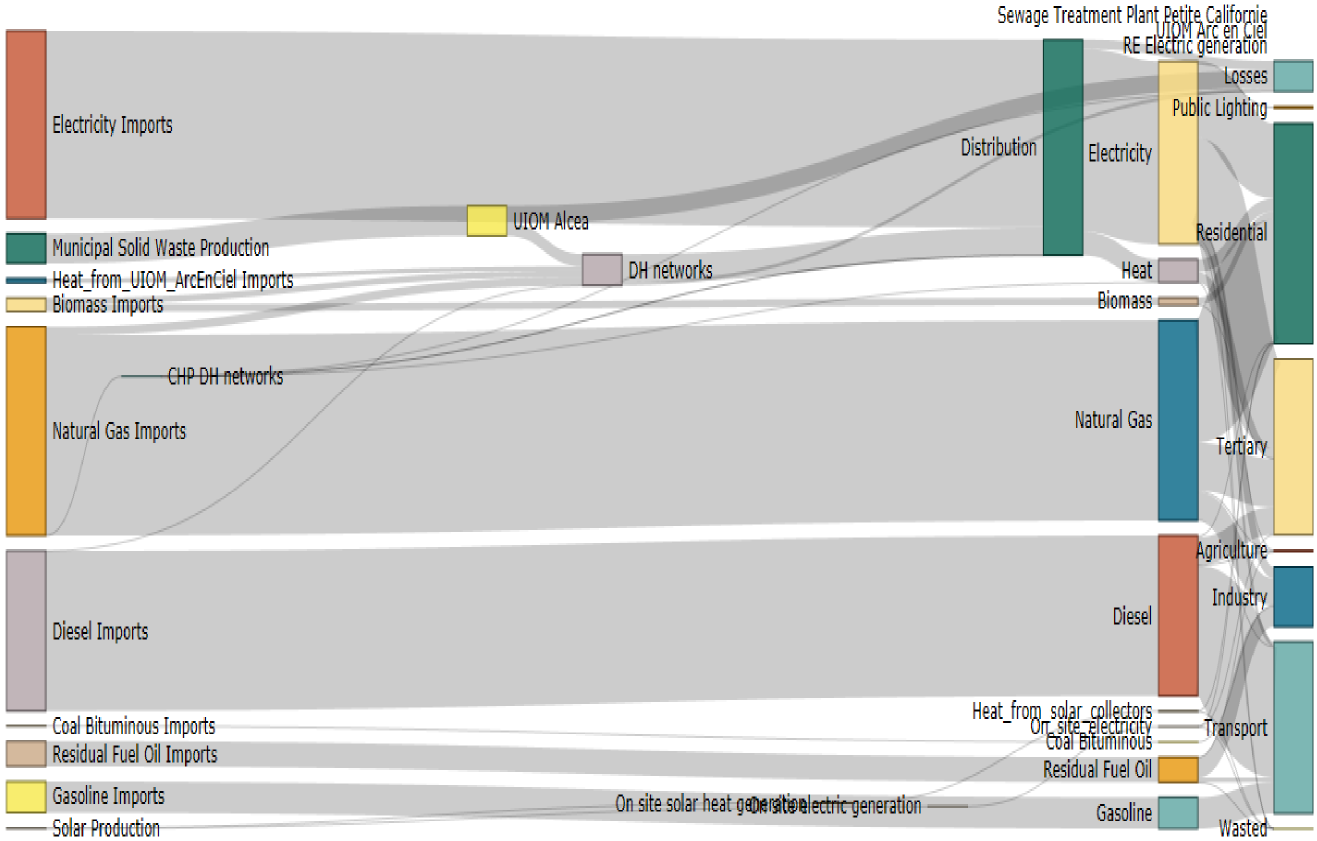

Figure 41: Sankey diagram of Nantes city region BaU scenario in the year 2050.

6.1.2 Alternative scenarios for Nantes

This subsection describes the two alternative scenarios developed for Nantes. The first one correspond to the mySMARTLife intervention scenario and the second one to the mySMARTLife interventions replication scenario. The years and regions considered for the scenarios are: 2019 in the Nantes city region for the former, 2020 to 2050 in both Nantes city and Nantes Métropole without Nantes city regions for the latter.

6.1.2.1 Analysis of the interventions of the city and alternative scenarios modelling

The first scenario is based on the interventions that were planned initially for the city in the framework of the project. Therefore, from the total list of interventions to be implemented in Nantes, the way of modelling them into the global model created in LEAP is described here.

- Action 1. “Inspiration” new construction programme:

The action corresponds to "INSPIRATION" New construction programme which is focused on a set of high performance buildings, comprising 4 blocks - 28000 m2. The intervention is modelled as a reduction of the energy in the residential, offices and commercial buildings.

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- Scale-up criteria for the alternative scenario 2 (mySMARTLife interventions replication scenario):

Only the savings in the energy intensity corresponding to the new residential m2 have been considered. The scale-up criteria is further developped in Action 5.

- Action 2. Retrofitting multi-owner residential building:

The action focuses on the Multi-owner residential building - BELEM Buildings. The intervention is modelled in the "Demand\Residential\Buildings\Housing Block\Heating" section of the model as a reduction of the energy intensity due to the retroffiting action.

Table 42: Energy reduction considered in the alternative scenario 1 for the action 2.

Currentnormative heating demand	Future heating demand	Energy savings including interventions
2152,80 MWh/yr.	270,11 MWh/yr.	1882,1 MWh/yr. - 87%
167 kWh/m^{2}yr	21 kWh/m^{2}yr	

- Scale-up criteria for the alternative scenario 2 (mySMARTLife interventions replication scenario):

According to the "Plan Climat Air Energie Territorial" of Nantes Métropole, 10000 households should be refurbished by 2030. This data has been disaggregated between housing blocks and single family houses m2 using the average surface of these type of buildings in both "Nantes city" and "Nantes Métropole without Nantes city" regions.

Considering the same saving ratio for housing blocks, the energy intensity is reduced by 0,00042 MWh/m2 each year from 2020 to 2030 due to buildings refurbishment. The savings have been extended to 2050, considering the same refurbishment rhythm The same procedure has been adopted for the replication of the Action 3 with a different saving ratio due to single family houses refurbishment.

- Action 3. Retrofitting of individual houses:

The action focuses on the installation of Insulation of attics and walls, installation of smart thermostats in individual houses. The intervention is modelled in the "Demand\Residential\Buildings\Single Family House\Heating" section of the model as a reduction of the heating energy intensity of 195 MWh/m2yr according to the designed specifications.

- Scale-up criteria for the alternative scenario 2 (mySMARTLife interventions replication scenario):

The same scale-up criteria as for the Action 2 has been adopted. In this case the energy intensity of the single family houses is reduced by 0,00056 MWh/m2 per year from 2020 to 2050.

- Action 4. Building Pierre Landais:

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The action focuses on the actuation in the building Pierre Landais. The intervention is modelled in the "Demand\Tertiary\Non commercial\Community\Heating" section of the model as a direct reduction of 161,45 MWh/yr in the heating demand.

- Scale-up criteria for the alternative scenario 2 (mySMARTLife interventions replication scenario):

This action has not be replicated.Only savings due to new residential buildings have been modelled.

- Action 5. Social housing building Oseau des Iles:

The action corresponds to Social housing building Oiseau des Iles which is focused on the installation of 2 digital boilers which provides 50% of the heating needs for hot water and the connection to the high-performance district heating for 28 dwellings. The intervention is modelled in the "Demand\Residential\Buildings\Housing Block\Heating" section of the model.

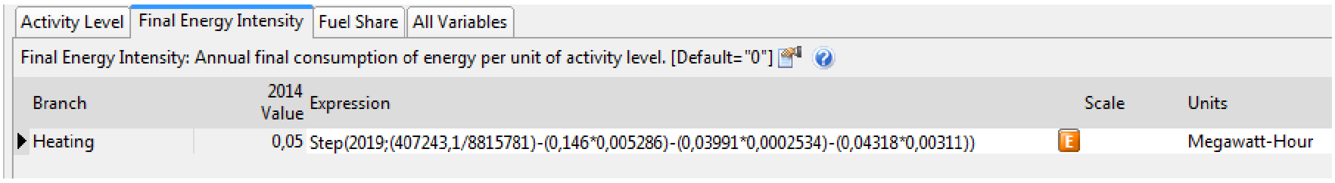

Figure 42: Interventions modelled in LEAP (heating demand reduction in alternative scenario 1 for the residential sector).

- Scale-up criteria for the alternative scenario 2 (mySMARTLife interventions replication scenario):

Starting from the yearly new residential area value determined in the BAU, a saving of 0,0415 MWh/m2 (resulting from the average savings of the actions 1 and 5 in residential buildings) is used for each percentage of new constructed area from 2020 to 2050.

- Action 8. PV plant on building parking des Machines:

The action focuses on the installation of a PV-Thermal hybrid solar plant on building Parking des Machines (225 kWp). The intervention is modelled as Step(2019;88,19+225) in the "Transformation\On site electric generation\Processes\Transport PV panels" section of the model.

- Scale-up criteria for the alternative scenario 2 (mySMARTLife interventions replication scenario):

The replication of this action is considered implicittely in the replication potential of new and refurbised residential buildings.

- Action 9. Solar thermal panels in BELEM building:

The action focuses on the installation of solar thermal panels in BELEM building. The intervention is modelled in the "Housing Block solar collectors" section of the model as an increase of the capacity equivalent to the generation of 90000 kWh/yr and maintaining constant the maximum operating hours as

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in the rest of the solar collectors (9,69%), resulting in an addition of 106,03 kW in the “Transformation\On site solar heat generation\Processes\Housing Block solar collectors” section.

- Scale-up criteria for the alternative scenario 2 (mySMARTLife interventions replication scenario):

This action has been replicated in combination with the Action 10. For each m2 of housing blocks refurbished, 0,0031 kW and 0,01 kW will be added to the electric and thermal installed capacities. These values have been obtained from the relation: new solar collectors (PV) installed capacity/refurbished area. For new housing blocks, the same relationships have been considered. Therefore for each new m2 of housing blocks, the solar collectors and PV panels installed capacities will be increased too.

- Action 10. Solar hybrid (PV+Thermal) in BELEM building:

The action focuses on the installation of a PV-Thermal hybrid solar plant in BELEM building. The intervention is modelled in the “Transformation\On site electric generation\Processes\Residential PV panels” and in “Transformation\On site solar heat generation\Processes\Housing Block solar collectors” sections of the model as an increase of the capacity of solar electric generation of 40,7 kW and solar thermal of 23,56 kW.

  - Scale-up criteria for the alternative scenario 2 (mySMARTLife interventions replication scenario):

The replication of this action has been previously considered in the expansion of the solar collectors (and solar PV panels) technology in Action 9.

- Action 11. Micro-wind turbines in BELEM building:

The action focuses on the installation of Micro-Wind Turbines in BELEM building. The intervention is modelled in the “Transformation\On site electric generation\Processes\Residential Wind microturbines” section of the model as an increase of the capacity of microwind of 3 kW.

The following picture shows the increase of the capacity due to the renewable energy technology installation in the project.

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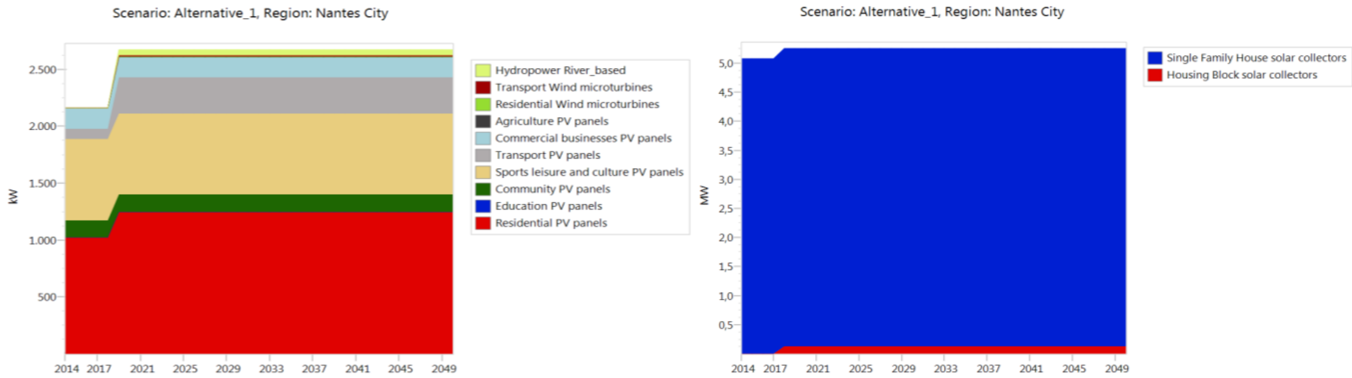

Figure 43: Intervention modelling in LEAP (increase of the capacity of renewable technologies in the alternative scenario 1).

- <u>Scale-up criteria for the alternative scenario 2 (mySMARTLife interventions replication scenario):</u>

The replication of this action is considered in the exploitation of wind resources in Nantes Métropole in the scale-up criteria for the Action 20.

- <u>Action 12. Hybrid solar power system:</u>

The action focuses on the installation of an hybrid solar power system in individual houses. The intervention is modelled in the "Demand\Residential\Buildings\Single Family House\Heating" section of the model as an increase of the capacity of electric generation with solar of 24,47 kW and an increase of the capacity of thermal generation with solar of 51,67 kW.

- <u>Scale-up criteria for the alternative scenario 2 (mySMARTLife interventions replication scenario):</u>

The criteria used in this case is similar to the one considered in the replication of actions 9 and 10. For each m2 of single family houses refurbished, 0,052 kW and 0,024 kW will be added to the thermal and electric installed capacities. These relationships will be considered too for the new single family house constructed areas.

- <u>Action 18. Public lighting optimization: gradation and remote management</u>

This action plans the replacement of 80 old bulbs by LED ones. Each LED lamp represents a 30% energy saving respect the conventional ones, wich consume 0,53 MWh per device considering the total public lighting consumption in Nantes Métropole (49815 MWh) and the total number of street lamps (94000) for the baseline year. Therefore, this action represents a reduction of 42,4 MWh in the consumption of the conventional lamps, and an increase of 29,68 MWh due to the new LED lamps in the Nantes city region.

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Final Energy Intensity: Annual final consumption of energy per unit of activity level. [Default="0"]

Branch	Fuel	2014 Value	Expression	Scale	Units
Rest of lamps	Electricity	14.477,00	GrowthAs(Key\Tertiaire as historic tendency)+Step(2014;0;2019;-0,53*80;2020;0)		Megawatt-Hour
LED lamps	Electricity	0,00	Step(2019;0,53*0,7*80)		Megawatt-Hour

Figure 44: Intervention modelled in LEAP (replacement of 80 street light lamps bulbs in alternative scenario 1)

- Scale-up criteria for the alternative scenario 2 (mySMARTLife interventions replication scenario):

For the replication of this action the total replacement (in both defined regions) of the street light lamps by LEDs by 2050 has been considered, meaning that by that year, LED consumption will be 70% of the total consumption projected in the BaU.

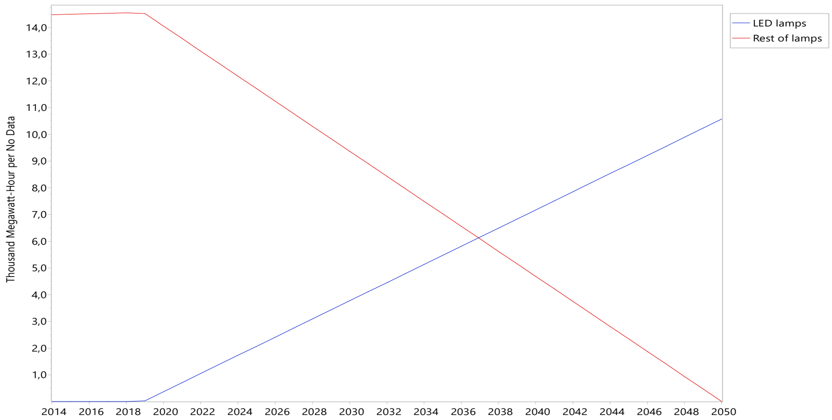

Figure 45: Final energy consumption of public lighting by type of lamp in alternative scenario 2

- Action 20. Urban micro turbines:

The action focuses on the installation of 100 micro-wind turbines (10 kWp) that will be installed in Parking des Machines.

The intervention is modelled in the "Transformation\On site electric generation\Processes\Transport Wind microturbines" section of the model as an increase of the capacity. Besides, it is defined in the model that this energy generation supplies the energy demand of "tertiary/non-commercial/transport".

- Scale-up criteria for the alternative scenario 2 (mySMARTLife interventions replication scenario):

For the replication of this intervention, the wind turbine potential presented in the city's baseline assessment has been used as main criterion. However, in this case, the defined wind systems are not micro-wind turbines but large-scale turbines installed in the outside of the Nantes city region and supplying the generated electricity to the grid and not to specific buildings or sectors. An annual 43 GWh generation potential has been considered which, maintaining the same maximum operating hours considered for the micro-turbines, corresponds to a 29 MW installed capacity. It is assumed that these wind farms will start working in 2030.

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- Action 21. River-based hydropower:

The action focuses on the installation of a River-based hydropower. The intervention is modelled in the "Transformation\On site electric generation\Processes\Hydropower River_based" section of the model as an increase of the capacity in 52,08 KW. Besides, it is defined in the model that this energy generation supplies the energy demand of "tertiary/non-commercial/transport".

  - Scale-up criteria for the alternative scenario 2 (mySMARTLife interventions replication scenario):

As for the wind turbines, a 224 MWh annual production potential (27 GWh of them in the city of Nantes) extracted from the city's baseline assessment has been used as scale-up criteria. These new systems supply electricity directly to the grid and not to specific buildings or sectors. This replication has been modelled as new processes of 24,44 kW (Nantes Métropole without Nantes city region) and 3,35 kW (Nantes city region) installed capacities, and will start working in 2030.

- Action 23. Twenty new 24-meters full electric buses

This action focuses in the replacement of twenty buses of the Busway line by fully electric vehicles. Considering a fuel efficiency of 5,2 kWh/km for diesel buses and 1,7 kWh/km for electric ones, and that the distance travelled by a vehicle in Nantes is 45000 km, the consumption associated to buses ("Demand\Road\Passenger\Buses") is reduced by 7,96%. The new fuel shares are then recalculated: 4,20% electricity, 12,78% natural gas, 83,02% diesel.

  - Scale-up criteria for the alternative scenario 2 (mySMARTLife interventions replication scenario):

For the replication of this action it has been considered that for both Nantes city and Nantes Métropole without Nantes city regions, the share of natural gas will remain constant, while the share of diesel will be cut by half in 2030 and fully substituted by electricity in 2050.

The interventions described above are modelled in LEAP and the results are shown. The description of these will focus more on the alternative scenario 2 (mySMARTLife interventions replication scenario) because the resulting values are easier esteemed when the actions are replicated than when dealing with punctual interventions, where the savings are less significative.

In the next figure, the final energy consumption in the end-use sectors is shown for the Nantes city region. In the final year (2050) a saving of 5,7% can be appreciate (4,5% in the case of the whole Nantes Métropole) respect to the BaU. It should be said that more savings can be achieved as this scenario only accounts for the interventions in the project's framework: many other actions and strategies which are not considered here can be developed in order to reach the city's targets.

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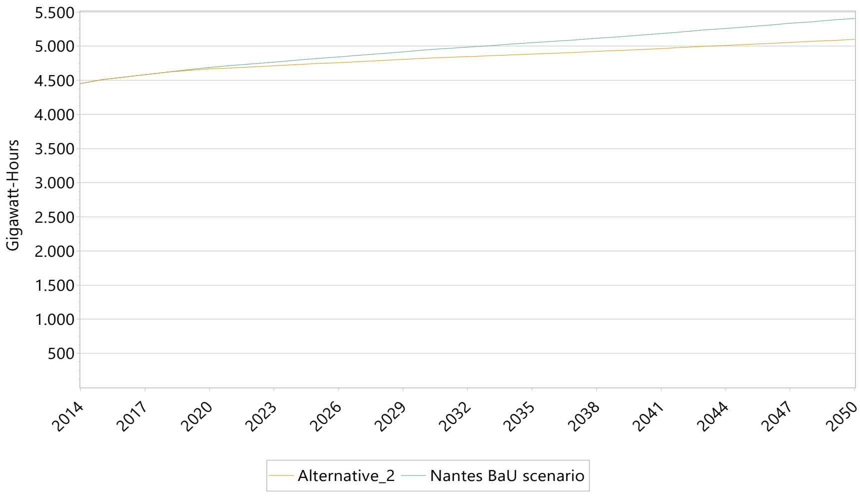

Figure 46: Total energy consumption comparison of the end-use sectors in the Nantes city region (BaU scenario vs mySMARTLife interventions replication scenario)

In the case of the residential sector, the savings are more significant as many of the interventions focus on this sector. As it can be seen in the next figures, the savings in this case reach the 13,73% energy reduction in the Nantes city region (14,92% in the whole Nantes Métropole city region) in the final year. It can be also noted the change in the fuels consumed in the sector: electricity from the grid and natural gas experience 18,86% and 25,69% decrease respectively, while electricity and heat from on-site renewable generation processes are considerably boosted.

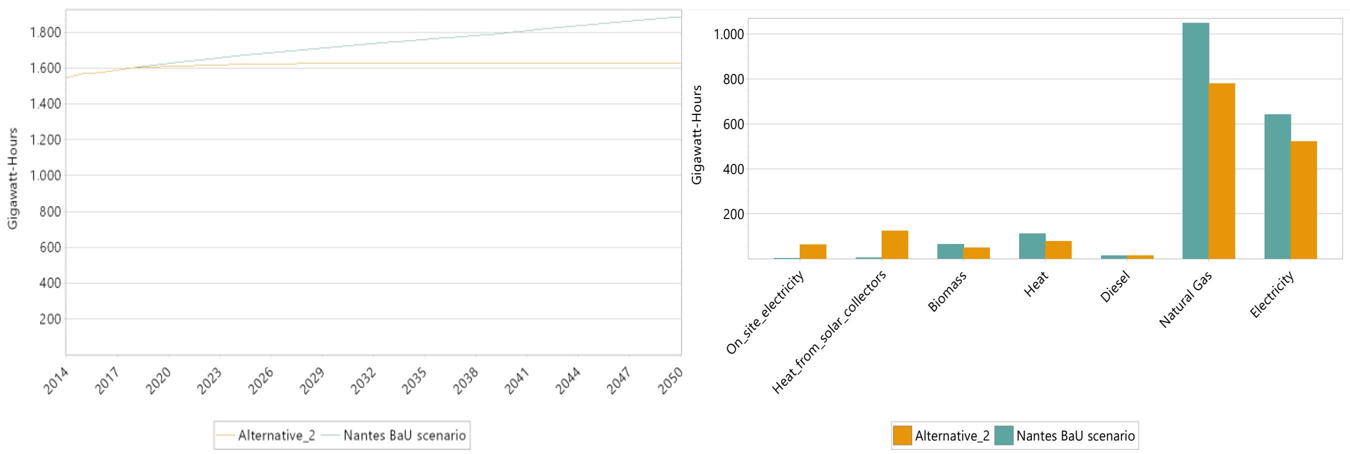

Figure 47: Total energy consumption (left) and energy sources detail (right) comparison of the residential sector of the Nantes city region (BaU scenario vs mySMARTLife interventions replication scenario)

The savings in the tertiary sector are hardly appreciable as the actions which affect this sector in the alternative scenario 1 are not replicated. However, refurbishment of tertiary buildings (especially public

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ones) and integration of renewable energy generation systems in buildings can be carried out as in the residential sector.

Energy consumption in the agriculture and industry sectors doesn't vary as inerventions are not put into practice.

As explained in the description of the intervention, the replication of the old street lamps substitution by LED ones manage to achieve a 30% saving respect the BaU scenario in 2050.

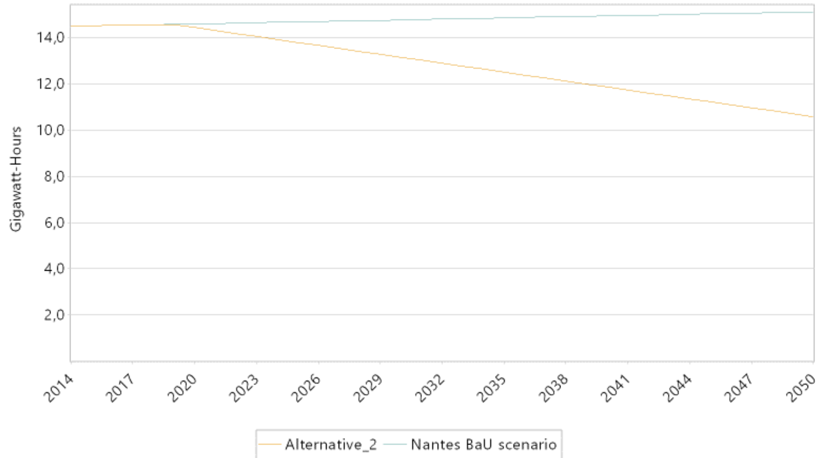

Figure 48: Public lighting consumption comparison in the Nantes city region (BaU scenario vs mySMARTLife interventions replication scenario)

In the road transport subsector, the savings are about 3% respect the BaU scenario in the Nantes city region in the end year (2% in the whole Nantes Métropole), due to the replication of the bus fleet subsitution by electric vehicles. Also, diesel consumption is decreased by 4,3%. However greater savings can be achieved if actions concerning the private cars fleet or the modal split are executed.

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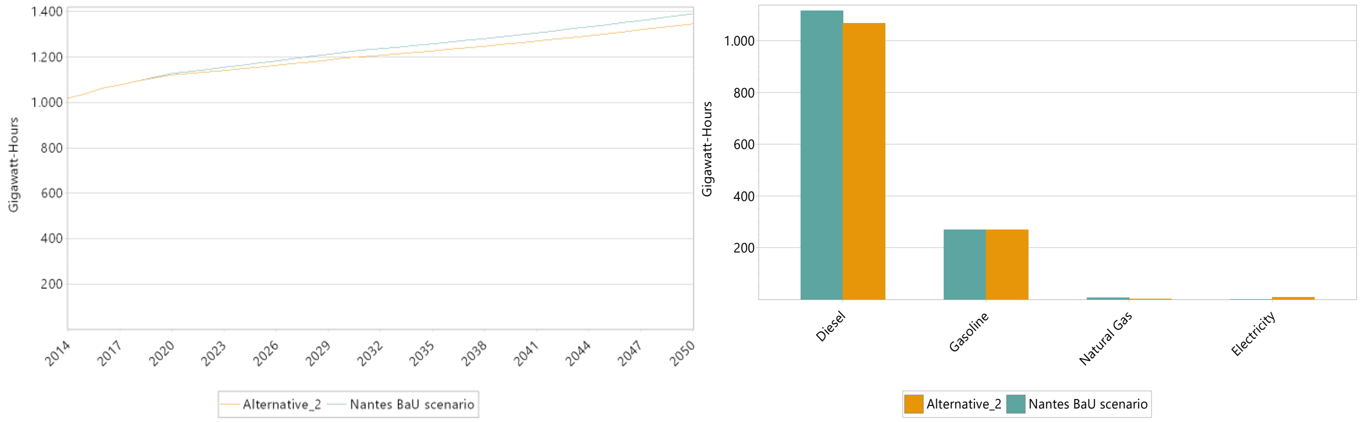

Figure 49: Total energy consumption (left) and energy sources detail (right) comparison of the residential sector of the Nantes city region (BaU scenario vs mySMARTLife interventions replication scenario)

Concerning the energy generation in the city, there is a 63,39% increase respect the BaU scenario in the energy production in the Nantes city region, mostly because of the boost of the renewable on-site power and heat generation. In the case of the whole Nantes Métropole area the increase is about 132% due to the interventions that have been replicated outside the Nantes city region (Actions 20 & 21).

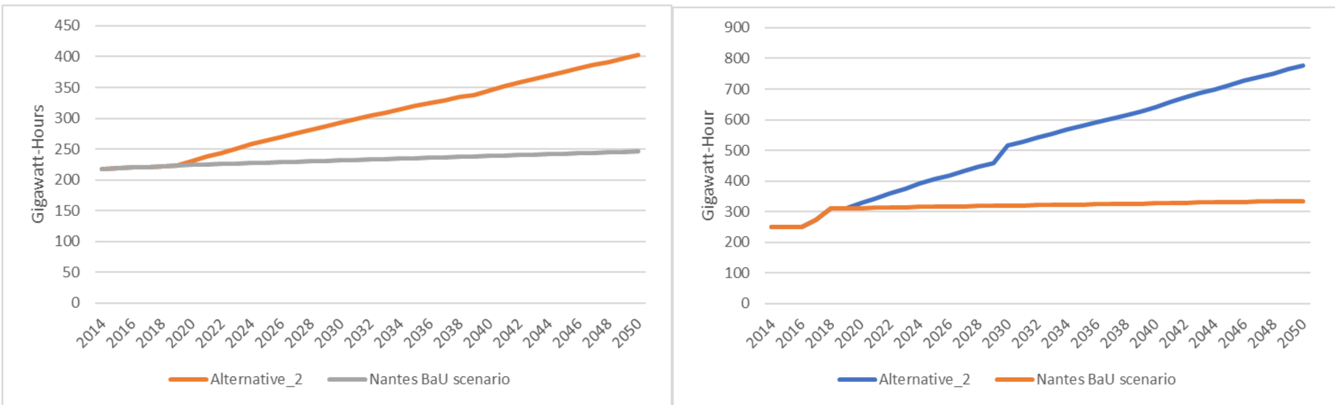

Figure 50: Energy generation comparison between the BaU scenario & mySMARTLife interventions replication scenario for the Nantes city region (left) and the whole Nantes Métropole area (right)

Respecting the heat generated in the District Heating networks, the general generation decreases by 17% in 2050 respect the BaU scenario in the Nantes city region. This is because the savings in the heating energy intensities manage to reduce the overall heat consumption and hence the heat produced in the district heating networks. In the next figure it can be seen the energy output by plant comparison between the BaU scenario and the mySMARTLife interventions replication scenario for the year 2050.

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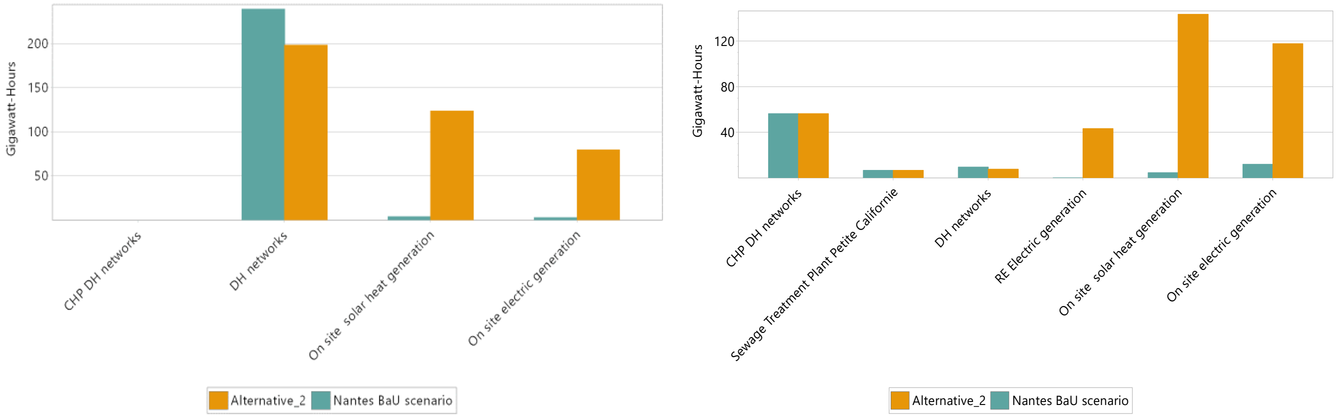

Figure 51: Energy generation by plant comparison between the BaU scenario & mySMARTLife interventions replication scenario for the Nantes city region (left) and the whole Nantes Métropole area (right)

Finally, the Sankey diagram is presented below for the mySMARTLife interventions replication scenario in Nantes city for 2050.

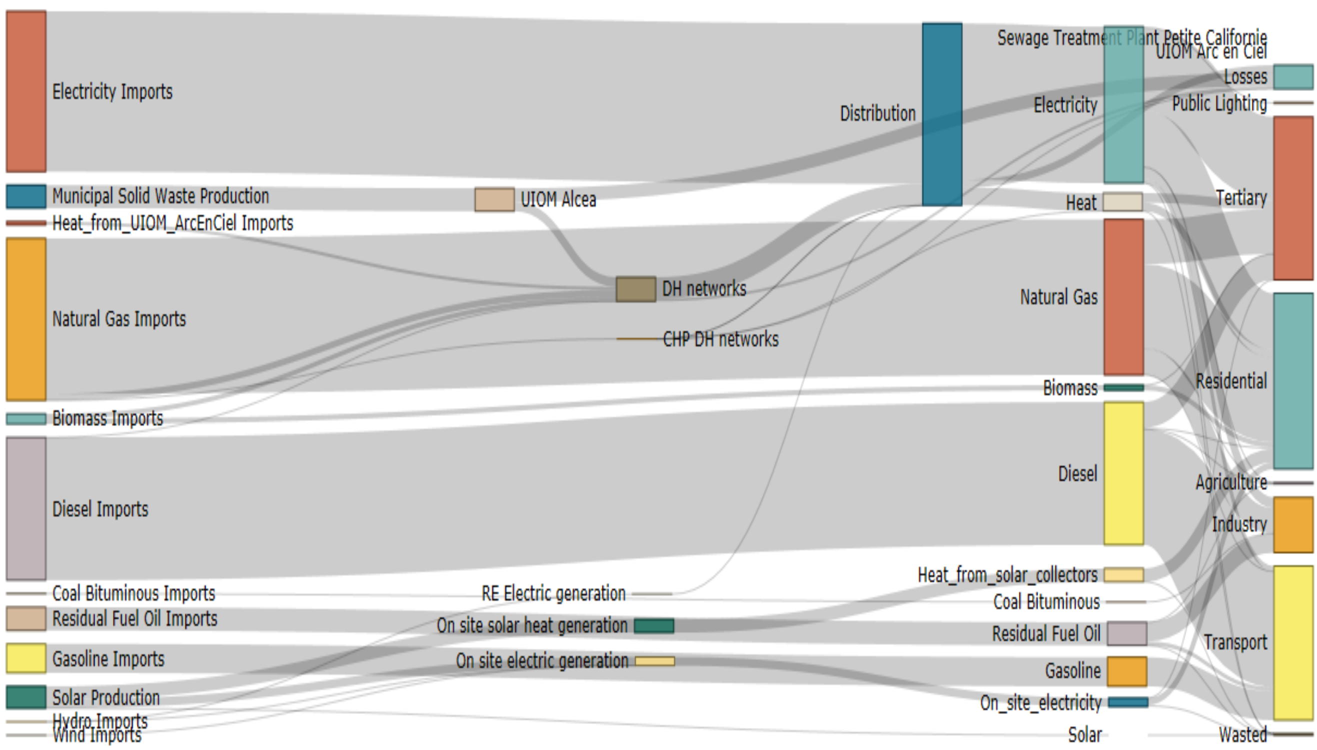

Figure 52: Sankey diagram of Nantes city region mySMARTLife interventions replication scenario in the year 2050.

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6.2 Scenario analysis for Hamburg

In the case of Hamburg, 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 of Hamburg

As described for the case of Nantes, the first step followed for the definition of the BaU scenario of Hamburg 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. In this case the relation between the drivers and the energy consumptions has also been carried out per each sector.

In terms of the data sources evaluated for the analysis of the historic evolution of the main drivers and energy consumptions the followings have been considered:

- **Klassifikation der Wirtschaftszweige 2008 (WZ 2008)** [38]: Socioeconomic information related to the GDP, the VA is available for Hamburg.
- **Eurostat** [39]**:** Energy prices for Germany are available in Eurostat distinguishing between the prices for different fuels and for different final users. Besides, other information such as the GDP, the VA and the income are available.
- **Transparenzportal Hamburg** [40]: General information about Hamburg.
- **Urban Data Platform** [35]: This data base provides several socioeconomic parameters' historic evolution and expected projection for different European urban locations. In this case, data related the GDP/Cap, population and constructed area and average travel distances have been evaluated.

6.2.1.1 Analysis of the correlations with the energy demands and driver selection for the definition of the BaU Scenario

This subsection includes a summary of the process followed for the analysis of this relation and the final selection of the driver or the general tendency of the energy consumptions of Hamburg.

- Residential sector:

Although several drivers have been evaluated for the residential sector, the one that shows the best correlation is the m2 of households of Hamburg. The figure below shows the main factor affecting the linear correlation index.

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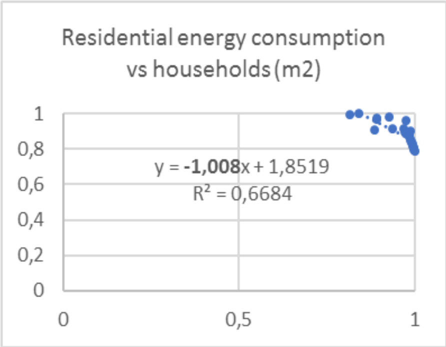

Figure 53: Analysis of the relation between the tendency of the residential sector energy consumption with the potential driver (m^2 of households) for Hamburg.

Therefore, the tendency of this parameter is evaluated more in detail. The historic data shows that its development follows a relatively good linearity in the long-term. This is the reason why one of the most direct criteria for the projection of this parameter is to follow the tendency as it is shown in the first option of the figure below. However, a more conservative projection is obtained according to the projections provided for the evolution of this parameter in the Urban Data Planform of the European Commission. With this aim, based on the expected increase of the area per inhabitant (-0,16% until 2020, -0,01% until 2030, -0,06% until 2040 and -0,24% until 2050) and the existing projections for the population, the projection for the new construction area has been obtained and represented in the figure below.

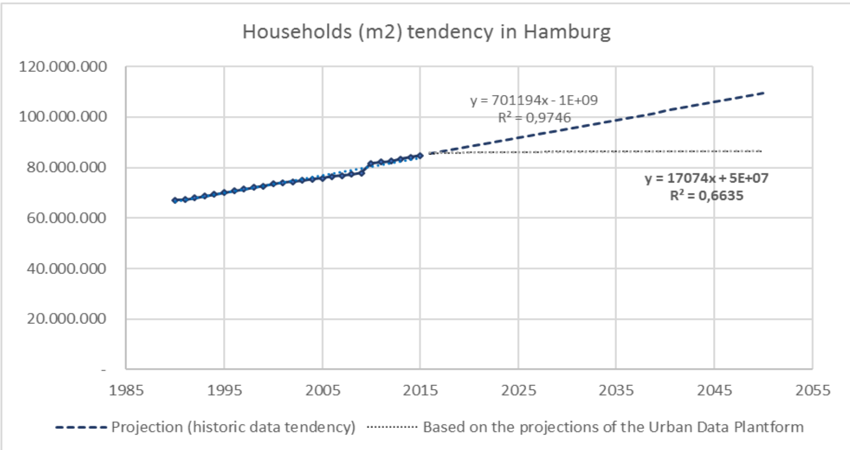

Figure 54: Households projection options for Hamburg. Linear projection based on the historic data vs projection based on the tendencies provided in the Urban Data Planform of the EC.

From the analysis of these two options it is concluded that the most realistic and appropriate tendency for this study is the second one, which considers that the growth of households will slow down with the time. Based on this projection the energy consumption for Hamburg for the following decades is obtained.

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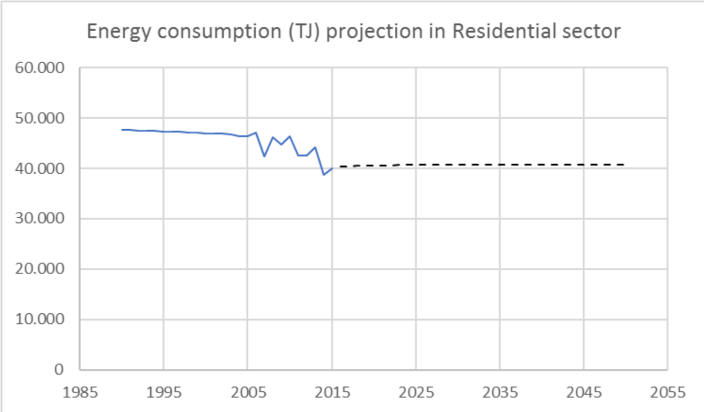

Figure 55: Energy consumption projection considered for the residential sector of Hamburg.

- <u>Industrial sector:</u>

Following the same procedure for the industrial sector, the main drivers evaluated are the VA and the electricity price for the industrial sector. As it is observed in the figure below, the best linear correlation index is obtained for the electricity price.

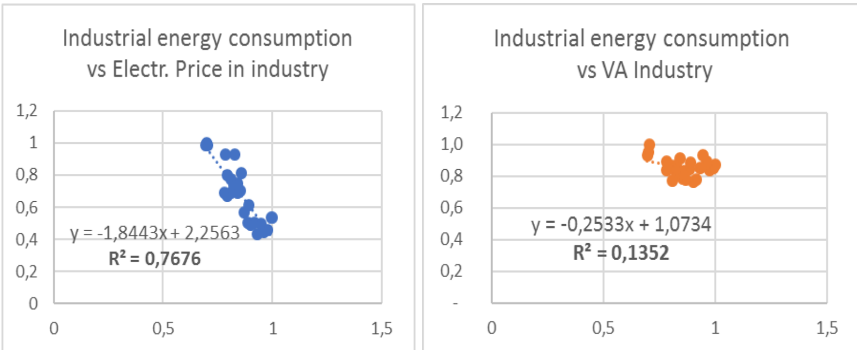

Figure 56: Analysis of the relation between the tendency of the industrial sector energy consumption with the potential drivers for Hamburg.

In the historic data it is observed that from the year 1992 to 2000 the energy consumption of the industrial sector increased as the energy price decreased. After that, there is a period in which the electricity price increased and the energy consumption continued to increase. Finally, after 2008 the energy consumption started to decrease. However, it is evident that this decrease cannot be linked only to the change of the energy cost, due to the occurred economic crisis. All this makes that the correlation of this driver with the energy consumption is not easy to define and predict. Considering this effect, the last years of the energy data available are evaluated and they show what it seems a new tendency of smooth increase in the energy consumption. This is precisely the tendency considered for the projection of the industrial energy consumption of Hamburg in the short-term (0,6%) to 2025. Besides, the increase hypothesis for the following decades (after 2025) is more conservative (0,3%).

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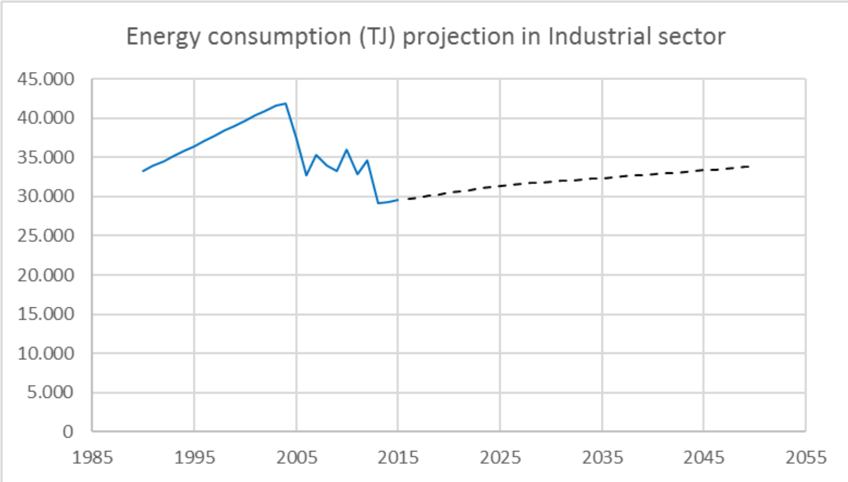

Figure 57: Projection considered for the industrial sector energy consumption.

- Mobility sector:

Transport sector´s projection is divided in this case into two different projections to distinguish the road and the non-road transport.

  - Road transport:

The observed correlation of the energy consumption of the transport sector with the VA of the transport sector and the number of vehicles evaluated in the short-term tendency is relatively good. The last one specially shows a good causal correlation.

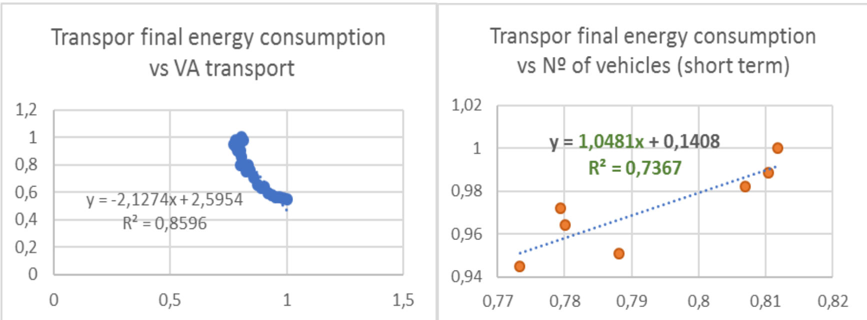

Figure 58: Analysis of the relation between the tendency of the road energy consumption with the potential drivers for Hamburg.

Focused on the driver of number of vehicles, for the projection it has been finally considered the forecasts available in the PRIMES EU28: Reference scenario(REF2016) [36]. This forecast shows the increase of the number of private cars and motorcycles for Germany ('2000-'2010; 0,63%; ´2010-'2020; 0,49%; '2020-'2030; 0,39%; '2030-'2050; 0,16%). Based on these increase rhythms the following curve is obtained. The figure below shows the energy consumption tendency considered for the road energy consumption in the model.

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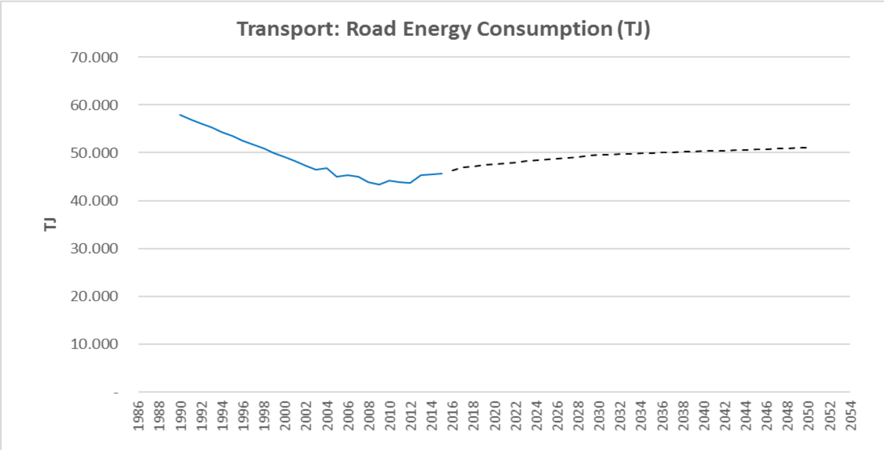

Figure 59: Projection considered for the road transport energy consumption.

- <u>Non-road transport:</u>

For the non-road transport on the other hand the selected driver has been the population. Therefore, the base for the forecast is the population projection obtained from Eurostat. Under these considerations, the following curve is obtained.

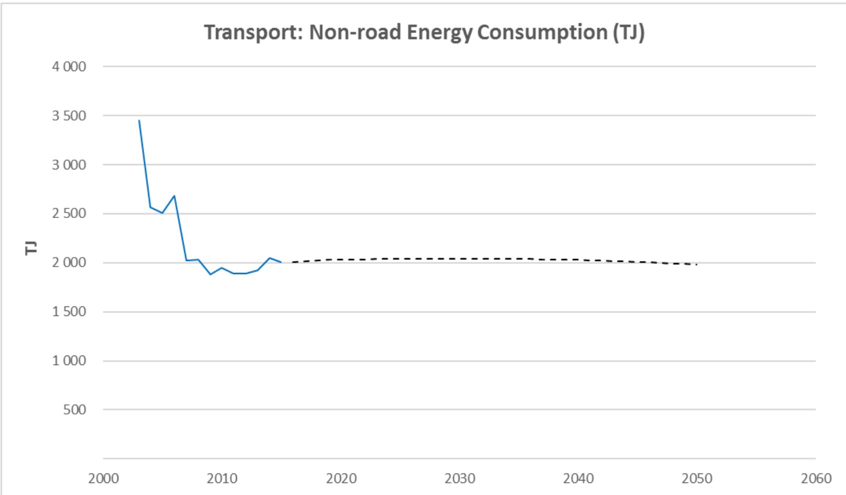

Figure 60: Projection considered for the non-road transport energy consumption.

<u>Tertiary and agriculture sectors:</u>

In this case, considering that the data available for the scenario development is aggregated for the tertiary and agriculture sectors, both are evaluated jointly in this section.

Different drivers have been evaluated for the tertiary sector; GDP/Cap, the VA of the tertiary sector, the electricity price. However, in this case it cannot be said that it exists any clear correlation with the energy consumption of the sector with these drivers. Therefore, in this case the historic tendency has been

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evaluated. As it is showed in the figure below the historic tendency follows a very smooth decrease (-0,08%) that in the long-term projections can be accepted as a reasonable hypothesis.

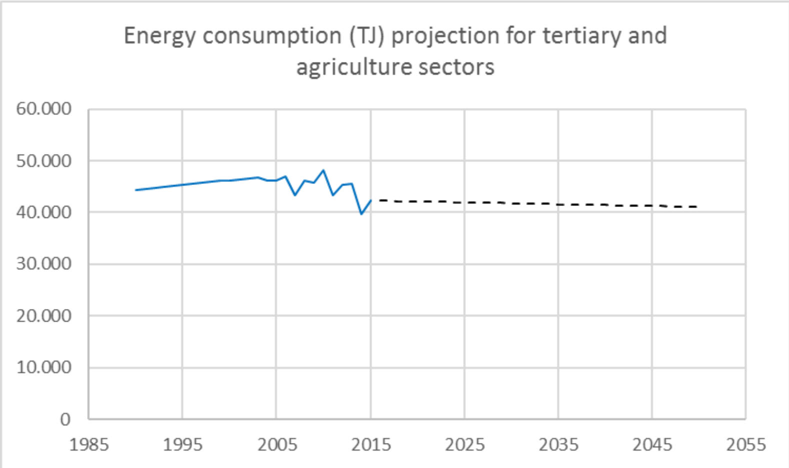

Figure 61: Projection considered for the energy consumption of the tertiary and agriculture sectors.

6.2.1.2 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 Hamburg the BaU scenario is modelled in LEAP. Based on these projections the energy consumptions as well as the energy generation, export and import are calculated until 2050. The following figures show the expected energy consumptions and generations for the scenario in which no extra measures are considered.

The figure below distinguishes the sectoral energy consumption evolution for Hamburg.

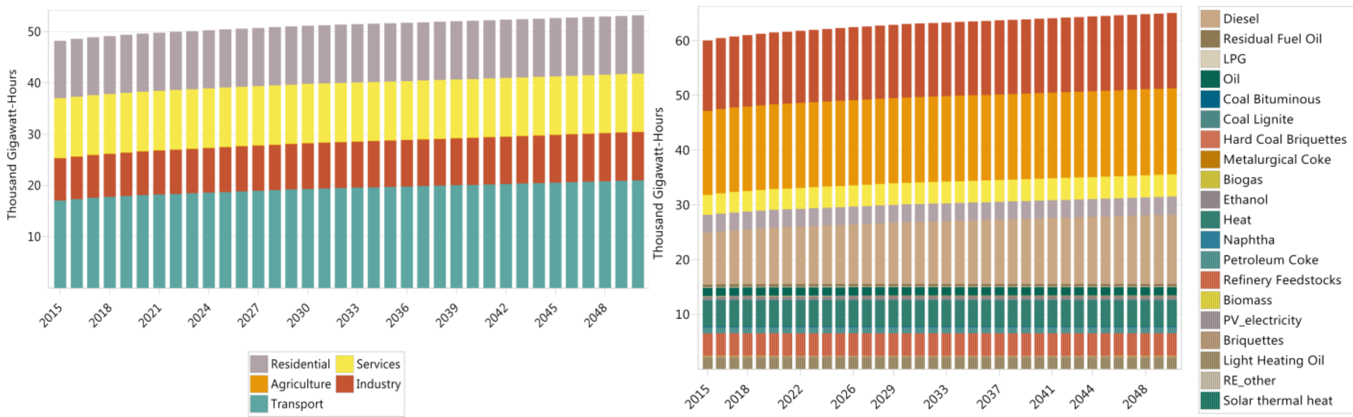

Figure 62: Projection of the sectoral final energy consumption (left) and fuel consumption (right) in Hamburg for the BaU scenario.

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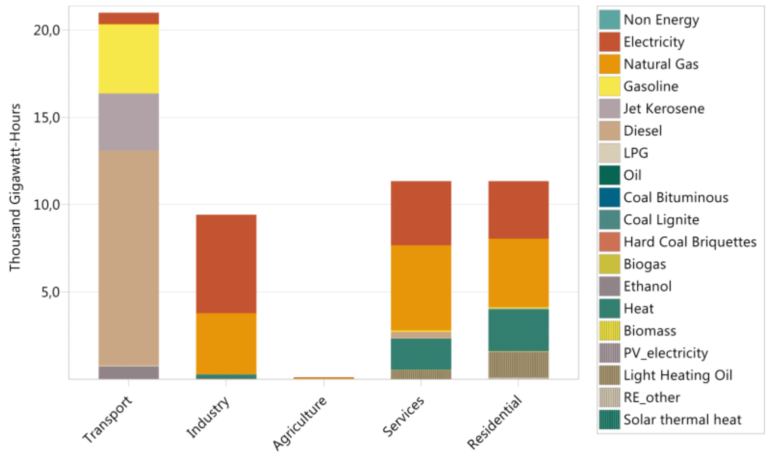

Figure 63: Energy consumption of each sector by fuel in Hamburg for the BaU scenario in the year 2050.

On the other hand, the figure below show the local energy generation in Hamburg in the BaU scenario for the year 2050 by generation plant and the input fuels required in each of them.

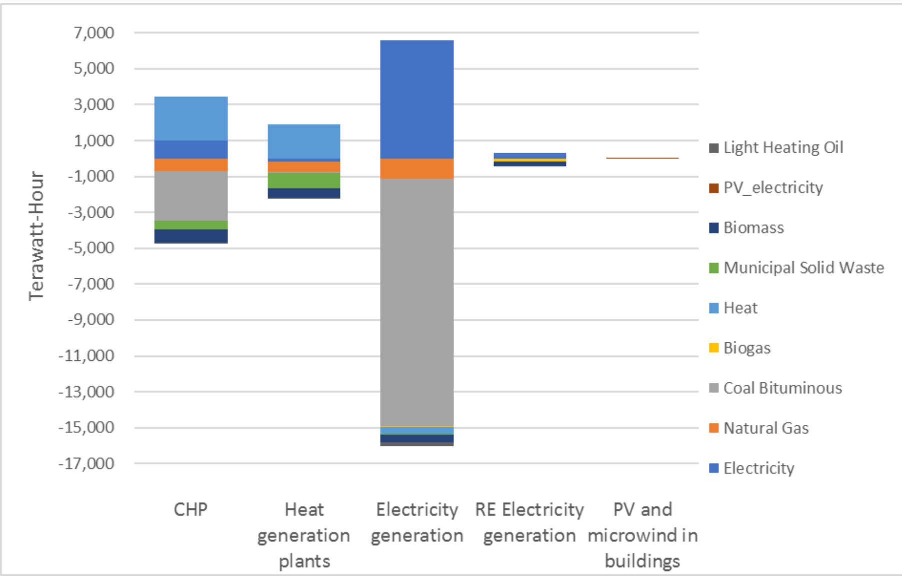

Figure 64: Energy input needed and energy generation in each of the local energy generation plants of Hamburg for the BaU scenario in the year 2050.

In order to understand better the energy generation by energy plant and by type fuel (mainly to separate the heat generation and electricity generation), as well as how it corresponds to the energy consumption by sector, the sankey diagram for Hamburg in the year 2050 is showed in the figure below.

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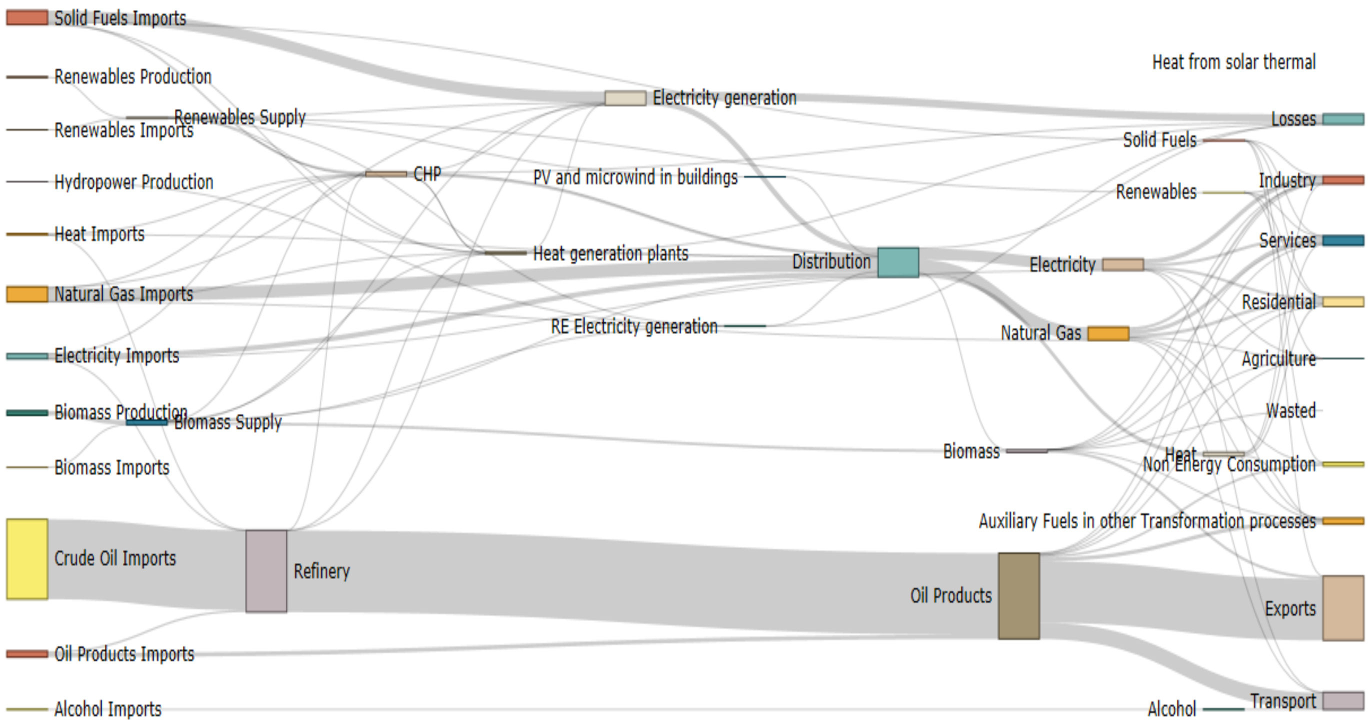

Figure 65: Sankey diagram of Hamburg BaU scenario in the year 2050.

6.2.2 Alternative scenarios for Hamburg

This subsection describes the two alternative scenarios developed for Hamburg. The first one correspond to the, mySMARTLife intervention scenario and the second one to the mySMARTLife interventions replication scenario.

6.2.2.1 Analysis of the interventions of the city and alternative scenarios modelling

The first scenario is based on the interventions that were planned initially for the city in the framework of the project. Therefore, from the total list of interventions to be implemented in Hamburg, the way of modelling them into the global model created in LEAP is described here. Besides, for the alternative scenario two, the scale-up or replication criteria per each intervention is also described in this section.

- <u>Action 1. “Schleusengraben” new construction programme:</u>

The action focuses on the construction of 37000 m^2 residential and 48000 m^2 non-residential, 79 buildings and 1500 flats. The intervention ensures that the new energy demand of the buildings will be lower than the current normative heating demand (56% lower). Therefore, this intervention affects both the residential and tertiary sector and it is modelled in LEAP for the mySMARTLife intervention scenario with a new heating energy consumption tendency “GrowthAs(Key\Mysmartlife heating)” which includes a punctual reduction of the energy demand of 1198,86 MWh/yr. According to the data provided, the effects of this reduction is included in the residential sector (43,5%) and in the tertiary sector (56,5%).

    - <u>Scale-up criteria for the alternative scenario 2 (mySMARTLife interventions replication scenario):</u>

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For the alternative scenario 2, the replication potential of the intervention in other areas of the city needs to be considered. In this case the potential needs to be limited to the residential and the tertiary sector. Besides, it needs to be considered that this intervention is implemented in new constructed area, therefore according to the data provided in the document "Growing city. Green Metropolis at the Waterfront", approximately it will be constructed 5500 new buildings per year. Maintaining the saving ratio per building, this allows obtaining the scalation factor for the scenario 2 of approximately 130 TJ/year saved in the residential sector of the entire city and 169 TJ/year of savings in the tertiary sector.

- Action 2. Bergedorf-Süd Retrofitting project:

The action focuses on Bergedorf-Süd retrofitting (zone 2), covering 500 buildings comprising about 5000 flats and 330000 m^2. The intervention´s effect is 51,9% reduction of the heating demand of the buildings. As in the previous case the intervention is modelled as a punctual heating consumption reduction of 25598 MWh/yr in the residential sector for the alternative scenario 1.

  - Scale-up criteria for the alternative scenario 2 (mySMARTLife interventions replication scenario):

The scale-up criteria used for this intervention it to evaluate the replication potential which is linked to the rhythm of retrofitting of the building stock of the city. As a general hypothesis, a 2% retrofitting rhythm is reasonable for developed cities. According to this criterion an annual energy saving of approximately 262,6 TJ is considered for the alternative scenario 2.

Action 1 and Action 2 are modelled jointly in LEAP. As an example, it can be said that for the residential sector the following projection is modelled "GrowthAs(Key\Residential tendency based on m^2 increase according to projections)+Step(2016;-130,79-262,651)". The figure below shows the effect of the replication of the two first actions deployed in the city.

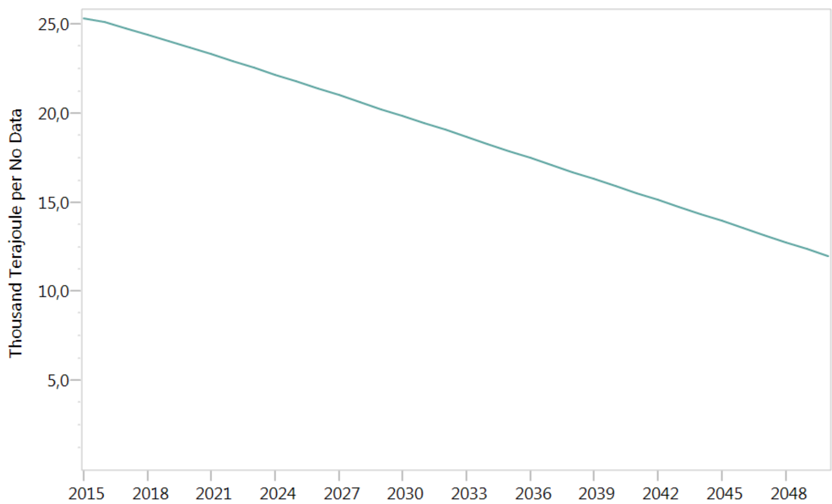

Figure 66: Heating consumption reduction tendency in the residential sector of Hamburg for the alternative scenario 2.

- Action 4. Hybrid PV and Wind turbines and Heat Pumps:

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

The intervention is focused on the zone 1 (new construction area) in which on suitable roofs it will be installed hybrid PV with small wind turbines. The PV plants are equipped with electrical power storages. The potential on non-residential building is approximately 10 MWh/yr wind energy, plus 50 MWh/yr PV energy.

The intervention is modelled as an increase of the capacity of local photovoltaic (0,055 MW) and wind (0,006 MW) technologies which affects the electricity consumption of the zone 1 (residential and tertiary buildings).

- Scale-up criteria for the alternative scenario 2 (mySMARTLife interventions replication scenario):

The criteria used for the replication of this intervention is the same used in Action 1 because the intervention is applied in new constructed areas. Therefore, it is estimated that the annual increase of the capacity would be 2,16 MW for PV and 0,24 MW for wind.

- Action 5. PVs on roofs:

The intervention is focused on the installation of PV technology on the roof surface of buildings included in zone 1. PV potential of approximately 1800 kWp or 1530 MWh/yr. Additionally a potential of 600 kWp or 510 MWh could be generated, provided that the parking lots are canopied. Besides, in zone 2 following the same approach, PV potential is 30000 m^2. It is estimated that 20% of electricity could be substituted by photovoltaics.

The intervention is modelled as an increase of the capacity of local photovoltaic (2,4 MW) which affects the energy consumption of the zone 1 (residential and tertiary buildings). Besides, it is modelled that 20% of the electricity demand of the zone 2 is covered by solar PV.

- Scale-up criteria for the alternative scenario 2 (mySMARTLife interventions replication scenario):

The criteria used for the replication of this intervention is divided into two criteria depending on the area of actuation. For the first part of the intervention the area of actuation is zone 1 new constructed area and therefore the replication potential is defined according the scale-up factor defined previously for the Action 2. However, in this case it is considered that from all the new buildings constructed only 15% will have the same conditions in terms of adequacy of the roof space and orientation. This means that, it is considered an annual potential of 8,18 MW in all the new residential buildings and 10,6 MW of solar photovoltaic in all the new tertiary buildings.

In the second part of the intervention the replication potential is obtained considering the same 2% refurbishment rhythm and that the solar technology will cover 20% of the electric consumption of these buildings. This sums a total of 512 MW of solar PV capacity cumulated at the end of the period in 2050.

The Actions 4 and 5 are modelled simultaneously in LEAP as it can be seen in the figure below.

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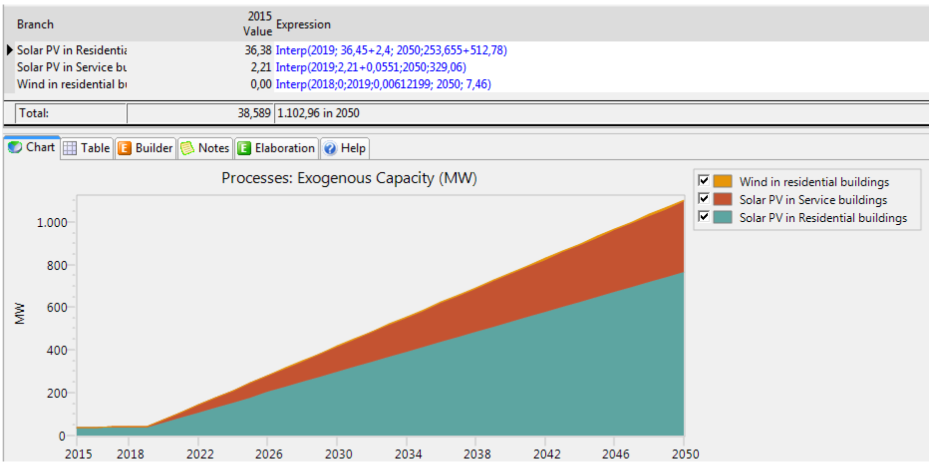

Figure 67: Solar PV and micro wind interventions modelled in Hamburg for the alternative scenario 2.

- Action 6. Solar Thermal:

This intervention is focused on the installation of solar thermal technology in zone 2 with a total power of 1350 MWh/yr and 34000 m^2 of panels. It is estimated that one third of heating demand could be substituted by solar thermal energy. The intervention is modelled as an increase of the capacity of the solar thermal technology of 1714 kW which will provide heat to the "Demand\Residential\Space Heating\Solar thermal" and "Demand\Residential\Water Heating" sections of the model.

  - Scale-up criteria for the alternative scenario 2 (mySMARTLife interventions replication scenario):

The replication criteria for the alternative scenario 2 is precisely 30% of the heating demand of the affected sector. Considering that in 2050 the heating demand of the BaU scenario is 11966 TJ, the estimated cumulative capacity of the solar thermal systems is 1403 MW in 2050.

- Action 7. Home batteries for self-consumption:

This intervention considers that the excess energy from PV modules in zone 1 is stored in 13 home batteries with 500 kWh of capacity (installed in 13 buildings). This intervention is directly modelled in combination with the Action 5 increasing the equivalent solar generation capacity.

The scale-up criterion is also inherently considered in the alternative scenario 2 of the Action 5.

- Action 8. Heating storage for load balancing. Buffer tank:

In this intervention a buffer tank will be installed in 79 buildings (new construction) zone 1 to store the excess energy from electricity form wind power plants or from the optionally installed biomass/biogas driven CHP plant. A total capacity of 1950 kWh is considered according to the data available which is already modelled in Action 4. The replication of this action is also considered in the replication potential of this intervention.

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The Actions, 9, 10, 11, 12, 14, 16 and 18 are not modelled in LEAP since there is no data enough to consider properly the energy saving potentials. Besides, the Action 13 is not modelled since in the moment of the study there is no information about the future development of this action.

- Action 15. Smart Street lighting:

The intervention is related to the implementation of 30 lighting assets with LED lamps in the zone 1. The calculated savings by the 30 lamps is 0,0189 TJ/year (estimations based on the data provided in dena deutsche energie agentur [41]). The intervention is modelled in the “Demand\Services\Public offices. Administration\Lighting” section of the model.

  - Scale-up criteria for the alternative scenario 2 (mySMARTLife interventions replication scenario):

This intervention is relatively small to see directly the effects in comparison with the total energy consumptions at city level. However, it has a high replication potential (127000 lamp in Hamburg) which is considered in the alternative scenario 2. Therefore, it is estimated that the maximum energy saving potential due to the replication of this intervention is 5,7 TJ/year until 2030 when it is considered that all the lamps will be LED.

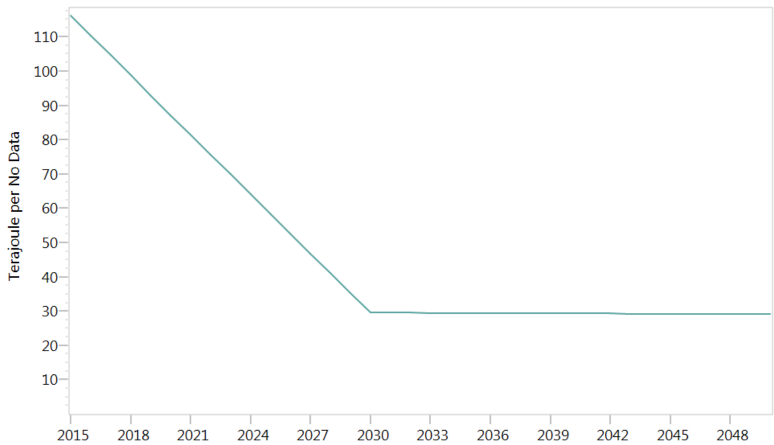

Figure 68: LED technology deployment modelled for the public lighting of Hamburg for the alternative scenario 2.

- Action 17. Large scale Solar Plant and Wind Turbines:

The action proposes the implementation of a wind farm close to the energy campus at schleusengraben (ZONE 1) with 5 turbines of a nominal power 13 MW. The interventions also consider a solar thermal plant in the south-east of zone 1, but at the moment of the study there is no enough information for this second part and has not been modelled for the moment. The wind farm is modelled in the “Transformation\RE Electricity generation” section as an increase of the capacity.

  - Scale-up criteria for the alternative scenario 2 (mySMARTLife interventions replication scenario):

In this case the capacity has been considered constant in the model also for the alternative scenario 2 since there is no a clear criterion for the replication of this intervention.

- Action 19. District Cooling storage (ice cooling).

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

The intervention is related to the implementation of a cooling storage at district level (Zone 1) with a total storage capacity of the 3000 m^3 of ice which comprises approximately 500 MWh capacity. The intervention is modelled in LEAP as direct reduction of the cooling energy consumption in the section "Demand\Services\Public offices. Administration\Cooling" of the model.

- Scale-up criteria for the alternative scenario 2 (mySMARTLife interventions replication scenario):

Based on the replication potential of the new constructed tertiary buildings (as considered in Action 2) it is observed that there is potential enough to cover the entire cooling demand (42,3 TJ in 2050) of the offices of the administration and the private offices. Therefore, in the alternative scenario 2 it is modelled as a linear reduction of the energy consumption of this subsector until 0 in 2040.

- Action 20. Decentralized battery solution:

The wind farm located in zone 1 will be complemented with a large-scale Li-Ion battery with a capacity of 1300 kWh and a charge/discharge power of 1.3 MW. The intervention is modelled combined with the wind farm of the Action 17 in which the capacity is increased in 0,795 kW. The replication of the intervention in the entire city in this case follows the same criteria as in Action 17.

- Action 21: Electrification of bus lines with 10 new e-buses:

The intervention includes ten new 12-meters electric buses that will be deployed. Moreover, a fast charging station will be implemented at central bus terminal. Considering that a diesel bus consumes 5,2 kWh/km and that a e-bus 1,7 kWh/km and that each bus works 70.000 km/year the obtained reduction of the energy intensity is 1,65%. On the other hand, it is also necessary to redefine the new share of fuels used in all the buses of the city (0,8% electricity consumption and 99,2% fossil fuels). This is included as a punctual intervention in Hamburg model in the "Demand\Transport\Road\Passenger\Buses" section.

- Scale-up criteria for the alternative scenario 2 (mySMARTLife interventions replication scenario):

In the alternative scenario 2 the replication potential of this intervention is based on the hypothesis of 30% e-buses in 2030 and 100% in 2050 which means a 4% annual reduction of the energy intensity until 2030 and 7% annual reduction until 2050.

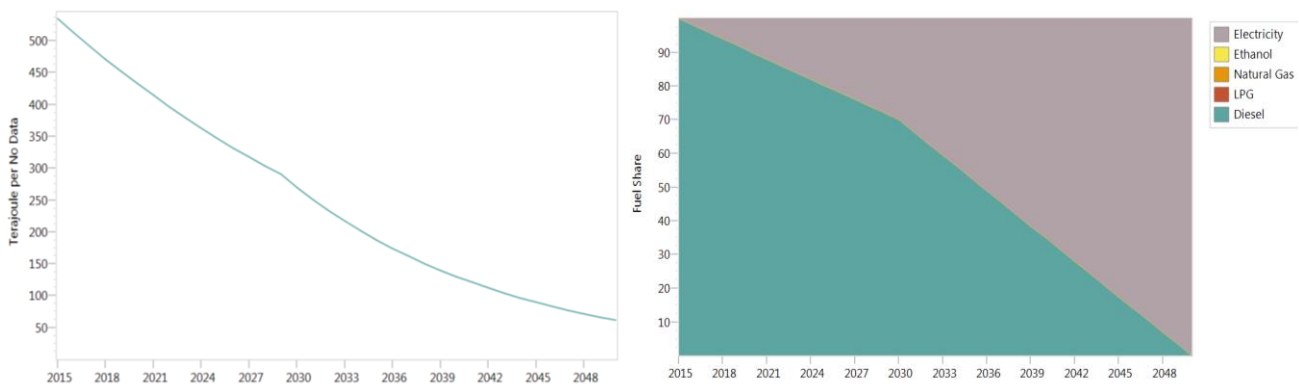

Figure 69: Reduction of the energy intensity (left) and new share of fuels consumed (right) by the buses in Hamburg in the alternative scenario 2.

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- Action 22. Electrification of public vehicle fleet (25 e-cars, 35 e-bikes, 10 last mile people movers) and Action 23. 15 e-cars and 15 e-bikes for e-community fleet sharing for new residential buildings

These interventions are modelled simultaneously and in a similar way to the previous action but in this case, it affects to the private vehicles. The new share of fuels for the alternative scenario 1 is 0,0018% electric and the total energy intensity reduction is 0,0146%.

  - Scale-up criteria for the alternative scenario 2 (mySMARTLife interventions replication scenario):

The replication scenario is obtained in this case considering that in the Hamburg Climate Plan describes that in 2020 5% and in 2030 25% of new car registrations will be zero emission cars and that there are approximately 135946 new cars/year. Therefore, the new share of fuels will include 0,5% (2020), 5,2 (2030) and 10,5% (2050) proportion of electricity. Besides, it is considered an annual reduction of the energy intensity of 0,8% until 2020 and of 4,12% until 2030.

Based on the described modelling of interventions the main characteristics of the obtained alternative scenarios are described in the following pages. The comparative analysis is showed more in detail for the case of the alternative scenario 2 (mySMARTLife interventions replication scenario) because in terms of total values the results are easier to understand and because in the case of the alternative scenario 1 in which several punctual interventions are modelled, the appreciation of their effects respect to the entire city energy development is more difficult.

The figure below shows the total energy demand in final units of the alternative scenario 2 respect to the BaU scenario. The expected energy consumption reduction (17% at the end of the period) due to the implementation and replication of all the interventions of the project considered can be clearly appreciated. It needs to be considered that this scenario only considers the replication of the actions implemented in the framework of the project and therefore the obtained effect cannot be as large as the total city objectives because there are many other strategies and interventions that are not part of the project but that will affect the future development of the city and will allow reaching its targets.

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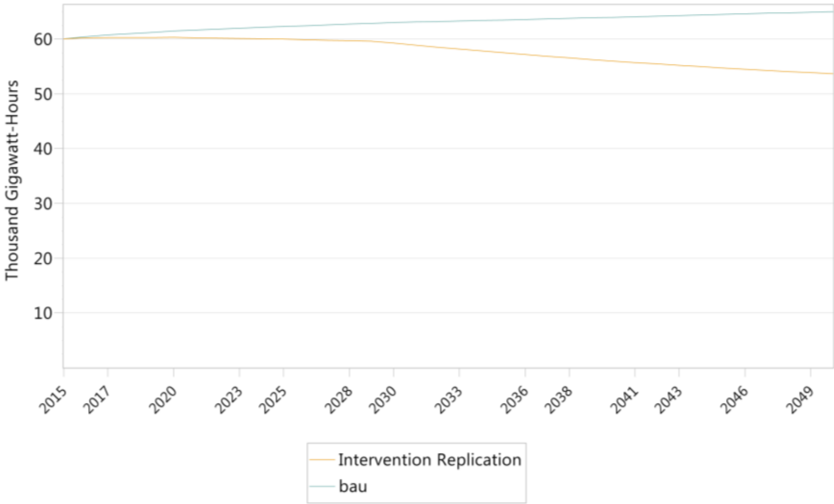

Figure 70: Total energy consumption comparison of the demand sector of Hamburg (BaU scenario vs mySMARTLife interventions replication scenario)

Evaluating more in detail the residential sector the energy reduction potential due to the replication of interventions is higher (34%). The main reduction is obtined in this case in the heating demand that will be reduced due to the new constructed building high performance and due to the gradual refurbishment of buildings.

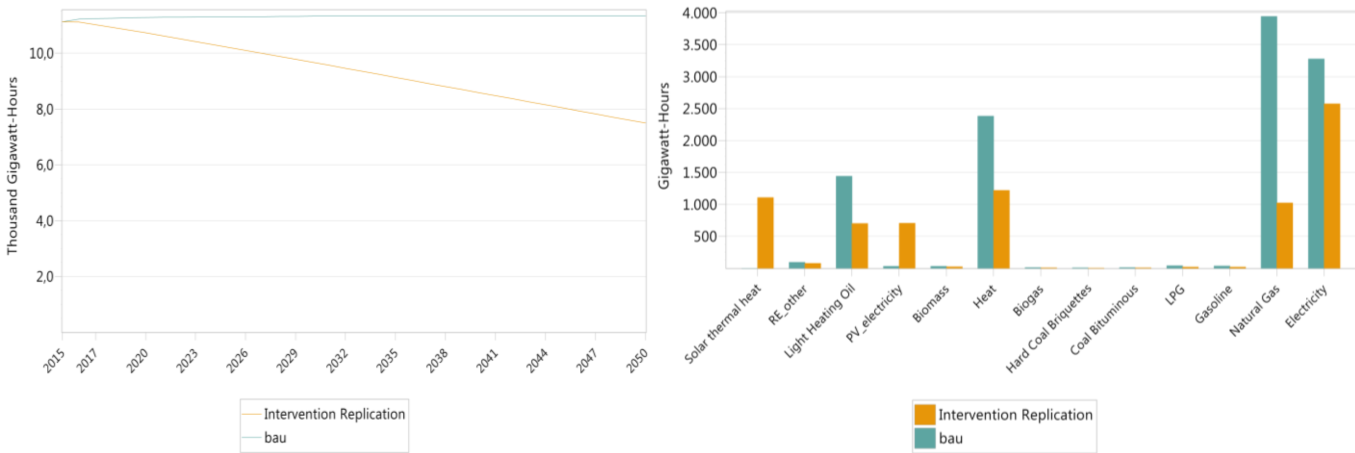

Figure 71: Total energy consumption (left) and energy source details (right) scenario comparison for the residential sector of Hamburg (BaU scenario vs mySMARTLife interventions replication scenario)

It is also appreciated the reduction of the use of several fuels such as the natural gas, imported electricity, light fuel oil and heat and the increase of some others related to the renewable energy generation such as the solar PV, wind or solar thermal.

Regarding the service sector, the obtained energy reduction at the end of the period is 15% lower than the obtained in the residential sector and the observed in the transport sector which is 28% in 2050 mainly due to the e-mobility interventions considered. As explained before there are other type of actuations that can reduce

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

considerably this energy consumption in Hamburg such as the change in the modal split through an increase of the use of public transport, walking and cycling that are not modelled in this scenario.

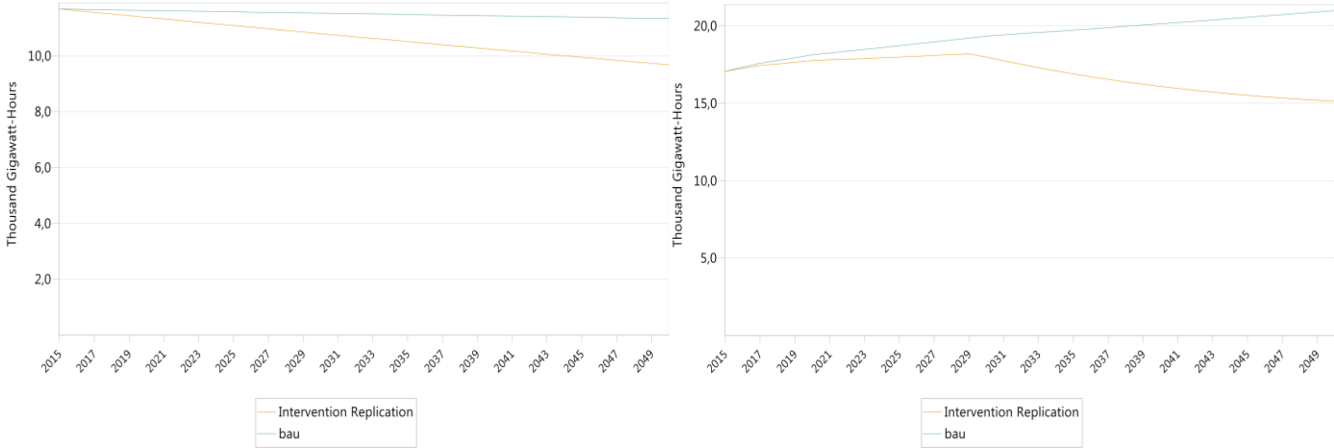

Figure 72: Total energy consumption of the service sector (left) and of the transport sector (right) comparison in Hamburg (BaU scenario vs mySMARTLife interventions replication scenario)

The transformation sector also shows some changes in the alternative scenario 2 respect to the BaU scenario. In this case the energy generation mix is transformed towards a higher share of renewables and lower imports.

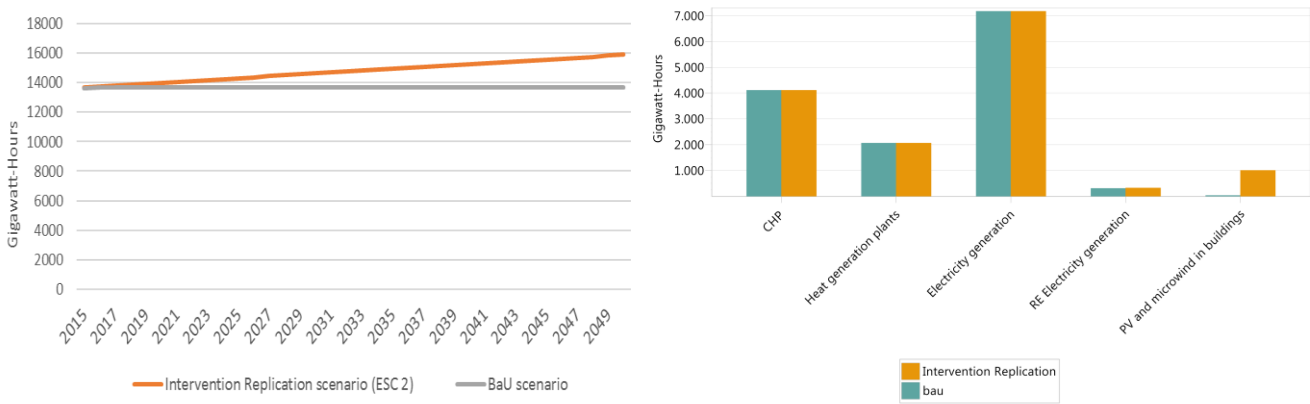

Figure 73: Transformation Outputs by feedstock fuel (left) and energy generation by technology in the year 2050 (right).

The figures presented in this report are just an example of the outputs of the model developed for the city. In any case, it needs to be understood that the main result is the model itself that allows the analysis of the effects that can be obtained due to the deployment and replication of the interventions of the mySMARTLife project. This is a dynamic model that could be updated in the case that an extra analysis is needed.

As a summary of the alternative scenario 2 the new Sankey diagram is presented in the followign figure for the year 2050.

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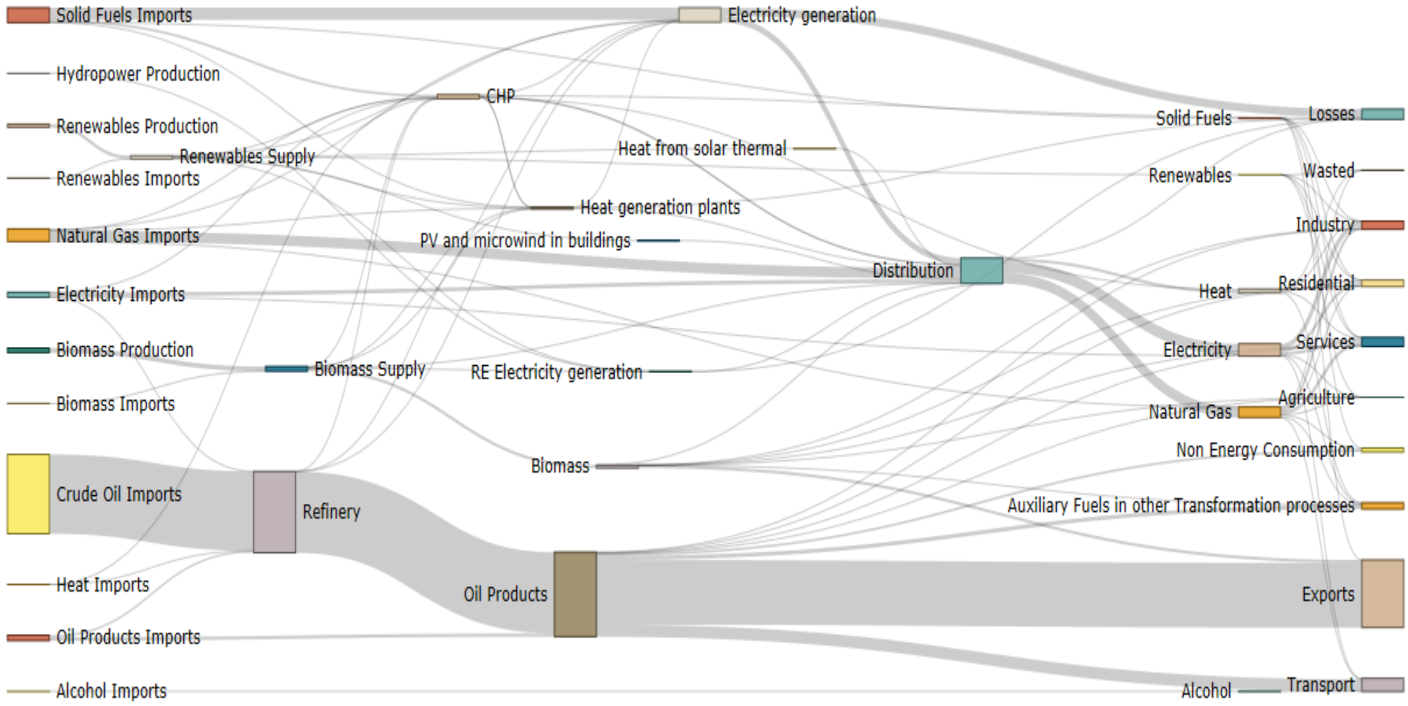

Figure 74:Sankey diagram of Hamburg in 2050 for the mySMARTLife interventions replication scenario.

6.3 Scenario analysis for Helsinki

In the case of Helsinki, the energy model has been created 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 of Helsinki

As described for the case of Nantes and Hamburg, the first step followed for the definition of the BaU scenario of Helsinki is to understand the potential relation between different socioeconomic parameters and other type of characteristics of the city with the energy consumption of the city. In this case the relation between the drivers and the energy consumptions has also been carried out per each sector.

In terms of the data sources evaluated for the analysis of the historic evolution of the main drivers and energy consumptions the followings have been considered:

- **Eurostat** [39]**:** Energy prices for Finland are available in Eurostat distinguishing between the prices for different fuels and for different final users. Besides, other information such as the GDP, the VA and the income are available.
- **Urban Data Platform** [35]: This data base provides several socioeconomic parameter's historic evolution and expected projection for different European urban locations. In this case, data related the GDP/Cap, population and constructed area and average travel distances have been evaluated.

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- **Helsinki's 2030 Climate Technologies, City Performance Tool** [25]**:** This source provides the expected values for different time horizons until 2050 for several parameters that have been evaluated as potential drivers and for the comparison of the obtained projections; Sectoral disaggregated energy consumptions of the city, projections of the expected surface occupied by different type of buildings, future share of the fuels of the energy generation plants and energy consuming sectors, etc.

6.3.1.1 Analysis of the correlations with the energy demands and driver selection for the definition of the BaU Scenario

This subsection includes a summary of the process followed for the analysis of this relation and the final selection of the driver or the general tendency of the energy consumptions of Helsinki.

- Residential sector:

Although several drivers have been evaluated for the residential sector, the one that shows the best correlation is the m^2 of households of Helsinki. The figure below shows the main factor affecting the linear correlation index. Other drivers such as the electricity price, GDP/cap or GDP have been also evaluated but the obtained correlation is in all the cases lower in comparison with the surface of households.

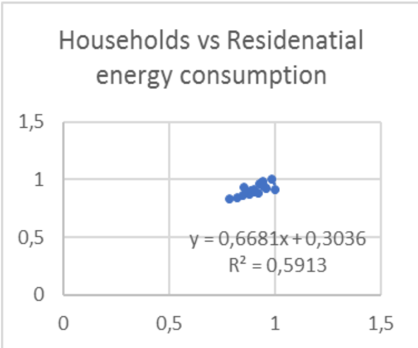

Figure 75: Analysis of the relation between the tendency of the residential sector energy (electricity) consumption with the potential driver (m^2 of households) for Helsinki.

Therefore, the tendency of this parameter is evaluated more in detail. The historic data shows that its development follows a relatively good linearity in the long-term. This is the reason why one of the most direct criteria for the projection of this parameter is to follow the tendency as it is shown in the first option of the figure below.

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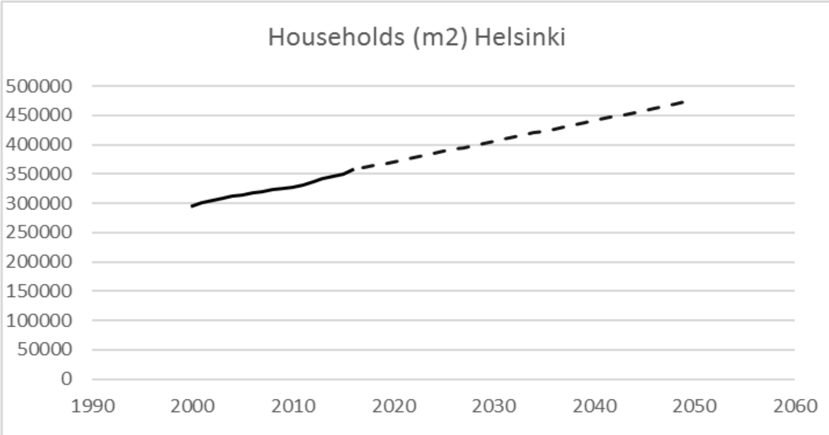

Figure 76: Households projection options for Helsinki. Linear projection based on the historic data.

It is concluded that the energy consumption of the residential sector will have the following tendency in LEAP;*Interp(2010;328164;2015;350314;2016;356975;2017;360478;2018;363981;2019;367483;2020;370986;2025;388500;2030;406014;2050;476070,2).*

- Industrial sector:

Following the same procedure for the industrial sector, the main drivers evaluated are the GDP, the GDPP and the electricity price. In this case the energy consumption and the electricity consumption are distinguished. From the analysis, it is observed that in the case of the electricity consumption the best linear correlation index is obtained with electricity price. On the other hand, in the case of the heat consumption, the best correlation is obtained with the GDPP. Therefore, the drivers selected in this case are both the electricity price and GDPP for the industrial electricity consumption and for the heat consumption respectively.

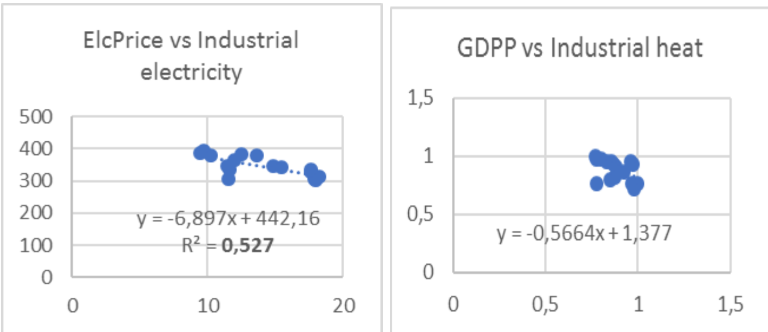

Figure 77: Analysis of the relation between the tendency of the industrial sector energy consumption and the potential drivers for Helsinki.

The figure below shows the projection used for the heat consumption of the industrial sector of Helsinki.

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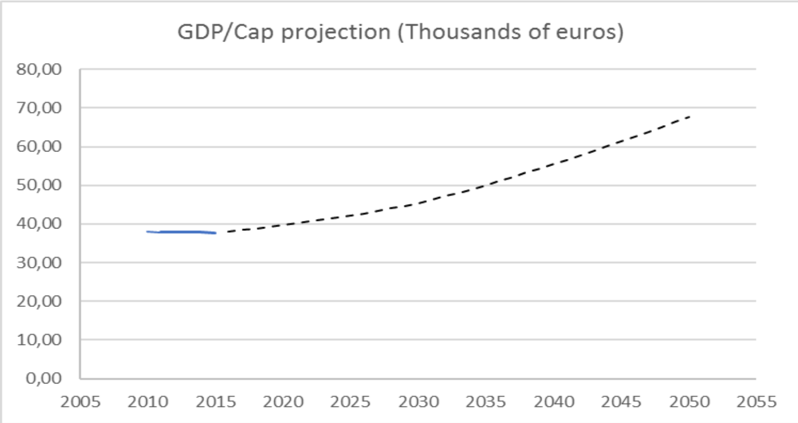

Figure 78: Projection of the GDP/cap of Helsinki that is used to define the projection of the industrial heat consumption of Helsinki.

On the other hand, the following figure shows the tendency adopted for the electricity price for Finland (according to the data available in Eurostat) which is based on the tendency followed in the last years. This tendency is used to project the electricity consumption of the industrial sector of Helsinki.

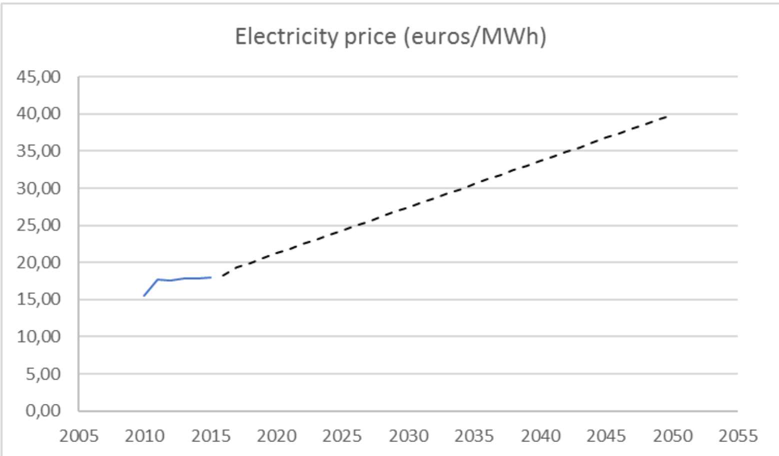

Figure 79: Projection of the electricity price in Finland that is used to define the projection of the industrial electricity consumption of Helsinki.

- <u>Mobility sector:</u>

Transport sector´s projection is divided in this case into different projections to distinguish the different modes of transport. The figure below shows the solution adopted and describes the driver selected for each case.

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Passenger:

Two wheels	63,06	GrowthAs(Key\GDPP)
Cars	1.361,11	GrowthAs(Key\Cars fleet)
Bus	202,50	GrowthAs(Key\Population)
Mopoautos	5,28	GrowthAs(Key\GDP)

Tramway	Electricity	1.046,12	GrowthAs(Key\Population)
Metro	Electricity	521,56	GrowthAs(Key\Population)
Regional Commuter	Electricity	304,24	GrowthAs(Key\Population)

Freight:

Trucks	324,72	GrowthAs(Key\GDP)
Light Utility Vehicles	177,22	GrowthAs(Key\GDP)
Rail	4,73	GrowthAs(Key\GDP)

Figure 80: Driver associated to each transport mode for the BaU scenario of Helsinki.

Therefore, different drivers (population, GDP, GDPP, cars fleet) have been evaluated respect to the disaggregated energy consumptions of the transport sector. However, the best correlation is obtained with the GDPP for the Two wheels vehicles, with the projection of the cars fleets for cars, with the population for the public transports, with the GDP for the freight transport modes.

Once that this relation has been established, the projections of each driver are obtained. The GDPP projection has already been showed above and the following figure shows both the population and GDP projections according to the sources mentioned initially.

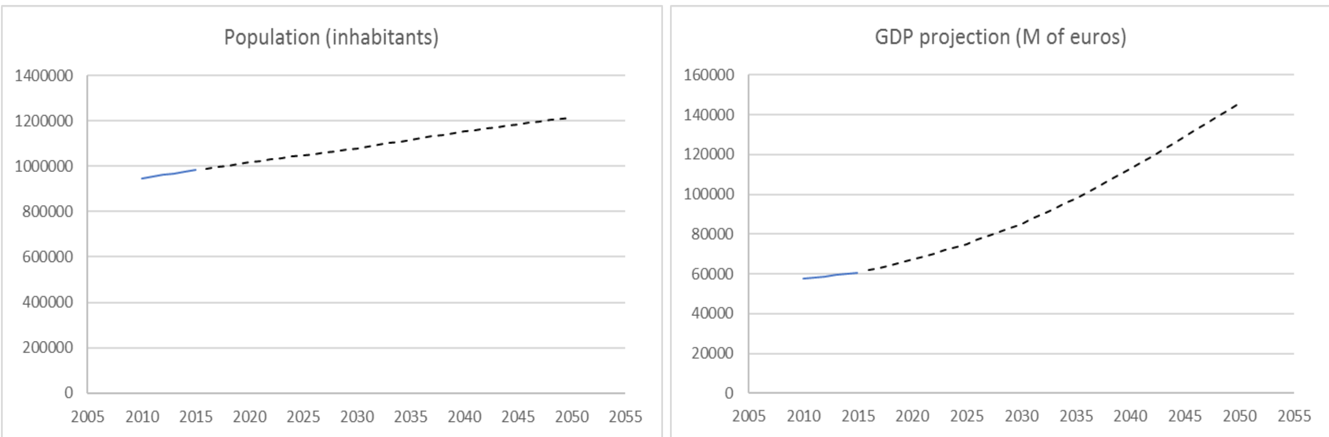

Figure 81: Driver projection (population left and GDP right) considered for the BaU scenario of Helsinki in the transport sector.

For the projection of the number of vehicles, the tendency of the last 15 years has been evaluated and it is observed that the interannually increase is relatively stable as it is showed in the figure below. Therefore, for the following years 2% average growth has been considered for the BaU scenario in the model.

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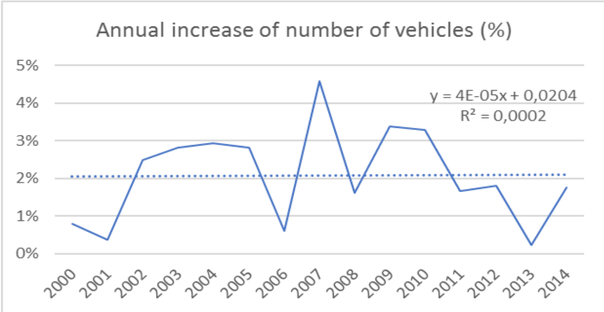

Figure 82: Annual increase of the number of vehicles considered for the projection of the number of vehicles in the BaU scenario of Helsinki.

- <u>Service and municipality sectors:</u>

In the case of the service and municipality sectors several drivers have been evaluated, the electricity price, GDPP, GDP and household projection among others. However, as it is observed in the figure below the one that shows the best correlation is the GDPP and this is precisely the one that is used for BaU scenario modelling.

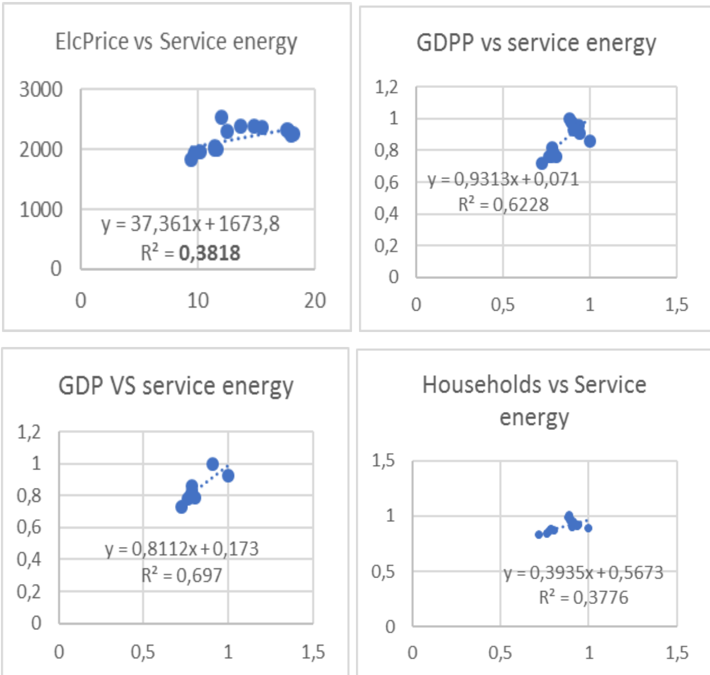

Figure 83: Analysis of the relation between the tendency of service and municipality sector´s energy consumption and the potential drivers for Helsinki.

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 Helsinki the BaU scenario is modelled in LEAP. Based on these projections the energy consumptions as well as the energy generation, exportation and importations are calculated until 2050. The following figure 83-left show the expected energy consumptions and generations for the scenario in which no extra measures are considered.

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The figure 83-right below distinguishes the sectoral energy consumption evolution for Helsinki for the same scenario.

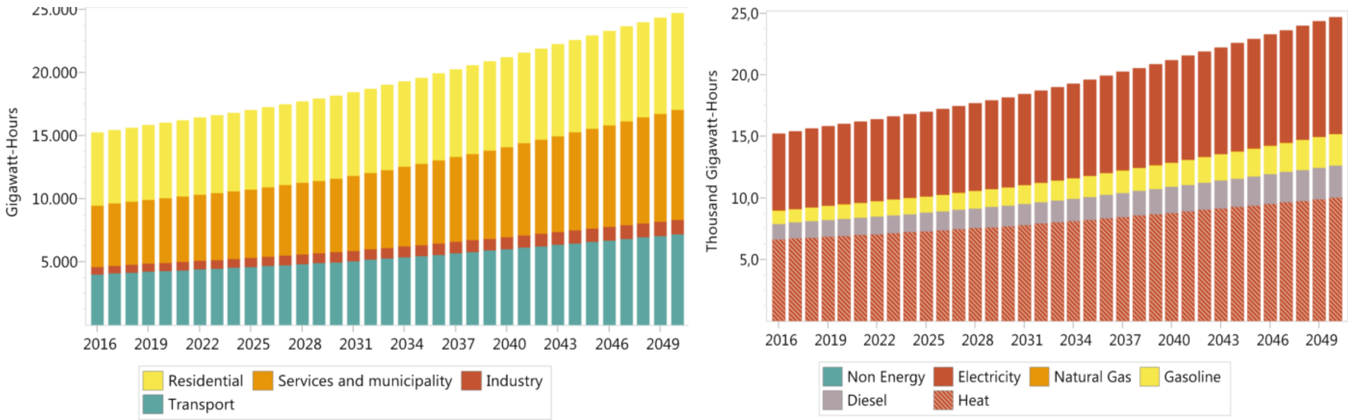

Figure 84: Projection of the sectoral final energy consumption (left) and energy consumption by fuel (right) in Helsinki for the BaU scenario.

Besides, the following figure distinguishes the primary requirements for each sector in the BaU scenario for the year 2050.

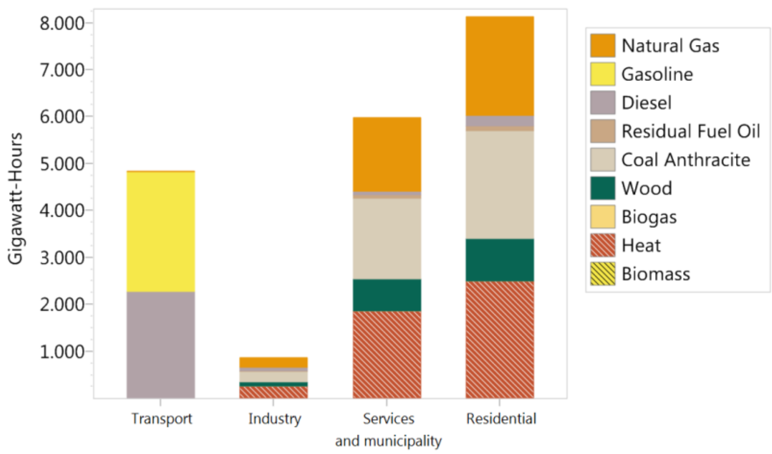

Figure 85: Primary requirements allocated to demands in Helsinki for the BaU scenario in the year 2050

The figure below show the local energy generation in Helsinki for the BaU scenario for the year 2050 by generation plant and the input fuels required in each of them.

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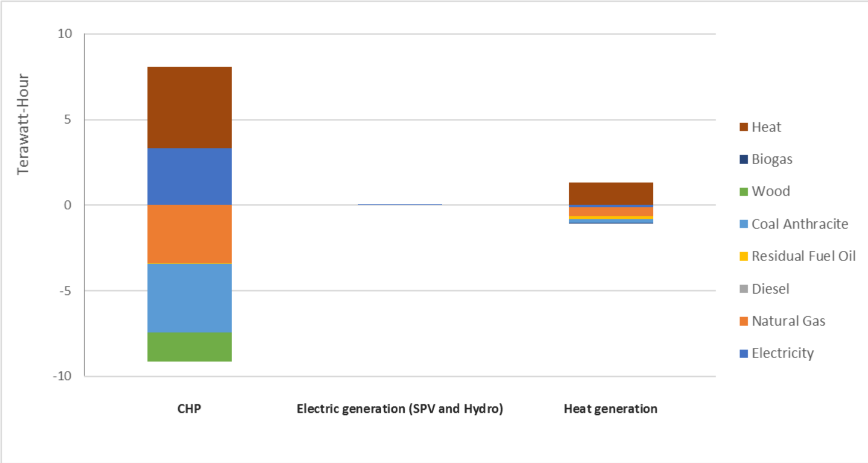

Figure 86: Energy input needs and energy generation in each of the local energy generation plants in Helsinki for the BaU scenario in the year 2050.

The energy generation for the next decades follows the same tendency as the energy consumption and is adapted according to their current and planned capacities to supply the new demand. In order to understand better the energy generation by energy plant and by type fuel, as well as how it corresponds to the energy consumption by sector, the sankey diagram for Helsinki in the year 2050 is showed in the figure below.

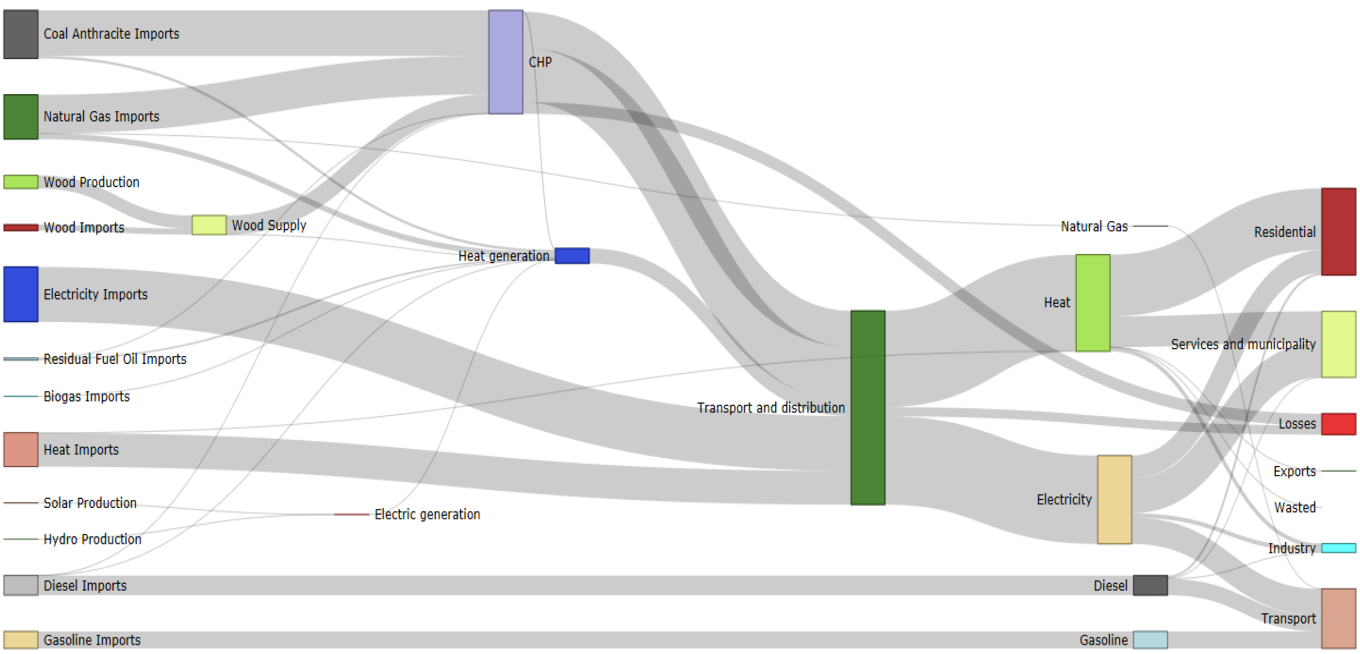

Figure 87: Sankey diagram of Helsinki BaU scenario in the year 2050.

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6.3.2 Alternative scenarios for Helsinki

This subsection describes the two alternative scenarios developed for Helsinki. The first one correspond to the, *mySMARTLife intervention scenario* and the second one to the *mySMARTLife interventions replication scenario*.

6.3.2.1 Analysis of the interventions of the city and alternative scenarios modelling

The first scenario is based on the interventions that were planned initially for the city in the framework of the project. Therefore, from the total list of interventions to be implemented in Helsinki, the way of modelling them into the global model created in LEAP is described here.

- Action 1. Multi-owner residential building - Merihaka and Vilhonvuori:

The action focuses on the retrofitting of 167 flats in which the installation of smart controls for management of apartment level heat and electricity demand will be carried out. The expected energy savings considered are provided in the project and can be seen in the table below.

Table 43: Expected energy savings due to the implementation of the Action 1

Current normative heating demand	Future heating demand	Energy savings including interventions
19318 MWh/yr	13523 MWh/yr	5795 MWh/yr - 30%
167 kWh/m2yr	117 kWh/m2yr	

Therefore, this intervention affects both the heating and the electricity consumption of the residential buildings and it is modelled in LEAP for the mySMARTLife intervention scenario as a punctual reduction of the energy consumption in the sections “Demand\Residential\Private residences\Housing blocks\Space Heating and DHW” and “Demand\Residential\Private residences\Housing blocks\Others” of the model. The intervention is introduced in two different periods, the first one assumed in 2018 (savings of 0,73149 GWh in heat and savings of 0,12736 GWh in electricity) and the second one in 2021 (savings of 5,0635 GWh in heat and savings of 0,88164 GWh in electricity).

  - Scale-up criteria for the alternative scenario 2 (mySMARTLife interventions replication scenario):

For the alternative scenario 2, the replication potential of the intervention in other areas of the city needs to be considered. In this case the potential needs to be limited for the residential sector by using an scalation factor of 0,007592 (obtained with the relation of the action 1 and the total energy consumption of the affected subsector 2544,4 GWh) for heat and 0,0215 (obtained with the relation of the action 1 and the total electricity consumption of the affected subsector 46,872 GWh) for electricity and with the hypothesis of an annual 2% retrofitting rhythm.

- Action 2. Kalasatama High-Performance residential buildings:

This second action is focused on increasing the requirements respect to the already strict national regulation in 4355 flats (986 in 2017, 574 in 2018, 1071 in 2019, 702 in 2020 and 1022 in 2021). From the design data of the intervention an (saving) improvement factor of 0,45 is observed and then expanded to the number of flats implemented in each year. In this way the following table is obtained which is modelled in

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“Demand\Residential\Private residences\Housing blocks\Space Heating and DHW” and “Demand\Residential\Private residences\Housing blocks\Others” sections of the model of Helsinki.

Table 44: Energy savings due to the Action 2 for each of the years affected.

Energy savings (MWh/yr)	2017	2018	2019	2020	2021
Electricity					
Scenario ALT 1	605,18	352,31	657,36	430,87	627,28
Heating					
Scenario ALT1	1559,94	908,12	1694,42	1110,63	1616,9

- <u>Scale-up criteria for the alternative scenario 2 (mySMARTLife interventions replication scenario):</u>

For the alternative scenario 2, in this case due to the lack of data the same scalation criteria than in the case of the Action 1 is used for both the heating and the electricity consumptions. This action combined with the Action 1 is modelled jointly in LEAP. The following figure shows the projection result for the heating energy consumption.

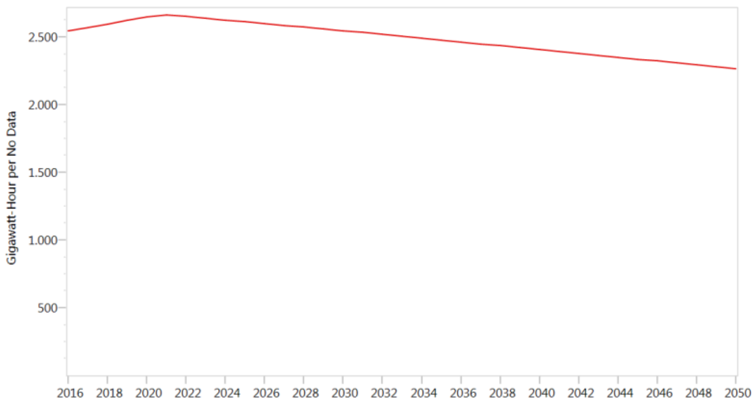

Figure 88: Expected reduction of the district heating energy consumption reduction due to the replication of the Action 1 and 2 in the alternative scenario 2.

- <u>Action 3. Vikki environment House:</u>

This intervention is related to the most energy efficient building in Finland. The energy savings data considered are the ones showed in the table below which have been modelled in the sections “Demand\Residential\City owned buildings\Housing blocks\Space Heating and DHW” and “Demand\Residential\City owned buildings\Housing blocks\Others” of the model as a punctual energy consumption reduction.

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Table 45: Energy savings due to the Action 2 for each of the years affected.

Current normative heating demand	Future heating demand	Energy savings including interventions
645,82 MWh/yr	212,6 MWh/yr	433,22 MWh/yr - 67%
95,1 kWh/m2yr	31,3 kWh/m2yr	

- Scale-up criteria for the alternative scenario 2 (mySMARTLife interventions replication scenario):

For the alternative scenario 2, in this case due as this action is applied in a municipality owned building, it has been modelled its effect based on the hypothesis that can be extended by 2050 to all municipality buildings.

- Action 4. Demonstration of smart home management (heat demand response) at apartment level at Merihaka/Vilhonvuori:

In this intervention a total of 167 flats will be equipped with smart thermostats connected to the district heating through IoT and cloud based intelligence to load balance the network. These actions are expected to reduce the total energy consumption by 10-15%. Therefore, based on the energy consumption of these buildings, it is modelled that a total of 0,1097 GWh/year is saved. The intervention is modelled in the year 2021 in the section "Demand\Residential\Private residences\Housing blocks\Space Heating and DHW" of the model.

- Scale-up criteria for the alternative scenario 2 (mySMARTLife interventions replication scenario):

For the alternative scenario 2, in this case the same scalation criteria than in the case of the Action 1 is considered.

- Action 8: Viikki Environment House RES production.

This intervention is related to the implementation of solar panels placed on the façade and roof have a combined area of 572 m² and production capacity of 60 kW_{peak}, which accounts for 20% of the building's energy needs. This intervention is modelled in LEAP based on the data available (7,72% de maximum operating hours factor, 15% of technical efficiency and 2600 hours of capacity factor). This intervention is directly modelled as an increase of the solar generation capacity in the section "Transformation\Electric generation\Processes\Viikki building PV panels" of the model.

- Scale-up criteria for the alternative scenario 2 (mySMARTLife interventions replication scenario):

This intervention is replicated for the alternative scenario 2 considering that it is implemented in municipality owned buildings that are intervened. As in the previous case it is considered that before 2050 all buildings of this type will be affected (with a total future energy consumption of 484,65 GWh/year). Considering the energy consumption of the building affected the scalation factor considered is 1/0,00133 which gives an increase of the capacity of the solar photovoltaics of 45,02 MW at the end of the period.

- Action 12: Business model development for the compensation of reactive power - with solar power at solar plants Kivikko.

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Based on the interpretation of this action a new solar technology based plant has been created in the model which increases the capacity of PV by 50 kW.

- <u>Scale-up criteria for the alternative scenario 2 (mySMARTLife interventions replication scenario):</u>

The replication of this action has been previously considered in the expansion of the SPV technology in Action 8.

- <u>Action 15: Smart dynamic public lighting up-take.</u>

This intervention is related to the implementation of dynamic LED based outdoor lighting systems to replace the current gas-discharged lamps. It is modelled directly in the alternative scenario 2 in which it is considered that in 2030 all the public lighting will be covered by LED technology. The energy intensity factors used for the analysis are showed in the figure below for each type of lamp and technology.

Final Energy Intensity: Annual final consumption of energy per unit of activity level. [Default="0"]

Branch	Fuel	2016 Value	Expression	Scale	Units	Per
Mercury lamps	Electricity	0,62	0,62		Megawatt-Hour	per Device
High pressure sodiur	Electricity	0,60	0,60		Megawatt-Hour	per Device
New High pressure s	Electricity	0,50	0,50		Megawatt-Hour	per Device
Xenon lamps	Electricity	0,04	0,04		Megawatt-Hour	per Device
Induction lamps	Electricity	0,33	0,33		Megawatt-Hour	per Device
Fluorescent lamps	Electricity	0,20	0,20		Megawatt-Hour	per Device
Halogen lamps	Electricity	0,35	0,35		Megawatt-Hour	per Device
New Halogen lamps	Electricity	0,31	0,31		Megawatt-Hour	per Device
LED lamps	Electricity	0,30	0,30		Megawatt-Hour	per Device

Figure 89: Energy intensities considered for each type of technology used in Helsinki for public lighting.

Based on these energy intensities the share of the use of each technology changes towards 0 in the year 2030 as it is showed in the next figure. Therefore, the energy savings obtained with the complete implementation and replication of this action is of 21,4718 GWh.

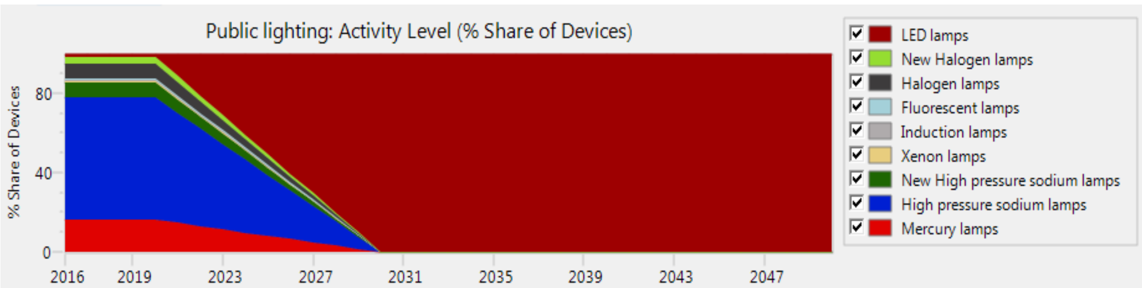

Figure 90: Share of use of each type of technology Helsinki´s for public lighting.

- <u>Action 17: Solar power plant implementation for Korkeasaari zoo.</u>

In this action a new solar technology based plant has been created in the model which increases the capacity of PV in 200 kW.

- <u>Scale-up criteria for the alternative scenario 2 (mySMARTLife interventions replication scenario):</u>

The replication of this action has been previously considered in the expansion of the SPV technology in Action 8.

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- Action 19: Optimise the storage system in the DH and cooling (10% heating savings, 12% cooling and 15% peak demands).

This action is applied in the “city owned buildings\housing blocks\DH” section of the model by a 10% reduction of the heat energy consumption (1,2482 GWh) which affects the zone 4 and that has been modelled in the year 2021.

  - Scale-up criteria for the alternative scenario 2 (mySMARTLife interventions replication scenario):

For the replication of this intervention it has been considered that the scalation factor between this intervention (energy consumption of zone 4) and the total energy consumption of this type of buildings in the city is 1/0,059. This is the factor that has been used in the section “City owned building\Housing block\Space heating and DHW” of the alternative scenario 2.

- Action 21: Electric bus up take.

This intervention considers the deployment of e-buses in Helsinki. The table below shows the implementation rhythm considered in the model.

Table 46: Expected e-buses deployment in Helsinki.

Large-scale up-take of electric buses in Helsinki region				
2016	2017	2020	2022	2025
3	12	140	260	390

This intervention has been modelled considering an energy intensity of 14,9 MJ/km for traditional diesel buses, 20 MJ/km for CNG buses and 3,05 MJ/km for e-buses and adapting the share of each type of buses in the following years (30% for 2025).

  - Scale-up criteria for the alternative scenario 2 (mySMARTLife interventions replication scenario):

The intervention replication has been modelled by assuming the same deployment rhythm defined until 2025 which has been extended in the same proportion.

- Action 28: Smart personal EV charging - demonstrate dynamic load balancing of the EV charging stations optimized to low-cost electricity hours of the private Evs.

In this intervention the deployment of e-cars in Helsinki is considered. Due to the lack of specific data the assignation criteria considered is the comparison of the energy consumption of the zones 1 and 2 respect to the entire city (0,00903) and it is assumed that in 2030 30% of the fleet will be electric. Based on the analysis the energy consumption reduction associated to the interferential is 4,15 GWh with the corresponding change of the fuel share.

  - Scale-up criteria for the alternative scenario 2 (mySMARTLife interventions replication scenario):

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For the replication of the intervention the proportion of the zone 1 and 2 respect to the entire city which gives an expression of “Interp(2030;1914,622-(0,84*(1914,622-1454,79)))” that is included in the model in combination with the new shares by fuels in 2030; 50% gasoline, 10% diesel, 30% electric and 10% NG.

Based on the described modelling of interventions the main characteristics of the obtained alternative scenarios are described in the following pages. The comparative analysis is showed more in detail for the case of the alternative scenario 2 (mySMARTLife interventions replication scenario) considering that in the case of the alternative scenario 1 in which several punctual interventions are modelled, the appreciation of their effects respect to the entire city energy development is less representative.

The figure below shows the total energy demand in final units of the alternative scenario 2 respect to the BaU scenario. The expected energy consumption reduction (14% at the end of the period) due to the implementation and replication of all the interventions of the project considered can be clearly appreciated. As explained for the case of the previous cities, it needs to be considered that this scenario only considers the replication of the actions implemented in the framework of the project and therefore the obtained effect cannot be as large as the total city objectives because there are many other strategies and interventions that are not part of the project but that will affect the future development of the city and will allow reaching its targets.

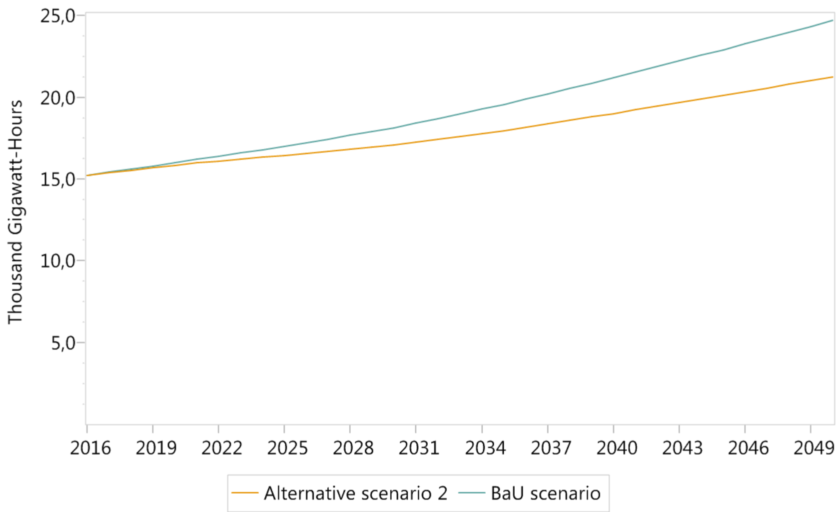

Figure 91: Total energy consumption comparison of the demand sector of Helsinki (BaU scenario vs mySMARTLife interventions replication scenario)

Evaluating more in detail the residential sector the energy reduction potential due to the replication of interventions is higher (22%). The main reduction is obtined in this case in the heating demand that will be reduced due to the new constructed building high performance and due to the gradual refurbishment of buildings.

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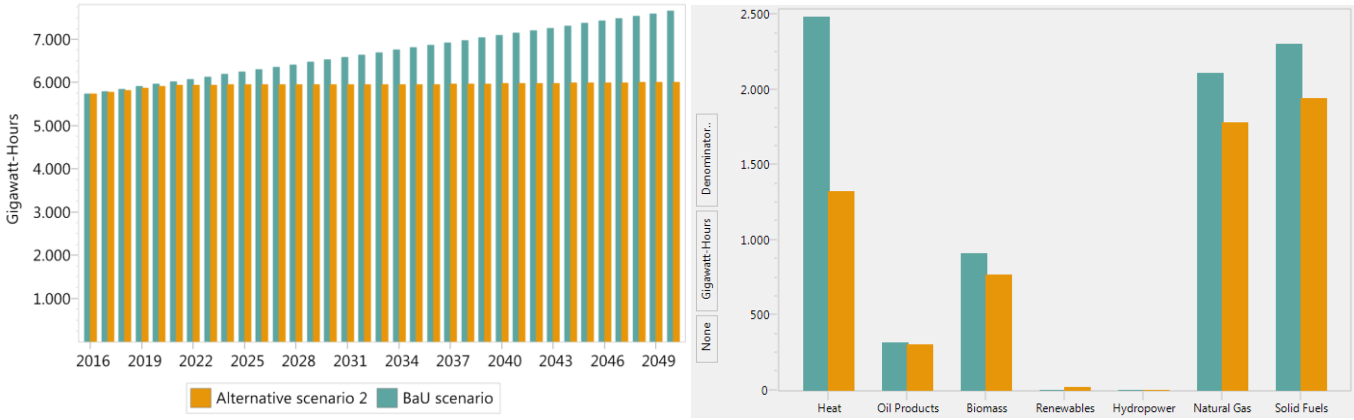

Figure 92: Total energy consumption (left) and energy sources detail (right) comparison of the residential sector of Helsinki (BaU scenario vs mySMARTLife interventions replication scenario)

It is also appreciated the reduction of the use of several fuels such as the coal or the natural gas and the use of district heating heat and the increase of some others related to the renewable energy generation such as the solar photovoltaic.

Regarding the services and municipality sector the obtained energy reduction is low since the replication of actions has been concentrated in the residential sector. In the transport sector on the other hand the obtained reduction in the final energy consumption is 24% in 2050 mainly due to the e-mobility interventions considered. As explained before there are other type of actuations that can reduce considerably this energy consumption in Helsinki such as the change in the modal split through an increase of the use of public transport, walking and cycling that are not modelled in this scenario.

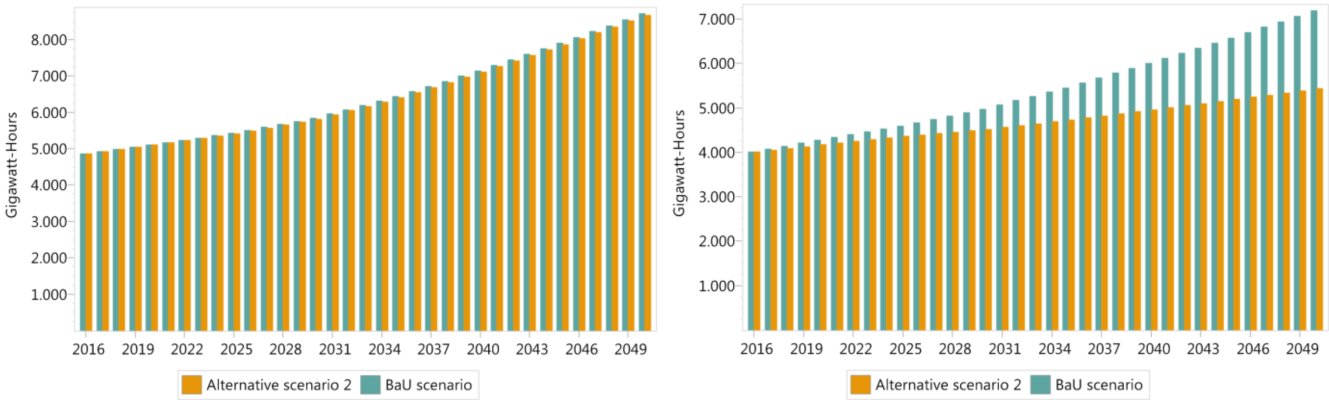

Figure 93: Total energy consumption of the service sector (left) and of the transport sector (right) comparison in Helsinki (BaU scenario vs mySMARTLife interventions replication scenario)

The transformation sector also shows some changes in the alternative scenario 2 respect to the BaU scenario. In the figure below it is observed on the one hand that the local energy generation increases in the alternative scenario 2 due to the massive expansion of the solar PV technology. On the other hand, the distribution losses are reduced because the local generation increases and the energy import needs are reduced.

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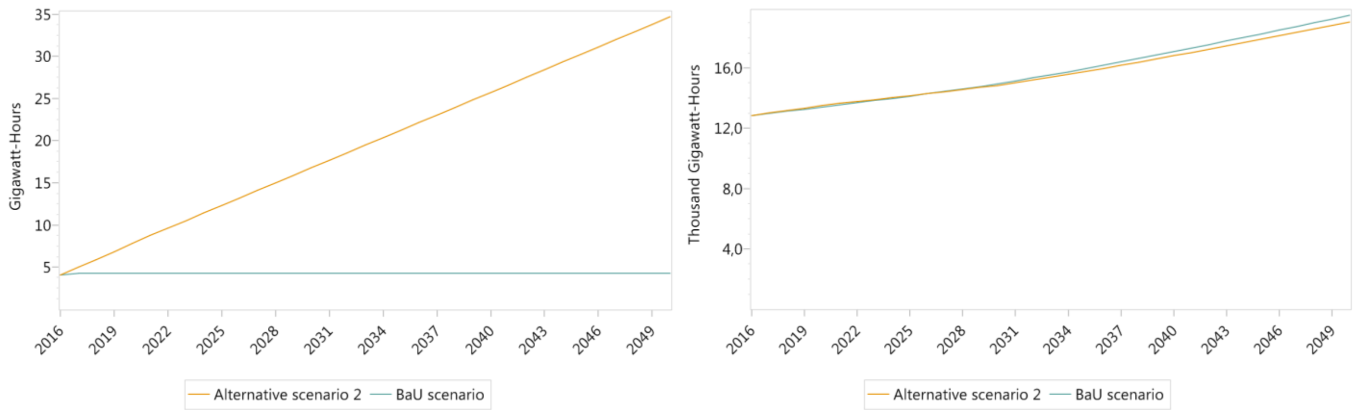

Figure 94: Local (only solar and hydro) energy generation in final units (left) and transport and distribution energy losses (right) comparison in Helsinki (BaU scenario vs mySMARTLife interventions replication scenario)

The figures presented in this report are just and example of the outputs of the model developed for the city. In any case, it needs to be understood that the main result is the model itself that allow the analysis of the effects that can be obtained due to the deployment and replication of the interventions of the mySMARTLife project. This is a dynamic model that could be updated in the case that extra analysis is needed.

As a summary of the alternative sncenario 2 the new sankey diagram is presented in the following figure for the year 2050.

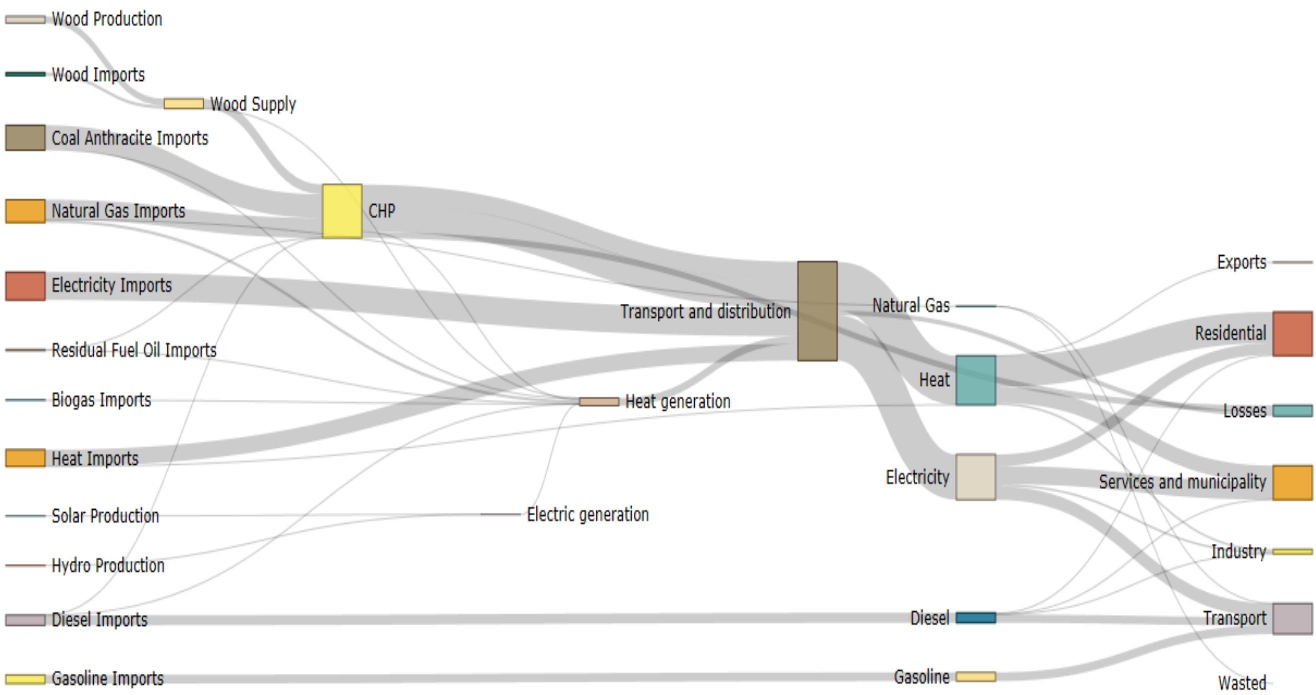

Figure 95:Sankey diagram of Helsinki in 2050 for the mySMARTLife interventions replication scenario.

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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 lighthouse 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 follower cities in the WP6 and in other cities out of the scope of the project. The methodological description provided in the initial sections of the deliverable allow 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 (considering only some of the sector or considering only the electric sector). In the study carried out and described in this subtask, all the steps of the scenario modelling have been described to facilitate its replication.

In terms of the analysis carried out, it can be concluded that the first step (base year modelling) is critic since the level of detail and flexibility of the scenario developments will depend on it. Here, the relation between the analyst and the data providers (municipalities and energy companies) is essential to gather and verify all the data used for the initial energy balance of the city. One of the difficulties identified in the process is the lack of standardization of the energy data of different cities. Here, different classification of sectors, as well as the different level of detail and disaggregation of the energy consumptions and generations in each city increases the difficulty of the analysis. Besides, this increases the difficulty for comparing the results of different cities. This issue has been overcome with the use of a similar structure of the sectors definition tree in LEAP software.

It has also observed that the identification and selection of the main drivers for each of the sectors of each city is a critical step of the scenario development, mainly for the BaU scenario since small variations in the inputs create relatively large differences in the long-term tendencies. In any case, it needs to be considered in this type of analysis that the BaU scenario is mainly developed in order to have a baseline in which the improvements obtained with the alternative scenarios can be compared. Needs to be mentioned also that in this type of forecasting analysis, the figures given must be understood as orders of magnitude or tendencies and not as exact values.

Regarding the alternative scenarios, two different scenarios have been evaluated for all the cases. This has been necessary because the specific effects of the alternative scenario one (which considers only the punctual implementation of the interventions of the project) are difficult to perceive and evaluate. Therefore, a second alternative scenario has been modelled and evaluated for all the cases to evaluate the effect that the replication of the interventions of the project would have in each city. Here, the replication potential hypothesis and analysis is identified as the most critical step.

In any case, it needs to be considered also that the alternative scenario two only considers the effects of the replication of several interventions (the ones that will be implemented in lighthouse cities). Therefore, there are many other interventions that can be implemented in each city during the following years that are

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not considered in this analysis. This needs to be carefully considered when comparing the improvement potential provided in the alternative scenario with respect to the specific targets that each city has previously defined in their plans for different time horizons.

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 tool that needs to be used in city energy planning specially in the definition phase when comparing the potential effects of different alternative interventions for the city.

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