Coordination and support action (Coordinating Action)

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INSMART

Integrative Smart City Planning

Report on optimum sustainability pathways – Nottingham

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Author(s): G Long, D Robinson

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	Name (organization)	**e-mail**
Leading participant	Gavin Long (UoN)	gavin.long@nottingham.ac.uk
Contributing participants	Gavin Long (UoN) Darren Robinson (UoN) Rocco De Miglio (E4SMA) Andrew Whitley (NCC)	gavin.long@nottingham.ac.uk darren.robinson@nottingham.ac.uk rocco.demiglio@e4sma.com andy.whitley@nottinghamcity.gov.uk
WP Leader (WPL)	E4SMA	e4sma@e4sma.com
Project Coordinator (PC)	George Giannakidis (CRES)	ggian@cres.gr
Project Steering Committee (PSC)		

Executive Summary	
Development of the energy system model for Nottingham, definition and analyses of sustainability scenarios.	
Keywords	Energy system model, planning hypotheses, scenario analysis, technologies and measures.

Acronyms and Definitions

CHP – Combined Heat and Power

EfW – Energy from Waste

ESM – Energy City Model

E4SMA – InSMART project partner leading TIMES modelling

GIS – Geographic information system

MCDA – Multi Criteria Decision Analysis

NCC – Nottingham City Council

ONS – UK Office for National Statistics

PROMETHEE – Preference Ranking Organization METHod for Enrichment of Evaluations

PV – Photovoltaic

RES – Renewable energy sources

TIMES – The Integrated MARKAL-EFOM System

UoN – University of Nottingham

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1. Introduction

This report presents an application of the innovative city planning approach, developed within the EU FP7 project InSMART for the City of Nottingham. Nottingham is located in the UK's East Midlands region and is one of the UK's ten core cities. Nottingham city has a population of 318,900 (ONS, 2016a) with around 700,000 people living with the greater Nottingham area. (ONS, 2016b).

The main objective of the proposed methodology is the identification of an optimum mix of applicable measures and technologies that will allow the city to achieve its' sustainability and energy targets. Actions to deliver this aim will be defined according to the scope and limitations of the local authority's (Nottingham City Council) role as "urban planner", "regulator", "provider of support and information", "consumer" and as "supplier" of energy. Key city stakeholders provided their expert input for the design of a number of future energy scenarios for the city for the mid-term (i.e. to 2030).

The future energy scenarios for the city have been designed and tested using a city-Energy System Model (ESM). This Nottingham ESM was built using data collected throughout the project. A large set of quantitative data was gathered by combining bespoke surveys and existing spatial and statistical datasets (both local and national) across a wide range of energy sectors. A bottom-up model was used to create and explore combinations of actions and measures for the city with a particular focus on the residential and transport sectors.

The design and development of the Nottingham ESM was a joint enterprise between UoN and E4SMA. UoN's role was to provide data for the Nottingham model (including scenarios, costing models, energy data, etc.) to E4SMA. E4SMA, in their role as lead expert on TIMES modelling, performed the actual development of the TIMES model for Nottingham. The development of the Nottingham ESM was a highly iterative process between UoN and E4SMA with multiple versions of the Nottingham ESM created throughout the work package.

Making use of scenario analysis, the planning hypotheses are built around different themes with the aim of exploring the potential benefits (or drawbacks) of the combination of "competitive" projects, actions, standards, and targets. A "reference" development of the local system is then assumed to be modified through several different "strategic plans" aiming at representing and testing images of alternative pathways towards greater urban sustainability.

Compared to traditional planning methods, the advantage of the outputs of this approach is the fact that multiple future energy scenarios are analysed and cross-compared, and "integrated" strategies are identified.

A MCDA tool was then used to generate the final ranking on the basis of a set of criteria against which the scenarios are evaluated. Local stakeholders engaged in the design of the alternative planning hypotheses as well as in the analysis of uncertainties and of the responses of the tool (results).

2. City Energy System Model

2.1. Structure of the model and methodological approach

This section aims to describe the methodology used to represent the city energy system and the key characteristics of the model. According to the Description of Work of the project, the key outcome of the city ESM is the "*identification of an optimum mix of applicable measures and technologies that will pave the way towards the achievement of the cities' sustainable targets*". In order to assess the impact of different energy plans on the urban system, a technical economic model of the energy sector of the municipality of Nottingham was built making use of the TIMES model generator (The Integrated MARKAL-EFOM System), which is a widely-applied partial equilibrium, bottom-up, dynamic, linear programming optimisation model.

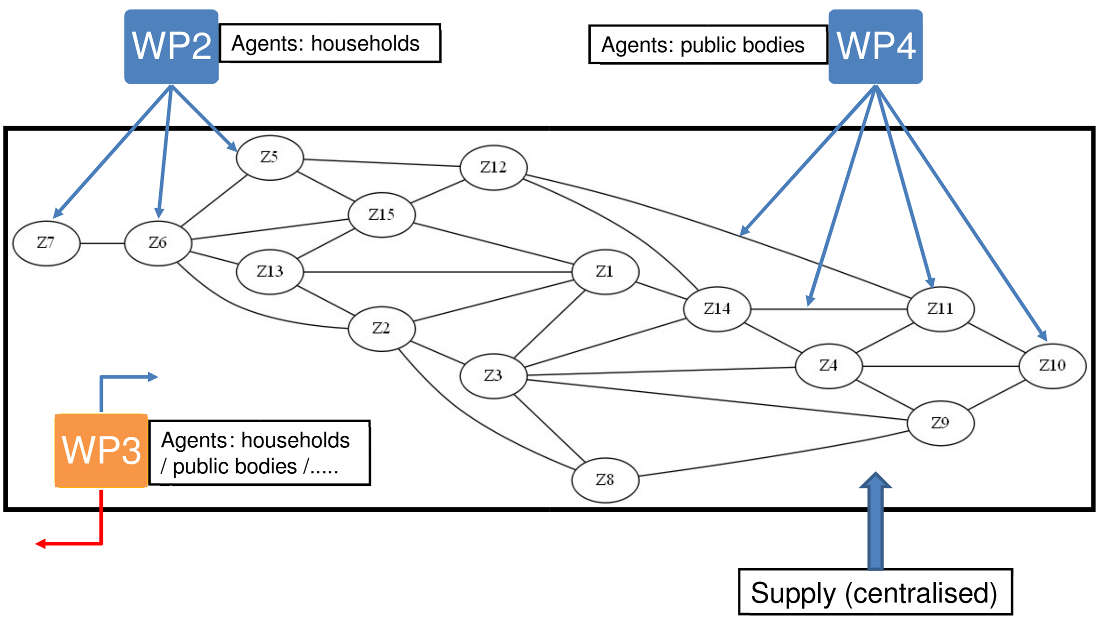

Figure 1: Topology of the ESM for Cesena

Making use of the graph theory concepts (and the graph shown below), the urban area is represented in nodes (“zones”) as shown in the example provided for the InSMART partner city of Cesena in Figure 1. Each zone is described as a subsystem characterized by a certain number and type of energy service demands (space heating, water heating, cooling, lighting, etc.), buildings and activities (detached, semidetached, blocks, hospitals, schools, etc.), potentials for renewables (e.g. PV solar) and by a number of zone-to-zone transport needs. Number and borders of the subsystems within the urban area are defined on the basis of homogenous zones which are suitable for the planning exercise (and are inherited by WP1, WP2 and WP3).

In the case of Nottingham, 20 zones were identified to represent the city boundary. For the Nottingham transport model an additional 5 zones were required to cover the transport impacts for the Greater Nottingham Travel to Work area. Figure 2 shows the geographical zones used for the city of Nottingham. Table 1 lists the zone names and population. Zones 1-20 are within the city boundary and are used for the modelling of WP2 and WP4. Zones 21-25 are only used for the transport modelling (WP3).

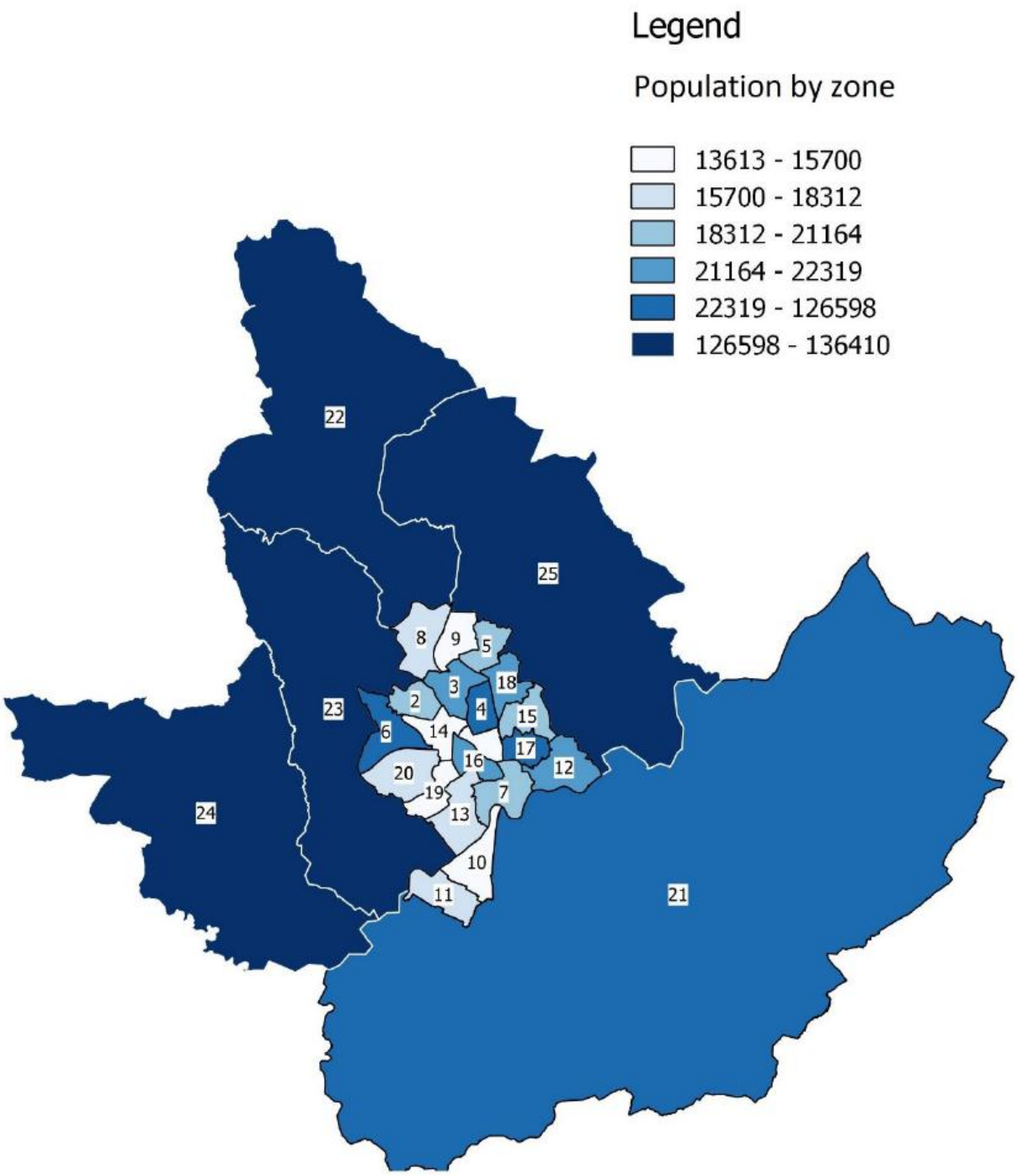

Figure 2: InSMART zones defined for Nottingham by population

Each zonal sub-system is characterised by stacks of "individual" behaviours (productions, consumptions, etc.) of all the agents acting in the zone. The "key" agent of the model is "virtually placed" in the dwelling (household) for which several energy needs are modelled, and to which investments decision variables (key element of the model) are assigned. Figure 3 shows the logic scheme used in the model: a generic household "demand" several energy services and use technologies to meet these demands.

Energy consumptions and demanded services are "decoupled": efficient technologies (boilers, refrigerators, lighting bulbs, cars, building refurbishment options, etc.) can be chosen by the final consumers to reduce the consumption and meet the same service level. Figure 4 below shows that consumption for space heating can be reduced if retrofit measures are included.

Table 1: City zone names and population

Zone	Name	Population	Zone	Name	Population
1	Arboretum	13613	**14**	Leen Valley	13918
2	Aspley	21164	**15**	Mapperley	20788
3	Basford	22114	**16**	Radford and Park	22319
4	Berridge	22410	**17**	St Ann's	27501
5	Bestwood	20101	**18**	Sherwood	22110
6	Bilborough	22946	**19**	Wollaton East and Lenton Abbey	13901
7	Bridge	19324	**20**	Wollaton West	17611
8	Bulwell	18312	**21**	West Bridgford & South	126598
9	Bulwell Forest	15700	**22**	Hucknall & North	133517
10	Clifton North	14358	**23**	Beeston & Kimberley	136410
11	Clifton South	16125	**24**	Ilkeston & Long Eaton	129362
12	Dales	21667	**25**	Arnold & East	129894
13	Dunkirk and Lenton	16518			

Zones of the city (20) hold different characteristics affecting the investment decisions of agents and affecting the operation of the technologies (e.g. different access to distribution systems, different PV potentials, different investments costs, etc.), therefore zone-specific developments/performances are also analysed in the framework of this research (although not included in the MCDA analysis).

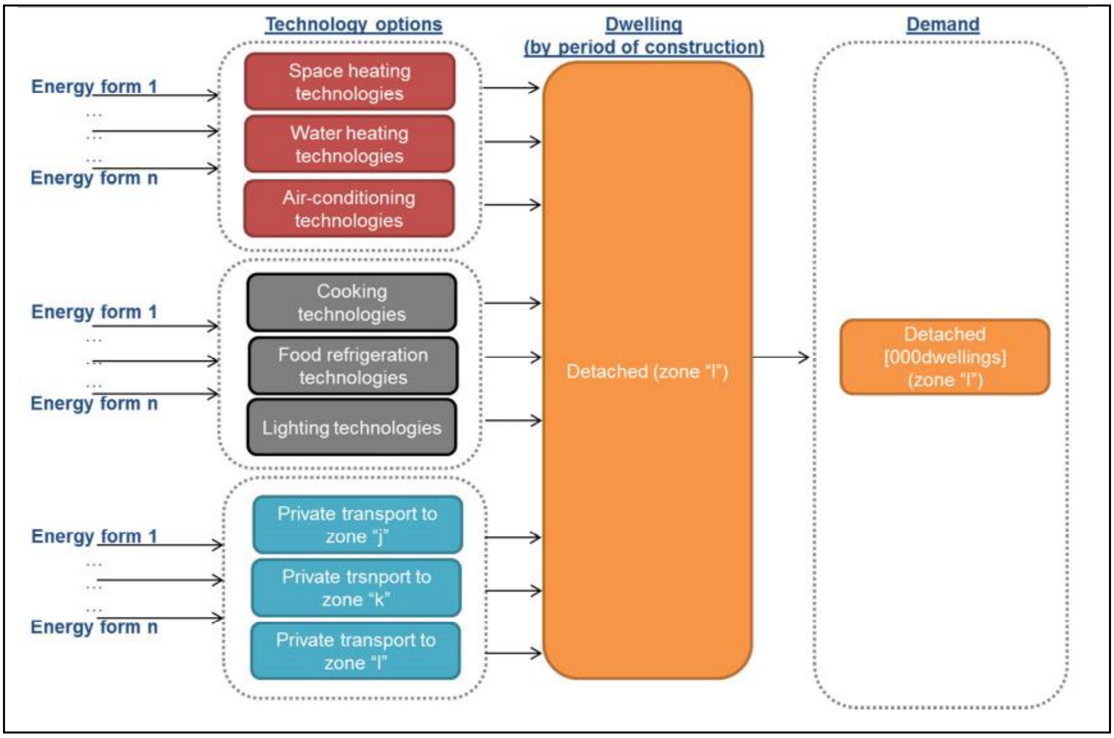

Figure 3: End-uses demanded by household (e.g. detached)

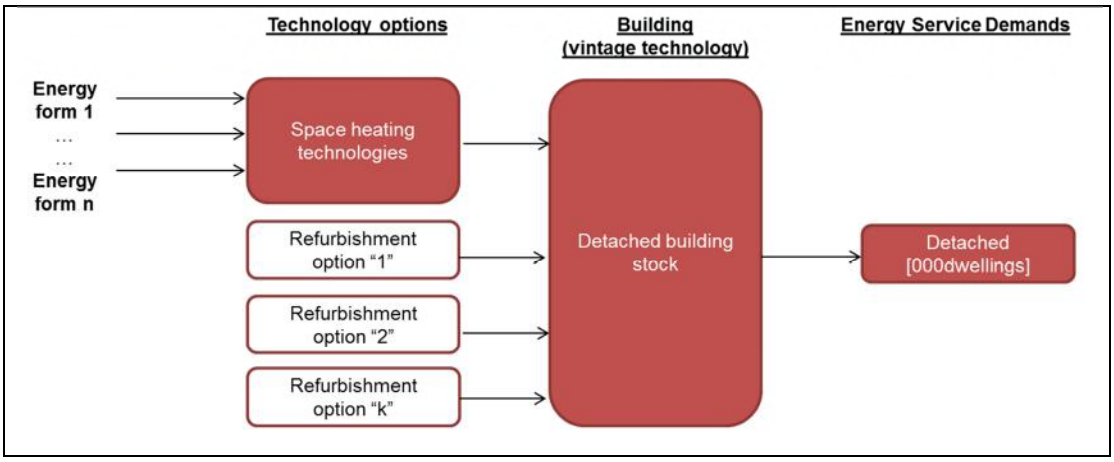

Figure 4: Space heating technologies and refurbishment options by household (e.g. detached)

Mobility demands (private) are allocated to the zones which are at the "origins" of the movements, by assuming that the corresponding investment decisions are taken by the agents located in the zone of origin. Therefore, costs, fuel consumptions and emissions are directly assigned to that zone (see Figure 5). A matrix of movements (origin-destination) by period and by transport mode if fully inherited from the transport specific analysis (WP3). One of the ESM's goals, is to provide the "optimal vehicles mix" with respect to that matrix of movements and to any possible sectorial measure/target (scenario) taking account of the possible integrations of the transport sector with other urban system components[1]. In so doing, "urban planning" and "energy planning" are carried

[1] Examples of such integration are presented in the following paragraphs.

out together in an integrative manner as decisions taken in one area generate feedbacks in the other.

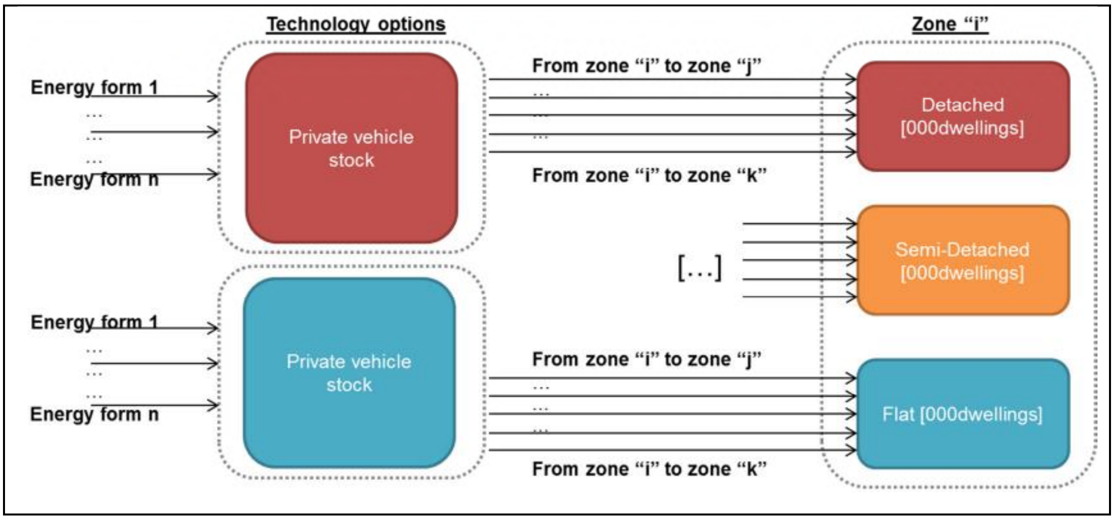

Figure 5: Private mobility from zone "i" as demands of the households in zone "i"

Table 2 illustrates the level of detail of the city model for Nottingham, describing the agents of the system and the key variables associated with these agents. Note that the agents described only represent households within the city boundary (zones 1-20). Transport related energy, emissions and costs associated with travel from those zones outside the city boundary (zones 21-25) is included as an additional input to the ESM.

Table 2: Basic settings of the Nottingham ESM

Key agent	Households - 16 building types: detached, semi-detached, terraced and flats by period of construction (<1914, 1915-1945, 1946-1964, 165-1979, >1979).
Energy services per agent	Space heating, water heating, lighting, electrical appliances, private transport from zone "i" to zone "j".
Location	Zone 1, Zone 2, .., Zone i,, …., Zone 20.
Variables	Consumption of different energy forms / sector / service, investment costs per each appliance/technology, emissions, etc.

Other energy sectors and activities including street lighting, energy generation, water, waste and the energy use associated with non-domestic building stock have been explicitly modelled as part of the InSMART programme of work. However, there are no planned variations in these energy services over the time horizon of the ESM in any of the future energy scenarios designed for the city. It was therefore agreed to exclude these services from the TIMES based ESM for Nottingham.

Other sectors that are included in the future energy scenarios, such as public transport and low carbon energy generation options, have been explicitly included in the ESM.

The Nottingham ESM has been designed to track many types of variables which are of interest in the development of a future energy strategy for the city: energy savings by retrofit measure per scenario, potential energy savings by building type by scenario, the electricity and gas consumption by zone and by scenario, CO2 emissions by sector and zone, investments cost by agent, service and , the penetration of low carbon energy generation systems, required subsidy levels by technology and sector, etc.

The following time granularity (Table 3) has been used to track energy consumption throughout each year. Specific actions can be targeted to the consumption/production of energy form in specific time-slots of the year.

Table 3: Time granularity of the Nottingham ESM

Time of day **Season**	**D** **N. hours**	**N** **N. hours**	**Year** **N. days**	**Start - End**
S1	12	12	90	1 Jan - 31 Mar
S2	12	12	183	1 Apr - 30 Sept
S3	12	12	92	1 Oct - 31 Dec

Chapter 4 of this report provides additional information on the variables and indicators used in the multi-criteria analysis element of WP5. Further details of the results will be analysed in the framework of WP6 (Development of Mid-term Implementation Action Plans).

2.2. Description of the baseline energy system for Nottingham

Using data collected as part of WP2 and WP4, a consistent framework (spreadsheet-based) was developed and elaborated in order to:

- Quantify and represent the stocks of energy demand technologies (e.g. MW of boilers, number of refrigerators, number of vehicles etc.) and distribution processes (such as gas and district heating systems) in the model
- Aggregate the information by zone
- Analyse key variables at the zonal level (e.g. the amount of natural gas delivered, or electricity consumed, etc.) in such a way that productions and consumptions are consistent with local statistics.

Figure 6, Figure 7 and Figure 8 illustrate examples of key quantitative details of the city energy system for the residential and utility sectors in the base year (2014). Residential energy data evolves dynamically along the period of analysis according to the different ESM settings for each pre-defined future scenario. Energy use by the utility sector remains relatively flat across the time horizon for all scenarios. Any increase in utility energy demand will be driven by population growth. Chapter 3 provides greater detail on individual settings by scenario and the effects of these settings are discussed in chapter 4.

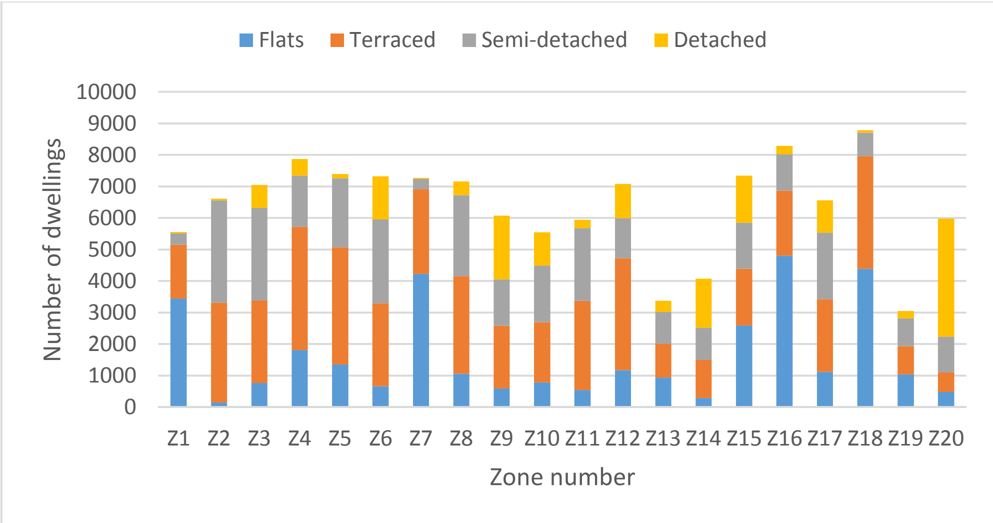

Figure 6: Breakdown of dwelling type by zone

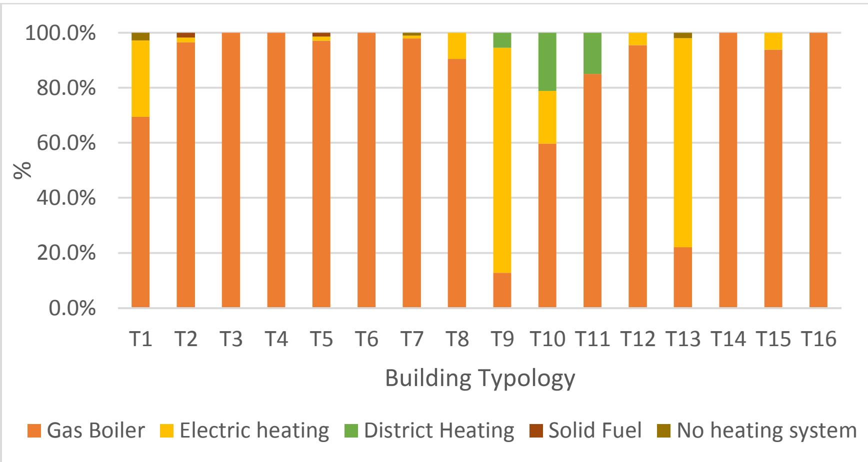

Figure 7: Heating system by building typology for the residential sector

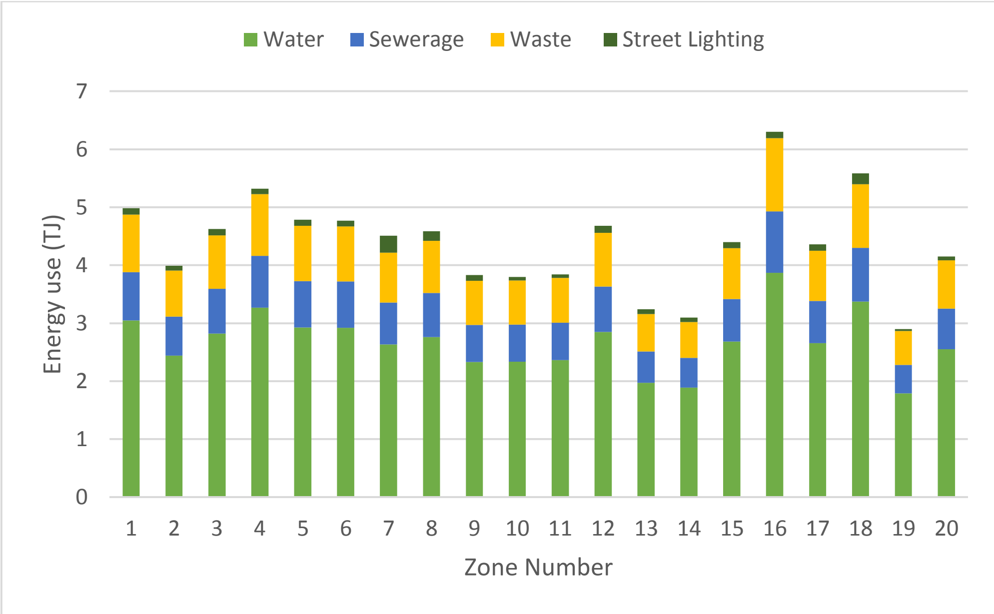

Figure 8: Energy use for other utility sectors

Energy consumptions and expenditures are calibrated "by type of dwelling" according to the information collected through local surveys for the base year of the analysis. Data on transport energy and emissions is fully inherited from the InSMART transport model for Nottingham and used in the model to project the utilisation/consumption of vehicles. Figure 9 shows base year (2014) energy use in the residential and transport sectors.

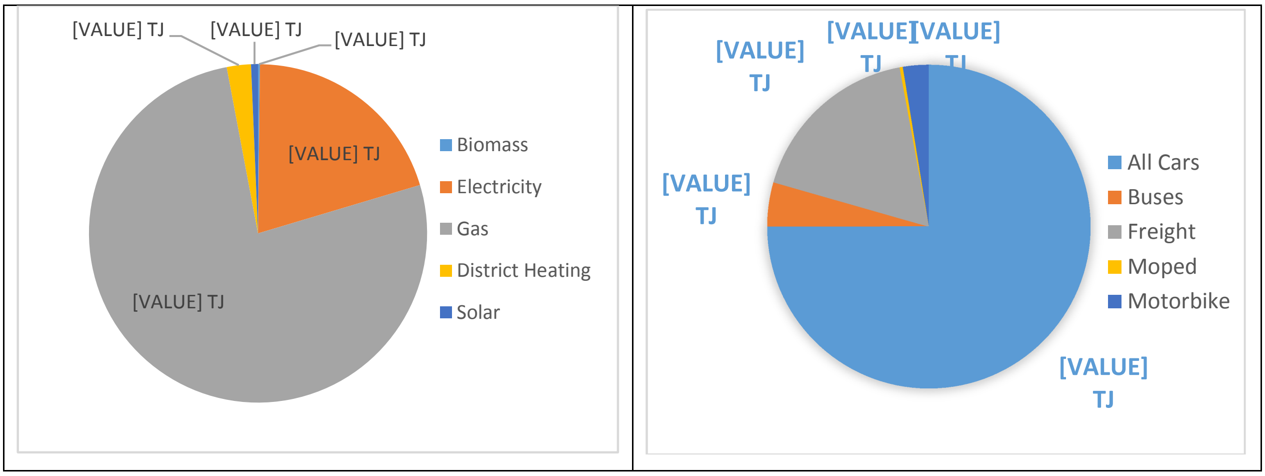

Figure 9: Base year consumption in residential sector by energy source and transport energy use by vehicle type

Dwellings are explicitly represented in the model, as are options for energy retrofits (savings and the costs of the retrofits are calculated using building stock simulations created in WP2). For each existing building typology and zone the heating demand, associated energy use, and retrofit options for demand reduction (R1: solid wall insulation, R2: cavity wall insulation, R3: roof insulation and R4: draught-proofing) are estimated and represented in the model. Figure 10 and Figure 11 below show two examples of data used in the analysis.

T 2	Victorian Terrace	
Use	Residential, Mixed	
City area	Inner city	
Construction period	Before 1914	
No of floors	2-3 Storeys	
Roof type	Sloped roof	
Wall type	Double layer brick	
Energy stats	Mean energy demand Electricity Gas Hot water	169 kWh/m^2 31.3 kWh/m^2 116.8kWh/m^2 20.9 kWh/m^2
Retrofit options (% demand reductionl)	R1- Solid Wall Insulation (22.8%) R3 – Roof Insulation (4.8%) R4 – Draught-Proofing (9%)	

Figure 10: Victorian terrace building typology

T 11	60s/70s Semi-detached	
Use	Residential	
City area	Inner city (Dales, St Ann’s, Bridge) Suburbs (Bestwood, Bulwell)	
Construction period	1964-1979	
No of floors	2	
Roof type	Flat roof, sloped roof	
Wall type	Cavity Wall (brick), Concrete	
Energy stats	Mean energy demand Electricity Gas Hot water	138 kWh/m^2 47.8 kWh/m^2 72.2 kWh/m^2 18 kWh/m^2
Retrofit options (% demand reductionl)	R1[2] – Solid wall insulation (26.4%) R2- Cavity Wall Insulation (24.5%) R3[3] – Roof Insulation (n/a) R4 – Draught-Proofing (9%)	

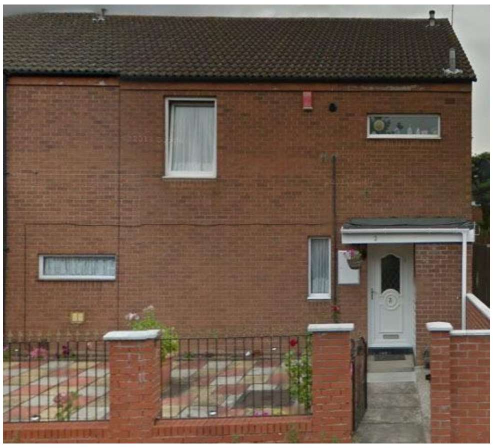

Figure 11: 1960/70s semi-detached building typology

2.3. Key static and dynamic components of the Nottingham ESM

The Nottingham ESM has been designed with the following characteristics, with the aim to provide a flexible platform for the analysis of the scenarios proposed by the municipality (presented in chapter 3) and for the exploration of other tests which may be of future interest

- The city is subdivided in 20 zones (An additional 5 zones are used by the transport model to cover the Greater Nottingham travel to work area). Each zone is a subsystem (region) of the TIMES-based city ESM.

[2] This retrofit option is only applicable to the small portion of this typology that is constructed using concrete walls.
[3] Survey found none of this typology to have uninsulated roof spaces

- The city ESM has a "multi-regional" structure, meaning that agents of the building sector and their demands are placed to different zones of the urban area, and that processes operate in different zones of the urban area.
- Different zones can be subject to different actions/measures.
- Buildings are classified following the typologies of the surveys (WP2).
- Each type of building is a "process" in the model, and so are refurbishment options (the number, the type, the savings and the costs of the refurbishment options are provided by WP2).
- Building construction (new demand) and demolishment are defined exogenously (WP2 and scenario design).
- Limits on refurbishment rates can be included as constraints (e.g. based on historical rates).
- The centralised supply (e.g. power plants) is not "explicitly" represented within the borders of analysis. Availabilities and prices of these supplied are part of the scenario storyline (exogenously defined).
- Requirements relating to local air quality can be taken into account (e.g. by banning some technologies from specific zones). Supports the development of a city centre low carbon zone which is a key element of many of the transport scenarios for the city.
- The projection of electricity and heat needs (consumption) is completely endogenous (per each agent, per each zone).
- Model allows the representation of different actors in the same decision platform: household (i), economic activity (j), public body (k), etc.
- Model is calibrated to the latest set of available data. Where possible data for the base year of 2014 was used. Calibration is meant to depict a consistent and reliable starting point for the dynamic analysis.
- Such a dynamic model deals with "feedback effects". Results capture the key features of urban dynamics, such as "price responses" and interaction with demand and supply choices per each type of "agent".
- "Behavioural-oriented" measures or phenomena like for example information campaigns, network effects, DSM and load shifting, can be considered in the model.
- The perfect foresight of the model is controlled making use of "budget constraints" aiming at simulating the maximum willingness to invest of the households.

3. Scenario analysis

Forecasts vs. Scenarios

Results for the city energy system model should not be considered as forecasts for the future. Results provide insights into the impacts of a particular scenario, which considers a discrete set of input assumptions in relation to variables such as macroeconomic drivers, fuel prices, resource availability and technology costs. These assumptions should not be seen as prescriptive, but rather as a snapshot of potential outcomes that may be realized. Comparing different scenario results is where the richness lies. The objective of useful systems modelling is to provide an evidence base to inform policy decision regarding potential future energy system configurations.

3.1. Narrative of scenarios

Scenarios for the city of Nottingham are built around a number of "areas of intervention" with the aim of exploring the potential benefits (or drawbacks) of the combination of specific "competitive" projects, actions, measures, and targets. The starting point of the analysis is a reference scenario which is used as a base case (counterfactual) against which to compare the alternative planning hypotheses (oriented to the sustainability) of the city. These alternative hypotheses have been developed through a combination of actions and measures across six main areas of action, namely i) Urban regeneration, ii) Urban development, iii) Transport, iv) Behaviour and Organization, v) Renewables, and vi) System.

3.1.1. The Reference scenario

The Reference scenario has been designed to simulate the current "reference" development of the local system. It considers all the current key policy developments that were formally agreed and funded. It provides a basis against which to compare the alternative city planning hypotheses (scenarios). The following assumptions have been assumed in the reference scenario:

- Population: the population and the number of households will grow in line with current projections for the city as published by in the Nottingham City Land and Planning Policies (LAPP) document 2016 [NCC, 2016]. This expects the delivery of an additional 17,150 households in the city by 2028. A temporal breakdown of this additional provision is shown below.

2011/13	950
2013/18	4,400
2018/23	5,950
2023/28	5,850

Figure 12: Projected additional housing provision for Nottingham [taken from LAPP [NCC, 2016, (p73)]

- New urban areas: Areas planned for future development taken from the recent LAPP report part 2 [NCC, 2016]. Table 4 shows the breakdown of new housing.

Table 4: Summary of future housing allocation for Nottingham

SUMMARY OF HOUSING ALLOCATION	Number of houses
Past Completions 2011-15	2,706
Waterside	1,624
Boots Campus	230
Stanton Tip	500
Other LAPP Sites	6,061
Other sites deliverable by 2028 (taken from Strategic Housing Land Availability Assessment)	5,354
Windfall Allowance	1,610
Demolitions	-886
Housing provision in Nottingham 2011-2028	17,199

A zonal allocation of new housing was calculated based on the data in the LAPP document and used as an input to the reference scenario

- New building stock: The energy standards of all new building stocks follows current national and regional building rules.
- Appliances: The substitution rates of appliances (e.g. light bulbs, washing machines, boilers, etc.) are driven by their technical obsolescence, their cost-effectiveness (i.e. no specific measure are assumed to support their substitution) and a “default” estimate of the willingness to invest of the families.
- Refurbishment of the existing stock: Rates of retrofitting for residential properties were taken from national housing survey statistics (no local data available). Data available on home insulation levels from 2008-2013 (most recent available) enabled the calculation of a 5 year average for each retrofit option. Figures used are:
    - Solid wall insulation (R1) – 0.4% per year of dwellings insulated
    - Cavity wall insulation (R2) – 3% per year of dwellings insulated

- Roof Insulation (R3) – 5% per year of dwellings insulated

No data available for Draught-Proofing measures (R4) so assumed no growth for this measure over the time horizon.

- Investment costs for residential retrofits are as follows:
  - Solid Wall Insulation (R1): £161/m2 of wall insulated
  - Cavity Wall Insulation (R2): £330-£720/dwelling depending on exposed wall area; e.g. Detached property = £720. Flat = £330. Terrace = £415
  - Roof Insulation (R3): £30/m2 of roof area
  - Draught-Proofing (R4): £200-£580/dwelling depending on property typology; e.g. T2 (Victorian terrace) = £400. T8 (Post war detached) = £450, T14 (Modern terrace) = £200.
- Thermal takeback, also known as the rebound effect, was included in the residential retrofit options. The rebound effect is a reduction in the energy saving associated with an energy efficiency measure due to the building occupants deciding to take back some of the saving as increased thermal comfort. UK national allowances for this effect were included for R1 and R2. It was decided that the energy savings for other retrofit options were not sufficient to warrant its inclusion for those measures.
- District heating: No further expansion of the district heating network is considered in the reference scenario
- Public lighting: All newly installed lighting systems in the Municipality are high efficiency LED systems, in line with the current local directives.
- Energy prices: Energy prices are calibrated in line with the current, and for future years they follow the national projections. Energy prices used in the Nottingham ESM are:
- Electricity (in £/GJ) : 43.75, 47, 52.5 (in 2014, 2020, 2030)
- Natural Gas (in £/GJ): 13.7, 15, 16.4 (in 2014, 2020, 2030)

- Behaviour: No changes in the energy behaviour (e.g. willingness to invest of the players, load shifting) are assumed in the period of the analysis.
- Transport: All the actions and transport measures already formally approved when modelling commenced were included in the reference scenario. For example, NET phase 2, the expansion of the city's tram network, was included in the reference scenario although it was not actually completed in the base year (2014). Other transport measures that were planned but not formally agreed have been included in the alternative scenarios. This provides the municipality

- Subsidies and incentives: No national, regional and local incentives or subsidies are included in the reference scenario, given the high uncertainty around the future availability of these mechanisms.

3.1.2. The Alternative scenarios

The alternative scenarios aim to explore possible routes for a more sustainable planning of the Municipality. These scenarios are designed to assess the implications of different integrated visions of the development of the municipality. The reference development of the local system[4] is assumed to be modified through a series of combinations of actions and measures aiming at representing *alternative planning hypotheses* of the city. The process of designing these alternative future energy scenarios is described in greater depth in the InSMART MCDA report for the city (InSMART, 2016).

The design of these storylines has followed a two-step approach: firstly a group of future energy themes for the city and the corresponding actions have been identified; secondly, these themes have been quantified and modified to suit a TIMES based approach to urban energy modelling. The initial step led to the creation of four potential future energy themes:

- **No Investment (NI)** – Assumes lower than expected income and spending on energy improvements compared to the reference scenario
- **Local Leadership (LL)** – Local authority and city stakeholders are engaged with the need to reduce energy consumption and carbon emissions.
- **Green Governance (GG)** – National focus on the green agenda with the introduction of a carbon tax and increased subsidies for energy efficiency schemes and low carbon energy generation options.
- **Green Growth (GG+)** – Ultra high investment scenario that goes beyond the GG scenario and includes higher subsidies for low carbon energy project and energy efficiency schemes. Also includes more ambitious targets for energy and CO2 emissions reductions.

In conjunction with our partners from E4SMA, these four visions were reviewed and adapted for TIMES modelling. It was decided to exclude the two "extreme" scenarios, NI and GG+, from the second stage of scenario design. These options were less well quantifiable and had the potential

[4] It is worth noting that the assumptions which underpin the reference scenario are all maintained and used as starting point for all further actions.

for skewing the results of the TIMES approach due to their greater divergence from what was deemed a likely possibility.

The second stage of scenario development used the more likely future visions, LL and GG, and created a number of alternate scenarios for future energy in the city based on these visions. This produced seven scenarios, four based on LL and three on GG, as described below:

- **LL-Low cost** – Low municipal engagement. No subsidies for energy retrofits. Limited expansion of transport infrastructure (cycle network).
- **LL-Engaged** – Public sector focused with district heating expansion and public transport upgrades. Subsidies for residential retrofits.
- **LL-Full** – Includes all planned transport and energy projects (e.g. Go Ultra Low, District heating expansion, Community scale biomass CHP, etc.).
- **LL-Growth** – Highest level of local engagement with 'forced' inclusion of biomass fuelled CHP generation, plant scale PV and low carbon housing.

All GG scenarios were based on the LL-Full scenario with the addition of a national Carbon Tax and increased subsidies for low carbon energy generation systems. Different routes for an expanded tram network (NET phase 3) are the main difference between the GG scenarios.

- **GG-West** – Includes proposed extension of NET line 1 to Kimberley.
- **GG-East** – Includes proposed addition of NET Line 4 to Gedling.
- **GG-All** – Includes all proposed NET extensions (Kimberley, Gedling and link to HS2 at Long Eaton) and the inclusion of an Anaerobic Digestion plant to increase low carbon energy generation potential.

The LL and GG scenarios include subsidies for building energy retrofits, low carbon energy generation, low carbon transport options. Specific levels of subsidy applicable are shown in Table 5. Infrastructure costs are not included for all energy measures in the TIMES model as this would have excluded their inclusion in the final results on economic grounds. Infrastructure costs can be added to the results in post-processing to allow the MCDA analysis to include all costs associated with each measure.

Table 5: Energy subsidies applicable to the future energy scenarios for Nottingham

Scenario	Measure	Subsidy
LL-Engaged	Residential retrofit R1	75%
LL-Full	Residential retrofit R2	75%
LL-Growth	Residential retrofit R3	90%
LL-Full	Community Biomass CHP	£0.052/kWh generated[5]
LL-Growth	Electric vehicles	25%
GG-West	Residential retrofit R1	80%
GG-East	Residential retrofit R2	Flat rate cost £100/dwelling
GG-All	Residential retrofit R3	Flat rate cost £100/dwelling
	Community Biomass CHP	50% £0.052/kWh generated[5]
	Solar PV	50%
	Solar Thermal	50%
	Heat pump	50%
	Electric vehicles	25%

The design of the LL and GG scenarios is based on incremental addition of energy measures with each scenario building upon a previous scenario. This can be seen clearly in the scenario summary table (Table 6).

All the future city visions were developed in close collaboration with the city council and other key city stakeholders during brainstorming sessions and workshops. This includes details of the specific energy measures associated with each vision and the quantitative used to model those measures (where available). Scenario design was a compromise between the original visions, the requirements of the TIMES model, data availability and ongoing input from the municipality.

[5] Subsidy in line with existing UK Renewable Heat Incentive scheme. Details available at https://www.ofgem.gov.uk/environmental-programmes/domestic-rhi/contacts-guidance-and-resources/tariffs-and-payments-domestic-rhi/histrocial-tariffs

Table 6: Energy measures associated with each future energy scenario for Nottingham

Scenario	Work from home & cycling infrastructure	Domestic PV and Solar thermal	Residential retrofits incl. rebound effect (R2-R4)	Electric buses and southern corridor	Solid wall insulation (R1)	District heating expansion	Go Ultra Low (electric vehicles, low carbon zone) & parking charge increase (LL2)	Community scale Biomass CHP schemes	NET Phase 3 - Kimberley	Carbon Tax	NET Phase 3 – Gedling	NET Phase 3 – All routes	Anaerobic Digester Plant	Plant scale PV at park and ride site	New Low carbon housing developments	Increased diffusion of electric vehicles [6]	Subsidies for Low carbon heating systems
LL – Low cost	X	X	X														
LL - Engaged	X	X	X	X	X	X											
LL2	X	X	X	X	X	X	X	X									
LL - Growth	X	X	X	X	X	X	X	X[7]						X[8]	X	X	
GG - West	X	X	X	X	X	X	X	X	X	X							X
GG - East	X	X	X	X	X	X	X	X		X	X						X
GG	X	X	X	X	X	X	X	X		X		X	X				X

[6] Agreed in discussions with E4SMA to use an additional 10% penetration of electric vehicles for this measure
[7] In this scenario the penetration of Community biomass CHP is to be 'forced' rather than left to the system
[8] In this scenario the plant scale PV sites at the two park and ride sites are to be included in the model irrespective of the economic case for their implementation

4. Results

4.1. Key indicators for a new SEAP

The key outcome of such a city energy system model (city-ESM) is the identification of an optimum mix of applicable measures and technologies that will pave the way towards the achievement of the city's sustainable goals. To support the municipality in the explorations of different strategies, the model aims to be a test-bed for assessing the impacts of different urban actions and measures and corresponding environmental-economic performances.

Performance Indicators have been chosen to assess the performance of the scenarios:

- Total Energy Use/Reduction in energy use (%)
- Total CO_2 emissions/Reduction in CO_2 emissions
- Low carbon energy generated (%)
- Investment (and maintenance) costs.
- Decarbonisation Cost Efficiency (£/tCO2 reduction)

Other indicators of potential interest include emissions of other particulates/pollutants, energy reductions by sector/zone, decarbonisation by sector/zone and subsidy levels required for viability of specific energy technologies/infrastructure.

4.2. Comparative analysis across scenarios

Results of the modelling exercises can be combined in different ways to create several types of indicators: "*static"* (to compare the performance of one scenarios with respect to other scenarios in one point of the time and/or in a cumulative manner) or "*dynamic"* (to track the evolution of a variable in the three milestone years of the model, 2014, 2020, 2030 and compare the different trend across scenarios). As the inputs for the MCDA model (which is used in conjunction with the ESM) are "static", the response of the model to the different stories are presented at one point of the time (2030, the endpoint of the analysis) or in terms of cumulative totals (sum over the 16 years of analysis.

Based on the sample set of results shown in Figure 13, it is clear that different scenarios can lead to different responses from the ESM. For instance, low carbon energy generation is greatly increased in the GG scenarios with the introduction of the carbon tax (and associated cost reduction for low carbon technologies); in contrast, in terms of CO_2 reductions, the lower cost LL scenarios show a large reduction against the Reference scenario but the difference in reduction between the LL and GG scenarios is quite modest. This is reflected in the greater cost efficiency (in terms of decarbonisation) for the LL scenarios (see chart bottom left).

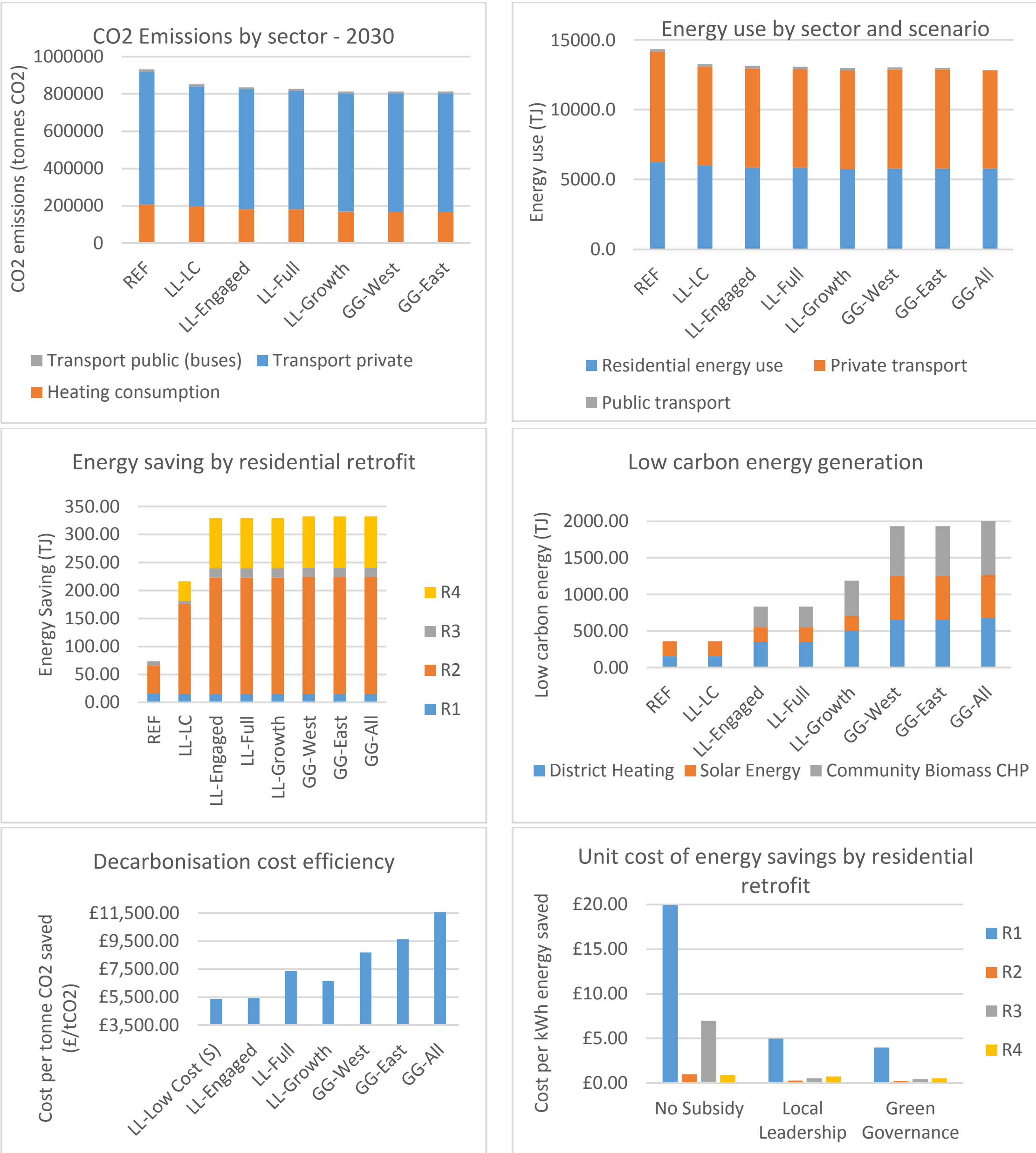

Figure 13: Charts showing ESM outputs by scenario for a range of key performance indicators

Looking at residential energy use and energy efficiency retrofits (charts mid-left and bottom-right), it is clear that the maximum penetration of retrofits is quickly achieved once subsidies are applied. Only the Reference and LL-Low Cost scenarios, the only unsubsidised scenarios, do not show full penetration of retrofits. The subsidy chart (bottom right) illustrates the effect of subsidies of the cost efficiency of energy savings. R1 (External solid wall insulation) is clearly the least cost-effective measure and this is reflected in the low penetration of this measure in the stock. R3 (Loft insulation) requires subsidy to match the cost effectiveness of R2 and R4. R2 and R4 (cavity wall insulation and draught-proofing) appear to be cost-effective measures irrespective of subsidy level. However, subsidy is required to reach maximum penetration of these measures (cart mid-left). These most cost-effective measures (R2, R4), show significantly higher levels of energy savings. R2 in particular, easily saves more energy than all the other retrofit measures combined.

The breakdown of energy use by sector (top-right) shows that energy use between the transport and residential sectors is fairly comparable. This contrasts with the difference in CO_2 emissions between the two sectors (shown in chart top-left). If local CO_2 emissions are the city's priority then reduction efforts should clearly be focused on transport.

Figure 14 and Figure 15 give a breakdown of investment requirements for each scenario. In Figure 14 the cost of transport infrastructure required has been included to the ESM results. Figure 15 shows the results from the ESM without these additional costs included. Clearly transport infrastructure costs make a large and significant difference to the economic viability and cost-effectiveness of the solutions. This is particularly true for the GG based scenarios where the cost of expanding the city's tram network can double the overall cost of these scenarios. It should also be noted that the cost models employed are, by their nature, imprecise and prone to revision. It is highly likely that the actual cost of implementing large infrastructure projects will be considerably higher than the figures used here. This issue will form a major element of the work undertaken in WP6.

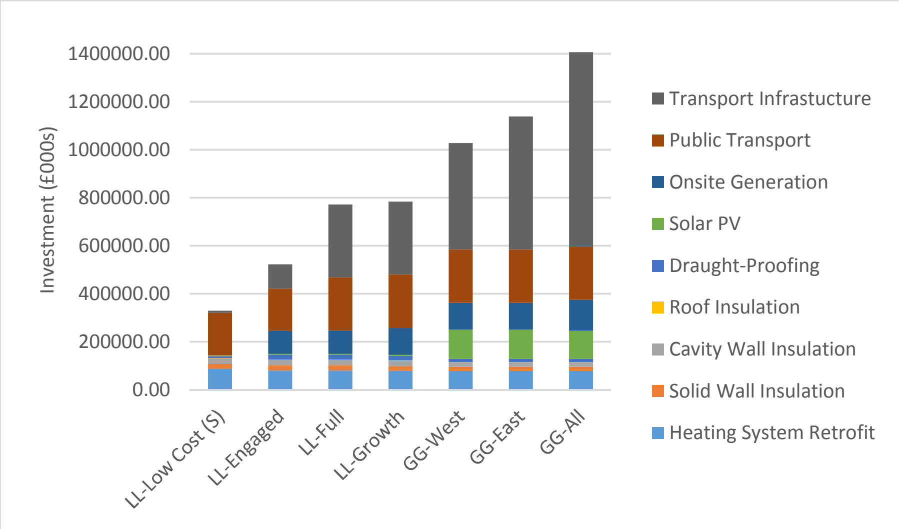

Figure 14: Total investment required by scenario

Figure 15 shows individual elements of the investment breakdown without the dominating effect of transport infrastructure costs. Investments required for heating system upgrades and residential retrofits remain fairly consistent across all scenarios (though the penetration of these measures varies according to the level of subsidy applied). Additional investment in the LL scenarios relates to on-site generation (community scale biomass CHP schemes). This investment carried over to the GG scenarios where the investment required for the large increase in solar energy (enabled by the carbon tax and subsidy for low carbon energy) is added.

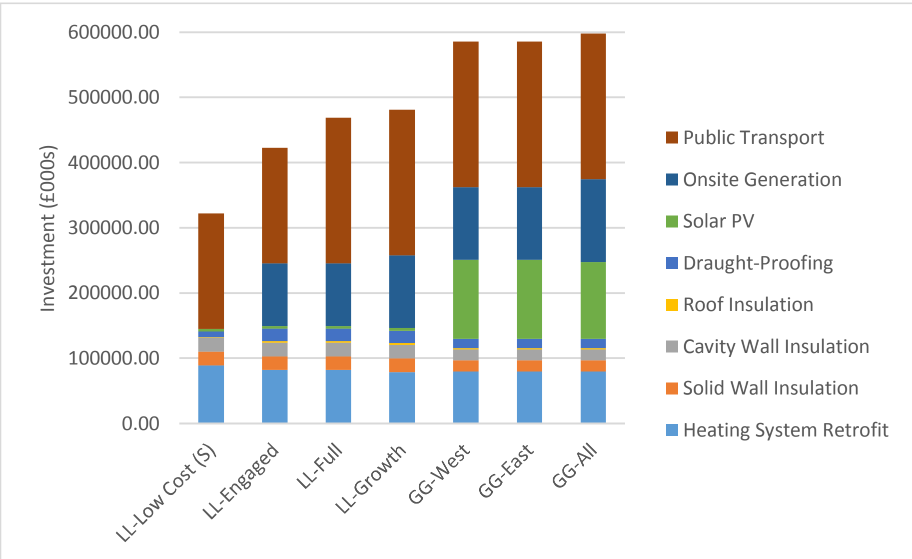

Figure 15: Investment required by scenario excluding transport infrastructure costs

By analysing the trends (dynamics) of important indicators, it is possible to track the actual evolution of the city-system from the existing configuration to the new one depicted by the model for the medium term (2030). Two examples of this type of output are shown in Figure 16 and Figure 17.

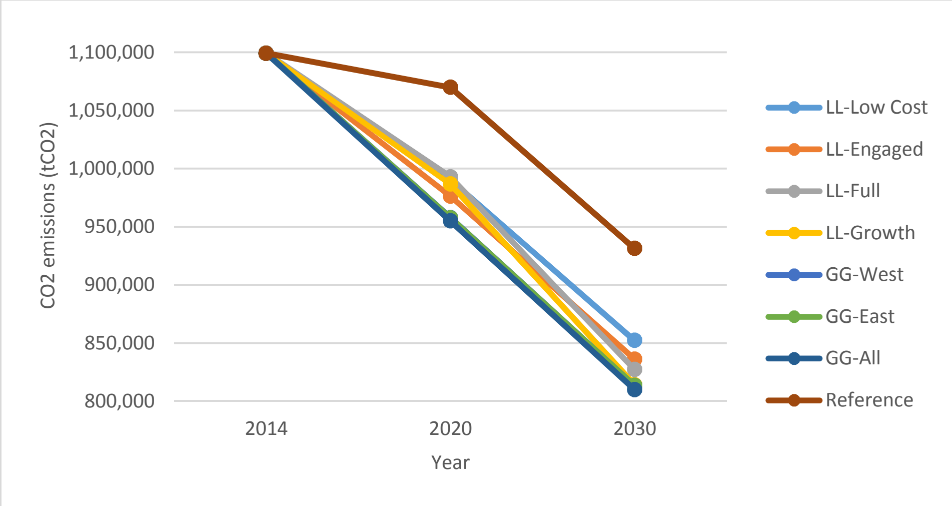

Figure 16: Evolution of CO_2 emissions over the time horizon by scenario

Figure 16 shows CO_2 emissions by scenario over the time-horizon modelled. Clearly all the alternate energy scenarios show significant reductions in emission compared to the Reference scenario. The rate of emissions reduction increases in the period 2020-2030 across all scenarios (especially Reference and LL-Growth). Interestingly, the LL-Engaged scenario has higher reductions in CO2 in 2020 compared to LL-Growth despite the much higher investment in decarbonisation under the latter scenario. The large CO2 reduction in LL-Growth after 2020 allows that scenario to outperform LL-Engaged significantly by the end of the time horizon.

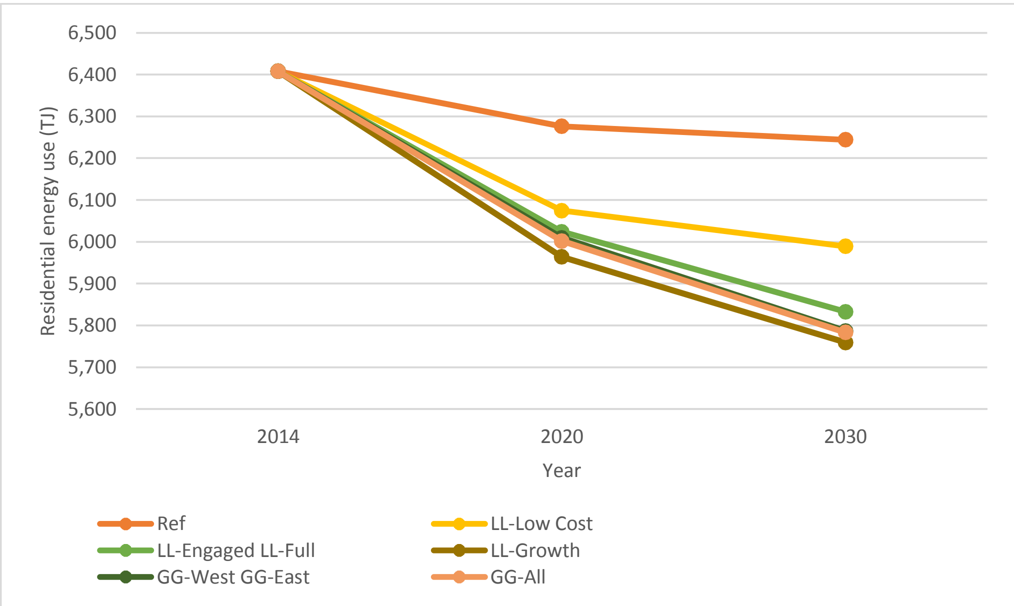

Figure 17: Reduction in residential energy use over the time horizon by scenario

Figure 17 shows the evolution of the reduction in residential energy demand over the time horizon. As with the CO2 emissions example, all alternate scenarios show a marked improvement over the Reference scenario. *LL-Low Cost* shows the least reduction against the Reference due it the lack of subsidy available for energy efficiency improvements. The reduction associated with the other scenarios is similar in magnitude. The rate of energy reduction is higher during the initial time-step (2014-2020) with a slower rate of reduction between 2020-2030. LL-Growth shows the highest reduction in residential demand even compared to the GG scenarios. This could be due to investment being used for low carbon energy systems over energy retrofits in the GG scenario caused by the increased subsidy available for such systems.

In depth analysis of the ESM outputs can focus on specific services, technologies, energy sources and zones. Data can be extracted from the ESM to investigate the response of the simulations to a range of topics of interest. The MCDA work carried out using the ESM (InSMART, 2016) will employ these features in order to provide a holistic and comprehensive ranking of the optimal solutions for Nottingham based on a diverse set of criteria.

The analysis shown here represents a small example of the potential for the ESM. The flexibility of the ESM and its ability to test a wide range of “What-if” scenarios will make it an essential tool in the formulation of the mid-term action plan for the city in WP6. Appendix I provides a user manual for the Nottingham ESM.

5. Findings and comments

Results show significant trade-offs among the key indicators, and different configurations of the system based on the specific energy scenario simulated. The decision about the most promising planning hypothesis (and about the specific actions included) will be carried out using MCDA to ensure that the final solution is based on a broad set of criteria. This will help ensure the energy plan developed has buy-in from city stakeholders and can be justified beyond a simple energy-economic basis.

In comparison to the existing Strategic Energy Action Plan for Nottingham, the InSMART method allows the exploration of multiple future energy scenarios and the modelling of the "integrated" urban system (explicitly modelled). The method also allows the engagement of local stakeholders in all the steps of the decision problem and ensures that solutions can be assessed beyond a cost-benefits analysis approach traditionally used. Table 7 summarizes the key differences and highlight the novelty of the method proposed for Nottingham in the framework of the INSMART project.

Table 7: Overview of the differences between the existing and the new planning method

	Existing SEAP approach	**INSMART approach**
Method	Top-down. Downscaling of national targets, policies and measures.	Bottom-up. Driven by urban specific needs and integrated with the urban planning.
Sectors (coverage)	Residential, Commercial, Public Administration Transport is not included.	Residential, Transport, Water, Waste, Public Services, non-domestic buildings (indirect)
Emissions (location)	Direct (within the urban area) and indirect (e.g. due to the generation of electricity consumed in the urban area).	Direct (within the system). All the emissions "directly" generated by the players of the system (e.g. households) are taken into consideration.
Emissions (type)	CO_2	CO_2, particulate
Measures	Simulation. Cost-benefit analysis of individual stand-alone measures.	Optimisation/Simulation (what if analysis). Integrated system approach.

References

InSMART (2016) InSMART Deliverable D5.5 *Report on the multi-criteria methodology, the process and the results of the decision making – Nottingham*. Available at http://www.insmartenergy.com/work-package-5/

Nottingham City Council (2015) *Local Plan Part 2 - Land And Planning Policies Document*. Available online at http://documents.nottinghamcity.gov.uk/download/444. Accessed 11/10/16

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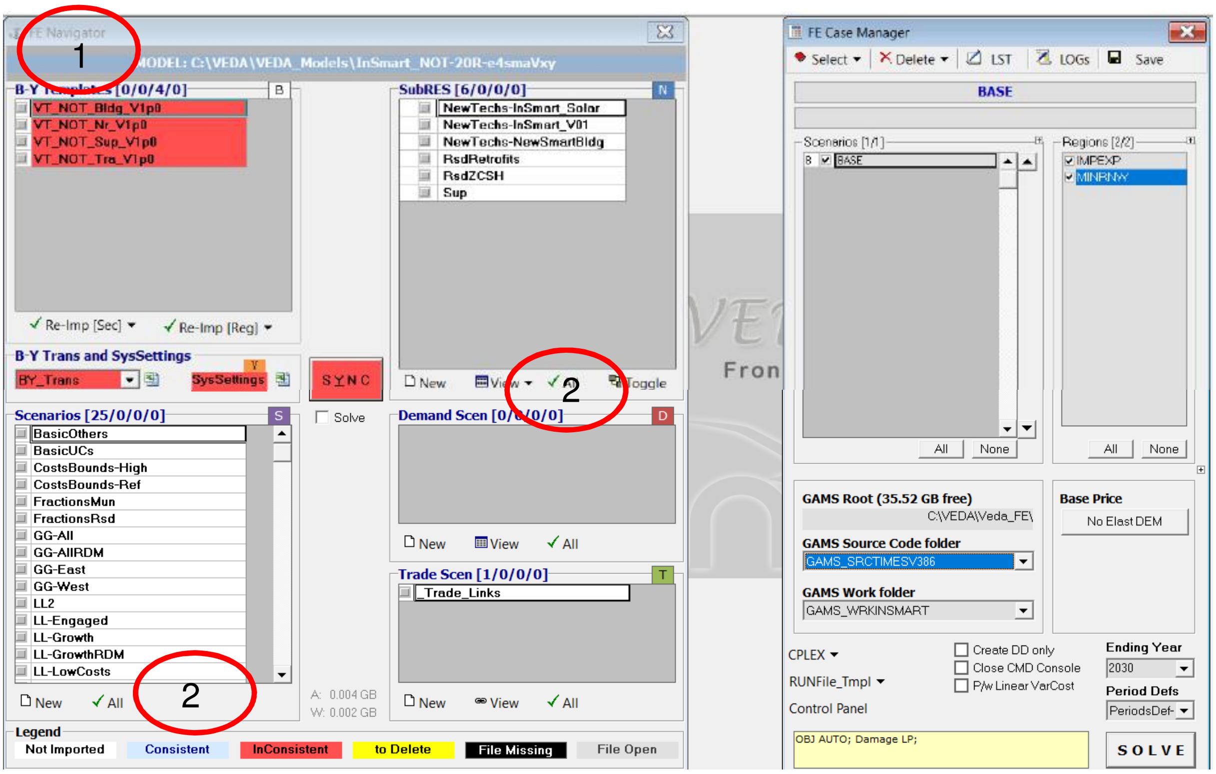
ONS (2016b). 2015 Mid-Year Estimates – Nottingham City. Population Estimates Unit, Office for National Statistics. Available online at https://nottinghaminsight.org.uk/d/171217. Accessed 20/10/16

Appendix I: How to run the energy city model of Nottingham

This appendix briefly describes the process that should be followed in order to run the ESM of Nottingham. More details about the operation of the VEDA-FE and VEDA-BE can be found in the document “Getting Started with TIMES-VEDA” v. 2.7, May 2009[9].

1) Start VEDA-FE, from VEDA-FE Navigator call the model (double click on the horizontal bar) to be imported. You will get a window similar to the one shown below.

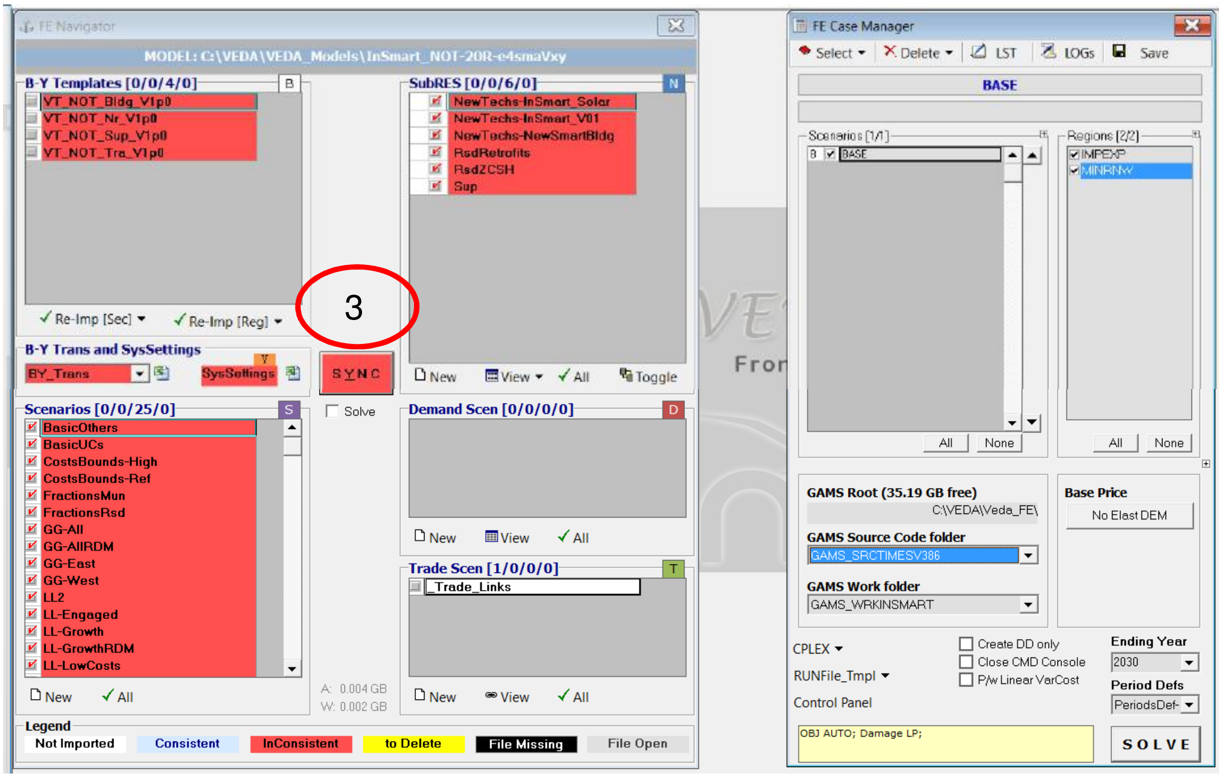


- *B-Y Templates (upper-left corner of the FE Navigator)* comprise the base year calibration templates with the data depicting the energy balance and current system composition.
    - organized by sector;
    - may contain some default time-dependent constraints (e.g. demolition rates for buildings).
- *System Files (centre-left in the FE Navigator)* corresponding to the base year (B-Y_Trans) and overall (SysSettings) system settings (e.g. adjustment factors, definition of time periods, time horizon, interpolation/extrapolation rules).

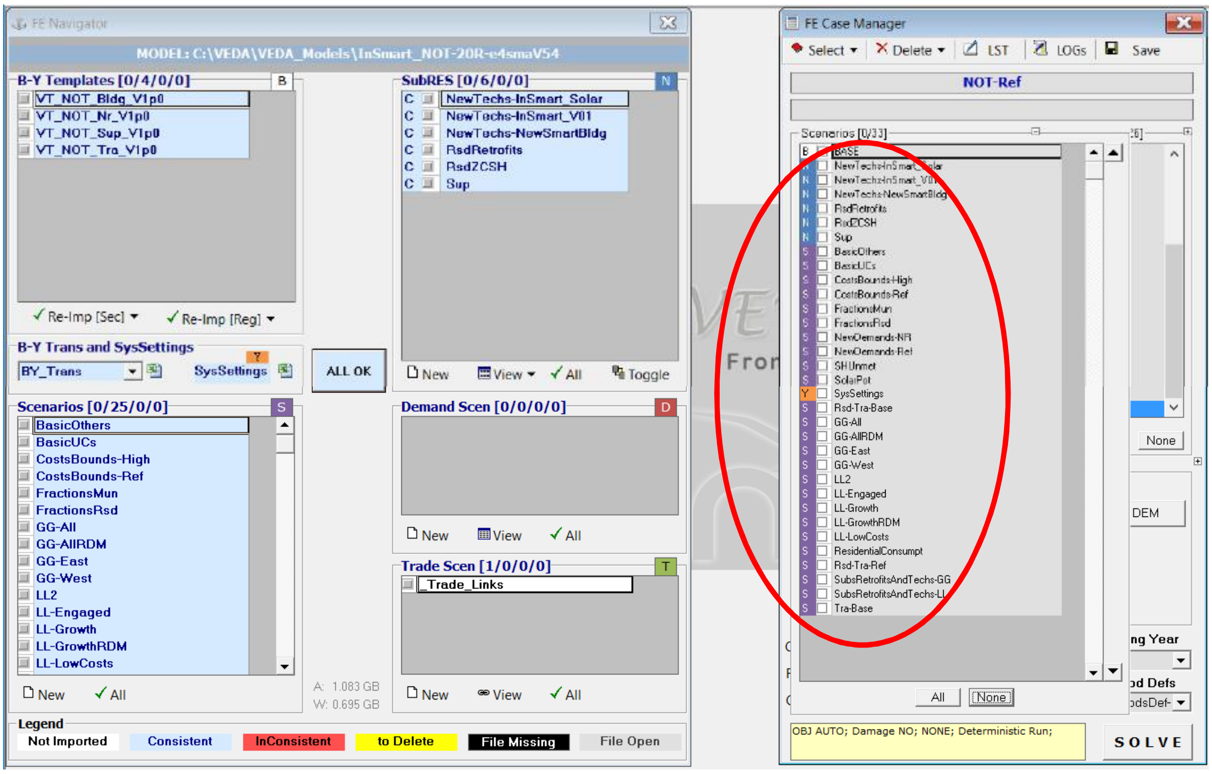
[9] http://www.iea-etsap.org/web/docs/Files_Times_Tutorial.zip

- *SubRes files (upper-right corner of the FE Navigator)* contain data specification and transformation for new technologies to be added to the B-Y system (e.g. new demand devices, alternative decentralized generation technologies, etc.).
- *Scenarios (lower-left corner of the FE Navigator)* consisting of the various modifications to the underlying energy system for the purpose of changing input data or introducing policy and other constraints on the system.

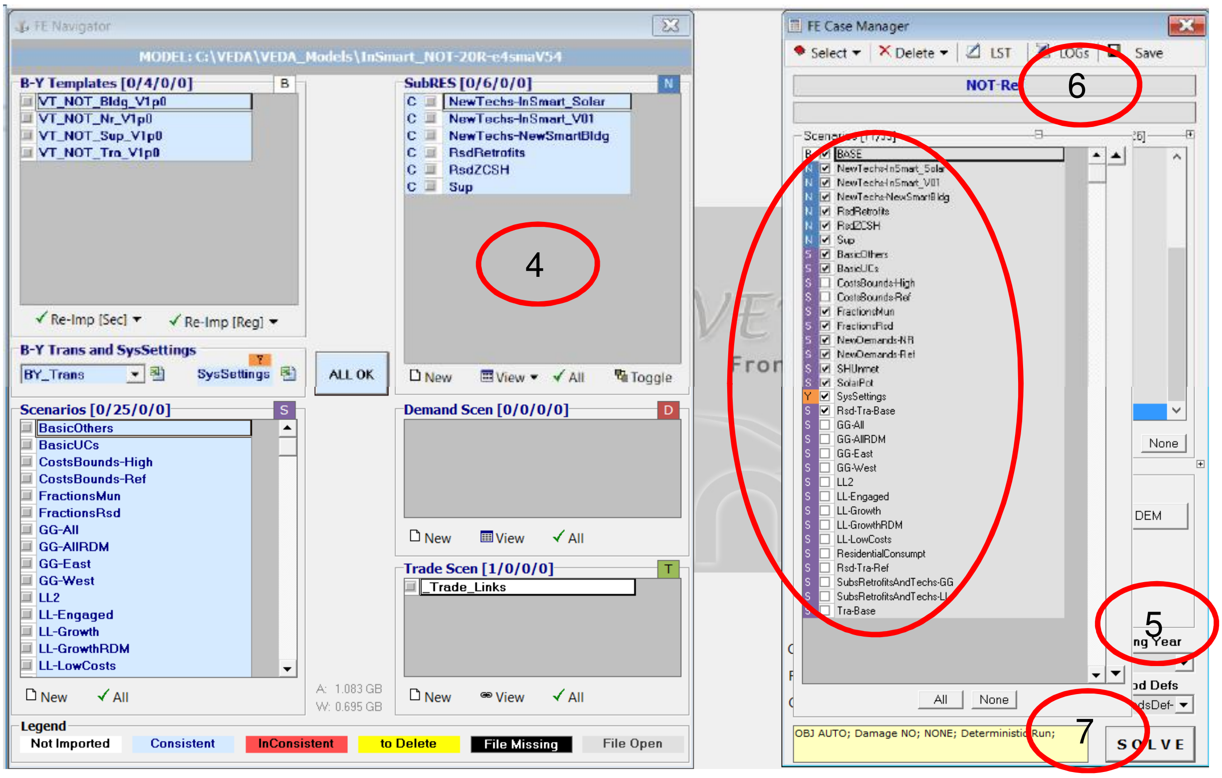
2) Select all (click on "All") the other files, or at least the subset of files required for the run. Once the selected files are viewed as "inconsistent" (as in the figure below), then synchronize the files.



3) Click on "SYNC" to import the content of the input files (.xls) in a VEDA DataBase, and to make the files "consistent" (light blue, see figure below). At the end of this stage, all the imported files (scenario files and SubRes files) will be listed under the FE Case Manager (right view of the screen).



4) Make sure to select a consistent set of files, and to sort them in the appropriate order, before running the model (see the dropdown menu of the case manager to select predefined combinations of scenarios).

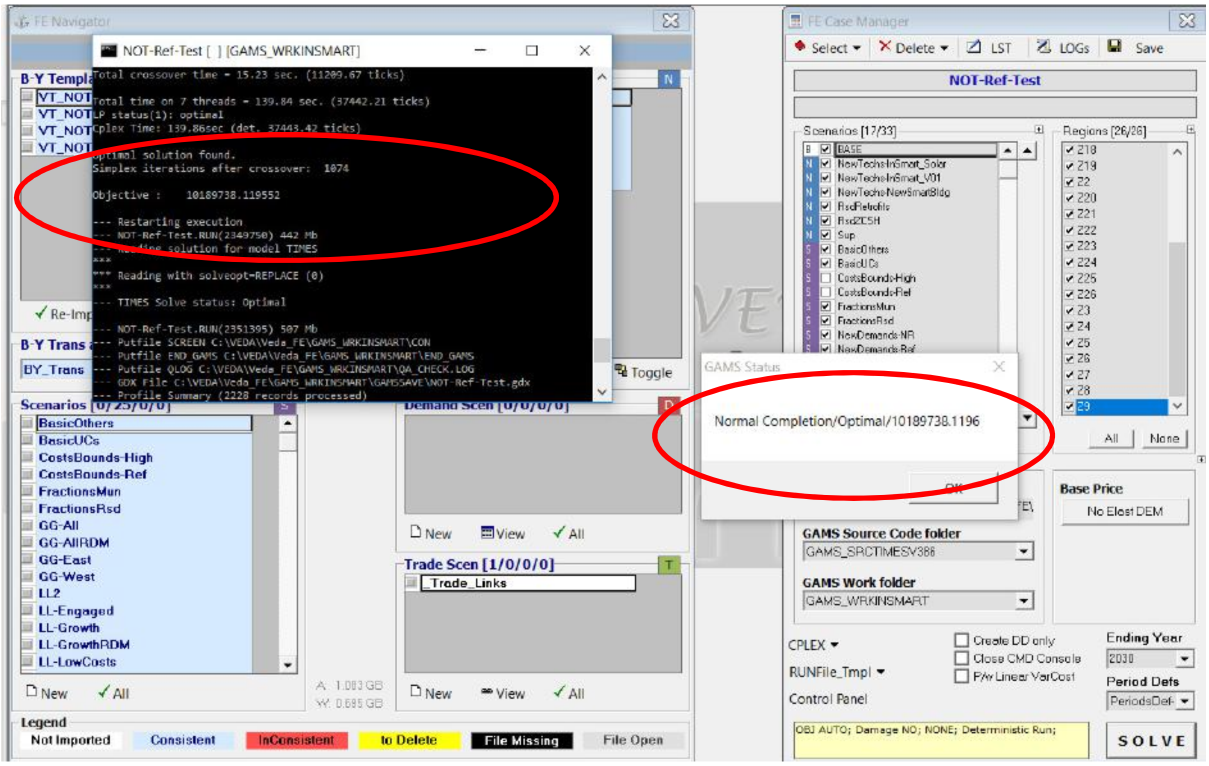


5) Select the Ending Year according to the type of test to be launched (by default the end of time horizon).

6) Type a name for the scenario under investigation (you will get the results in a DB with the same name!). *Hint*: to compare different scenarios, make sure to change the name of the alternative cases in order to save different sets of results.

7) Click to “SOLVE” and wait for the solution.

Objective function will be displayed together with some additional information (statistics and comments) about the solution.



<u>Overview of the key settings/assumptions of the ESM of Nottingham</u>

Space granularity: 20 Zones based on city wards (25 zones for transport model)

Time granularity: 3 seasons/year, End of Horizon: 2030

Base Year of the analysis: 2014

Level of detail of the building stock: 16 building typologies in the base year

Demands: Predefined growth in dwellings over the time horizon (driving energy service demands) fixed across all scenarios; transport demands (by transport mode and scenario dependent) inherited by the transport specific analysis.

Centralised supply: (exogenous) controlled by quantities/prices. Not explicitly modelled.

Decentralised supply: (endogenous) controlled by solar potential and costs of solar technologies. District heating based on EfW incinerator. Cost of additional residential connections to heat network included based on network capacity and location. Optional potential for community scale biomass CHP generation.

Retrofit measures: mainly driven by scenario hypotheses ("what-if" analysis). But such a model component can be turned into a pure cost-effectiveness based mode.

Non-Residential: Not included in standard model. Potential for inclusion as fixed energy demand over the time horizon (partially endogenous).

Coordination and support action (Coordinating Action)

FP7-ENERGY-SMARTCITIES-2012

INSMART

Integrative Smart City Planning

Report on optimum sustainability pathways – Trikala

D-WP 5 – Deliverable D5.2

Author(s): G. Giannakidis

P. Siakkis

C. Nychtis

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Project full title:

Integrative Smart City Planning

Coordination and support action (Coordinating Action)

FP7-ENERGY-SMARTICITIES-2012

Start date of project: 2013-12-01

Duration: 3 years

Deliverable D.5.2

Report on optimum sustainability pathways – Trikala

Project co-funded by the European Commission within the Seventh Framework Programme		
Dissemination Level		
PU	Public	
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Version	**Submitted by**	**Review Level***	**Date Submitted**	**Reviewed**
1	G. Giannakidis		30 September 2016	

Editors		
	Name (organization)	**e-mail**
Leading participant	G. Giannakidis (CRES) P. Siakkis (CRES) C. Nychtis (CRES)	ggian@cres.gr fsiakkis@cres.gr cnychtis@cres.gr
Contributing participants		
WP Leader (WPL)	E4SMA	
Project Coordinator (PC)	CRES	

Executive Summary
This report presents the setup, input data scenario formulation and the scenario results from the Energy System Model of Trikala. The model structure is presented in detail, describing the different energy consumption sectors that are modelled and the corresponding input data for the base year calibration. Fifteen "policy" scenarios were developed together with a Baseline scenario in order to examine the effect of different intervention on the development of the energy system of Trikala. A number of indicators were calculated and were used to compare the scenario results.

Keywords	Energy System Model, Scenario formulation, Scenario analysis.

Table of Contents

1. Introduction

INSMART aims to address the issue of integration in the energy planning approach of the cities participating in the project, and this will be done with the use of the City Planning Platform which will use an energy systems model (Figure 1-1). The work packages of INSMART have been structured in such a way so as to provide all the necessary information to the Energy System Model (ESM), in order to analyze scenarios in an integrated approach, and then provide input to a Multi-criteria Decision Analysis process in order to choose the "best alternative" for all the stakeholders.

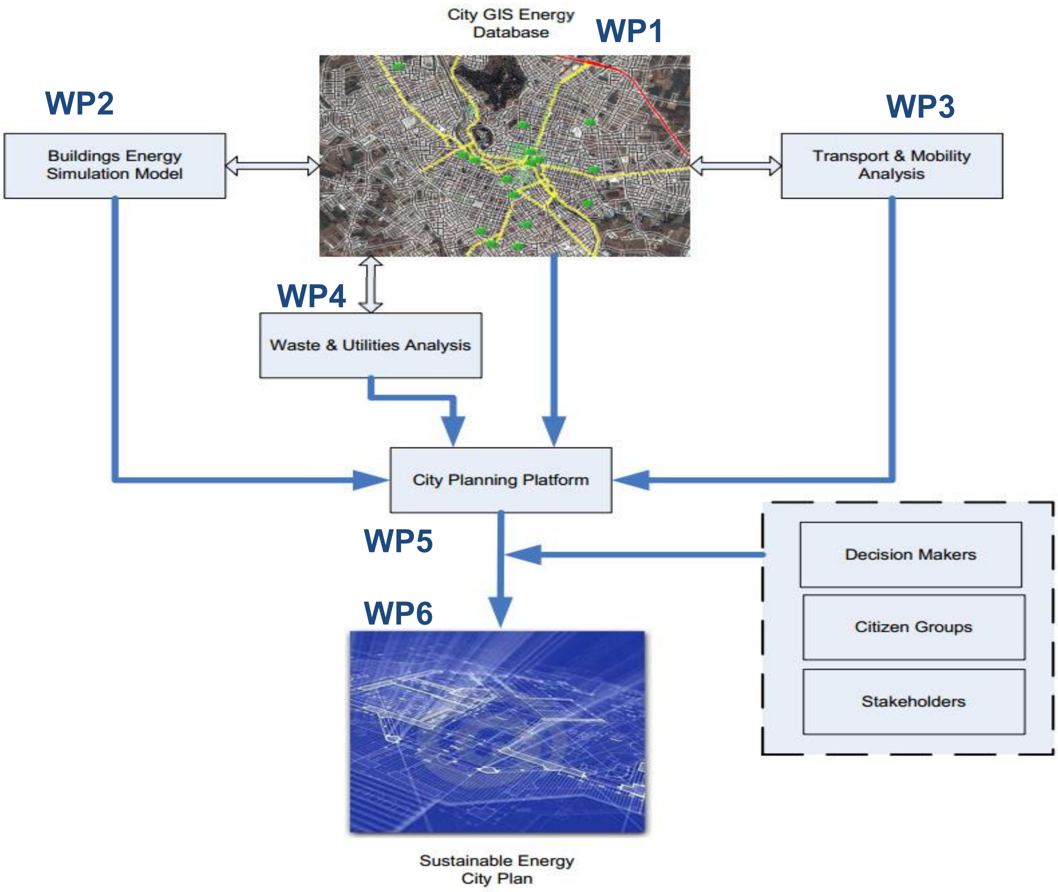


Figure 1-1: Overview of INSMART's approach

The analysis of the future development of the energy system of each city is performed with the use of an Energy System Model based on the TIMES model generator. TIMES, The Integrated MARKAL-EFOM System is a liner programming, bottom-up energy model generator which offers the possibility of an integrated modelling of the entire energy system. The TIMES model is demand driven, which means that exogenous assumptions are required for the future development of drivers which are causing changes in the demand for useful energy like space heating and lighting.

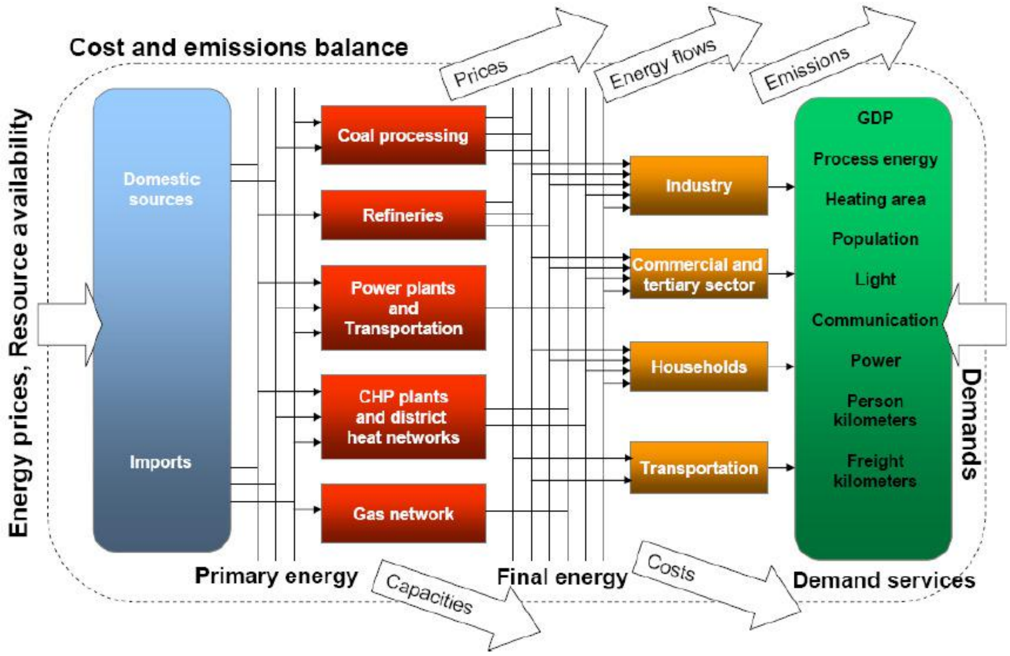


Figure 1-2: Overview of TIMES (Source: Remme U. 2007 Overview of TIMES. Proc. ETSAP Workshop November 2007 Brazil.

The solution of a TIMES model provided the optimal technology mix which can satisfy the useful energy demand, minimising the total system cost of equivalently maximising the net social surplus. The model computes both the flows of energy (materials and environment) and their prices, in such a way that the suppliers of energy produce exactly the amounts that the consumers are willing to buy. Furthermore, the model can include environmental constraints, resource availability constraints, technology availability constraints, capital availability constraints etc. Another feature of TIMES is the possibility of creating regional models, by dividing the area under analysis in smaller regions (city zones in our case) which can exchange energy commodities (e.g. natural gas) through interconnection technologies (natural gas grid). This can be used to study future increase of the interconnection capacities of the grids between city zones.

In the framework of the specific decision problem of the sustainable development of the energy system of a city, the TIMES model can be applied more in a simulation mode instead of a full optimisation mode. This was one of the common conclusions of the workshops that took place in the four cities of the INSMART project. The local policy makers are more interested to see the effect of specific actions, which can be implemented by them through concrete programs, instead of trying to analyse an optimum pathway that would most probably require interventions that they cannot control. For this reason the scenarios defined for the energy system of Trikala and are presented in the following sections include concrete actions/projects/programmes that will be analysed and ranked.

The data required for the setup of the ESM were provided from the other project work packages as described below (see Figure 1-1 for a schematic layout of the process).

Residential buildings: The characteristics of the existing building stock were collected through the surveys of **WP1**. The analysis in **WP2** provided the energy demand for the existing situation and the energy savings for alternative interventions which are both required in the modelling of the energy demand of the residential sector.

Municipal and Commercial Buildings: The energy demand of the municipal and commercial buildings was collected from the municipality and national data respectively in **WP4**.

Transport: The transport analysis of **WP3** provided a description of the existing situation, through the transport surveys, and snapshots for the development of the transportation demand in 2020 and 2030 in the baseline scenario and in alternative mobility scenarios. The demand of vehicle kilometres per city zone is used as an input to the ESM.

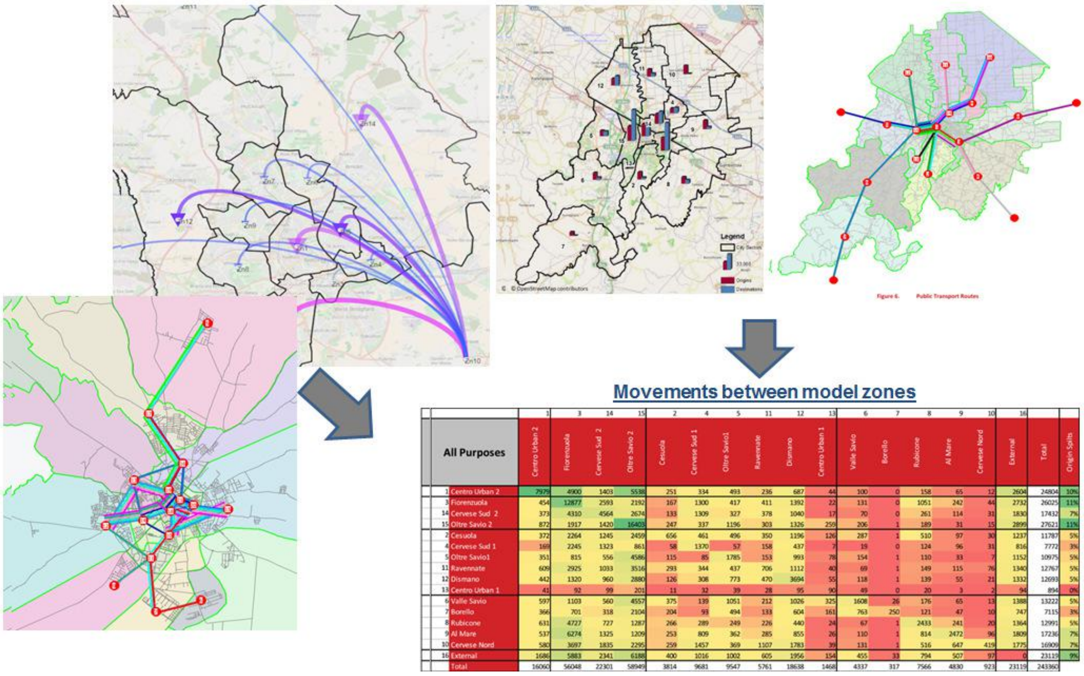


Figure 1-3: Transport sector approach and data used in ESM

Other consumption within the city: This includes consumption of water pumping and waste treatment and mobility of municipal vehicles. These data were collected in the framework of **WP4**.

Existing RE installations and potential: The only existing options for energy generation within the city of Trikala are RE technologies and in particular PVs. The existing stock data was collected in **WP4** and an analysis of the expected maximum technical potential was performed and is used as an ESM input.

2. City Energy System Model for Trikala

The energy system of Trikala was analysed using a TIMES model developed specifically for the city taking into account the existing infrastructure and the alternative options that are studied in the scenarios. The advantage of using a least cost optimisation energy system model is the fact that interactions between technologies and sectors can be identified and an overall economic optimum can be achieved. The Trikala ESM is a multi-regional TIMES model. The city is divided into 20 zones (see Figure 2-1), which are the same as the zones used in the transport model and the zones used in the presentation of all the energy data of the city (Table 2-1).

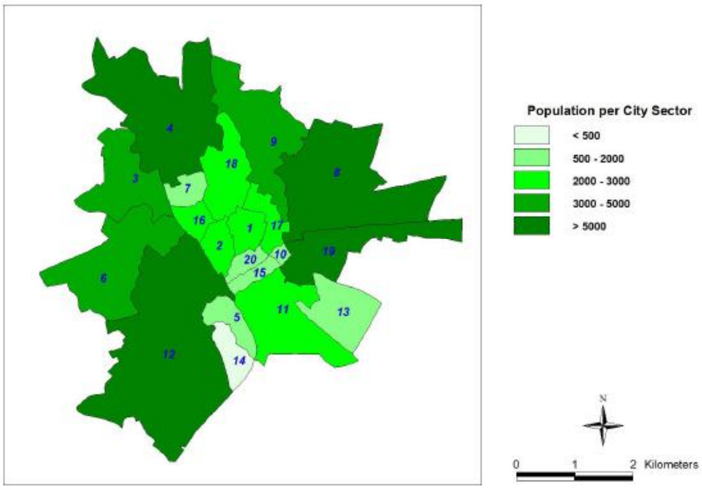


Figure 2-1: Twenty zones used in the Energy System Model of Trikala

Table 2-1: City zone names and population

SECTOR	SECTOR NAME	POPULATION
1	City Centre	2537
2	Alexandra	2473
3	Pirgos	3491
4	Koutsouflianis	7323
5	Papamanou	527
6	Pirgetos	4031
7	Nekrotafio Trikalon	1995
8	Mavili	6917
9	Paleologou	3434
10	Spartis	506
11	General Hospital	2974
12	Train Station	9422
13	Patmou	644
14	Flamouliou	364
15	Archimidi	1417
16	Dim Ntai	2042
17	Sokratous	2599
18	P Mela	2860
19	Ethniko Stadio	5222
20	Siggrou	1378

In order to capture the time variation of the energy demand, a number of time slices were introduced in the Trikala ESM according to the following approach. The year was divided into four seasons, namely Spring (R), Summer (S), Fall (F), and Winter (W). Then each day within each season was divided into four periods: Day, Night, Peak and Low in order to cover the intraday demand pattern in each season. This leads to sixteen time slices overall. Table 2-2 shows the duration of each one of these time segments used in the analysis.

Table 2-2: Time slices definitions

a) Definition of Seasons

Seasons	N. of Days in the season	Fraction of the year	Period covered
spRing	92	0.252	1st March- 31 May
Summer	92	0.252	1 June - 30 August
Fall	91	0.249	1 September - 30 November
Winter	90	0.247	1 December - 28 February
	365	1.00	

b) Definition of time of day

Hours within each period	Time of day			
Season	**Day**	**Night**	**Peak**	**Low**
spRing	11	11	1	1
Summer	14	8	1	1
Fall	12	10	1	1
Winter	11	11	1	1

The base year of the model is 2012, since this was the most recent year with a full set of statistical data available. The model is solved in a time horizon until 2032, using a step of two years in order to reduce the computational time requirements.

3. Structure of the model and methodological approach

The boundaries of the Energy System model for Trikala can be seen in Figure 3-1. The data and the analysis of WP2 (residential buildings), WP3 (transport) and WP4 (municipality buildings and other energy uses) are used as an input to the ESM in order to model the overall energy system. The players involved in the decisions in the energy sector are the households, which have a limited budget in order to cover their energy needs and to invest in more energy efficiency equipment and the public bodies (municipality) which are also in a similar situation.

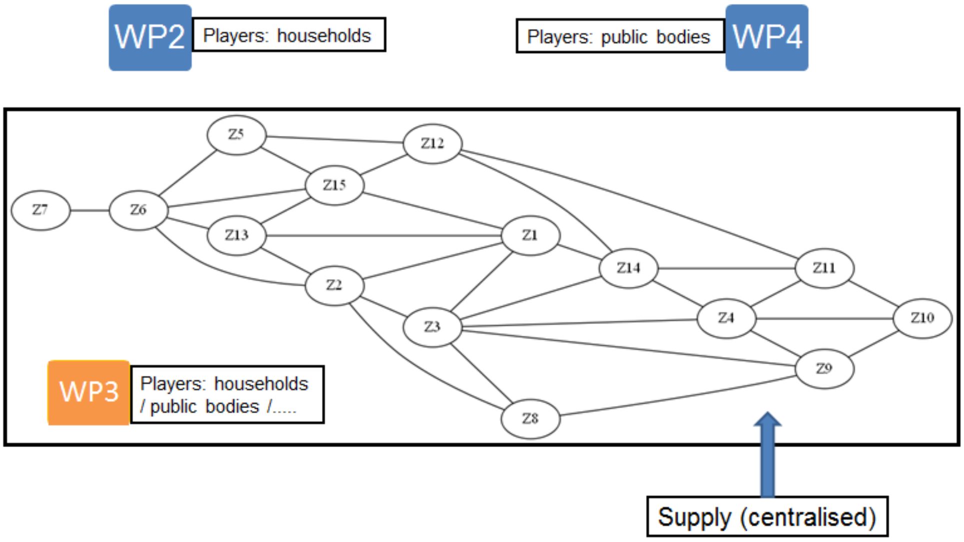


Figure 3-1: Boundaries of ESM for Trikala

The Trikala ESM includes the following energy consumption sectors:

- Residential
- Municipal activities
- Transport
- Commercial

A brief presentation of the model structure for each one of these sectors is presented in the following sections.

3.I.1. Residential Sector

According to the estimated energy balance data for Trikala, residential is the sector with the highest energy consumption overall. That is why this sector was targeted in the surveys and simulations of WP1 and WP2 and is analysed in more detail in the Trikala ESM. In the ESM approach the basic demand unit is a dwelling. The existing situation is presented by the existing dwellings per typology in each one of the twenty city zones (see Figure 3-2).

			TechName	Comm-OUT	Year	Z01	Z02	Z03	Z04	Z05	Z06	Z07
1	Detached	< 1900	Rdw_DetH	R_DetH	1900	0.0040	0.0146	0.0008	0.0024	0.0000	0.0028	0.0013
2	Detached	1980-2000	Rdw_DetH	R_DetH	1990	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	Semidetached	<1900	Rdw_SDetH	R_SDetH	1900	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4	Flat	<1980	Rdw_Flat	R_Flat	1980	0.5955	0.1017	0.0000	0.0000	0.0000	0.0000	0.0000
5 and 5i	Flat	1980-2000	Rdw_Flat	R_Flat	1990	0.3912	1.2069	0.0000	0.0000	0.0000	0.0000	0.0000
6	Flat	>2000	Rdw_Flat	R_Flat	2000	0.0066	0.3384	0.0000	0.0129	0.0000	0.0000	0.0000
7	Detached	<1980	Rdw_DetH	R_DetH	1980	0.0349	0.8732	0.1955	0.6929	0.0592	0.2513	0.3744
7i	Semidetached	1980-2000	Rdw_SDetH	R_SDetH	1990	0.0000	0.0660	0.1778	0.1508	0.0223	0.0915	0.0656

Figure 3-2: Existing Dwellings

The basic categories for dwellings are

- Flats
- Detached Houses
- Semi-detached Houses.

The reason for this distinction is the different behaviour for space heating, cooling and hot water demand for each one of these types of dwellings. The next level of categorisation is based on the construction year, which is used as a parameter in the model.

Each dwelling is considered to have a set of input demands which can be seen for the case of flats in Figure 3-3. The number of dwelling for each category is the demand that drives that energy consumption in the residential sector. Furthermore, in order to include the demand for transport, each dwelling is associated with a demand for each transport mode from one zone to another, as was calculated in WP3 using the transport sector model for Trikala. A more detailed presentation of this is given in the transport sector description, which follows. The demand for space heating, space cooling and hot water for each type of dwelling is based on the calculations performed in WP2, for each building typology. Currently this demand is the same across all city zones; however the model has the possibility to include different levels of demands in each zone if these data are available.

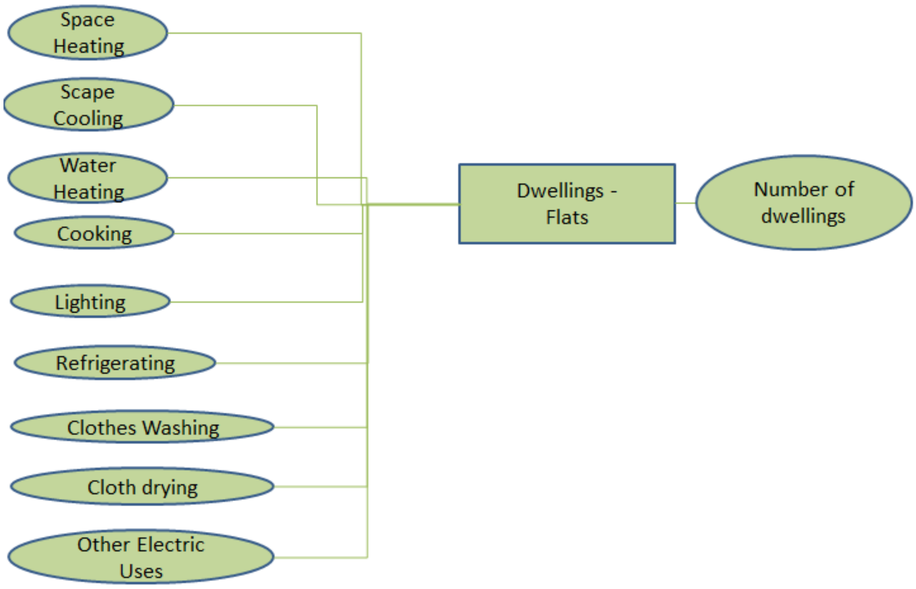


Figure 3-3: Uses in the residential sector

Different technological options exist for providing each one of the demands in the residential sector. The base year technologies are defined in the BY templates of the model, and the set of possible new technologies that will be available in the future are defined in detail as well. An example of the technological options for Space heating in Flats can be seen in Figure 3-4, and the full list of technologies is included in the model database.

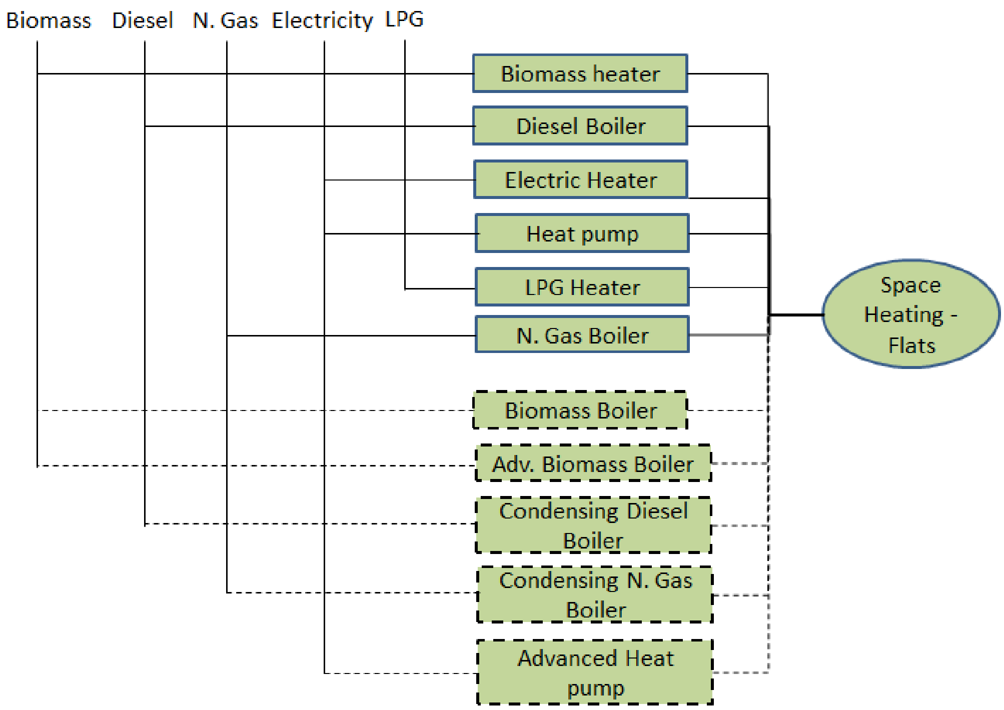


Figure 3-4: Technology and energy commodity options for space heating in flats. Dotted lines present future technological options.

The analysis of WP2 showed that the theoretical heating, cooling and hot water needs of the residential sector are not fully covered, based on the calculations of the actual energy consumption in the residential buildings of the city. Therefore there is an "unmet demand" which means that the internal comfort conditions in the buildings differ from the theoretical optimum conditions. In order to include thin in the analysis a number of dummy technologies were introduced in the model (see Figure 3-5: Dummy technologies for modelling the unmet space heating demand.Figure 3-5) and the assumption that the unmet demand is continuously reduced and is reaching zero by 2030, which means that all households reach the optimal indoor thermal conditions by that time.

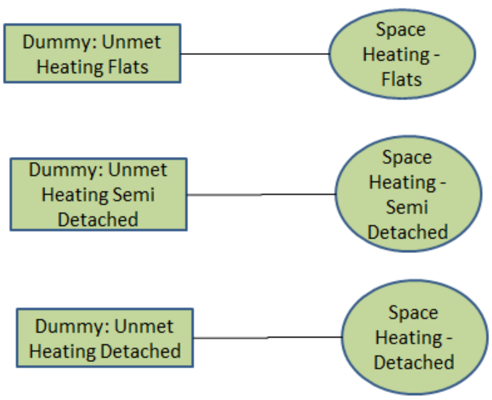


Figure 3-5: Dummy technologies for modelling the unmet space heating demand.

In order to model future refurbishment options, a set of dummy technologies were introduced in the model for each typology to represent specific options. These technologies can cover part of the space heating and cooling demand without energy consumption. According to the analysis presented in the WP2 report there are four possible refurbishment options that can be implemented in the residential sector buildings:

1. Installation of external insulation on the walls for typologies without insulation or insufficient insulation, according to the thermal properties defined by the Greek Regulation for the specific climate zone.
2. Installation of external insulation on the roof for typologies without insulation or insufficient insulation, according to the thermal properties defined by the Greek Regulation for the specific climate zone.
3. Replacement of existing windows, according to the thermal properties defined by the Greek Regulation for the specific climate zone.
4. Installation of external insulation on the walls and the roof for typologies without insulation or insufficient insulation and replacement of existing windows, according to the thermal properties defined by the Greek Regulation for the specific climate zone.

Each one of these actions has an implementation cost (which was estimated based on existing market data) and leads to a reduction of the space heating and cooling demand, according to the calculations performed in WP2. The ESM has the flexibility to choose among these available options, based on the relative cost, achieved energy savings and alternative options in the energy system. The reference energy system for this specific setup can be seen in Figure 3-6. It should be noted that option 4 includes all three previous options. Therefore, a user constraint is implemented in the model in order to ensure that if option 4 is applied none of the other options can be applied in the same dwelling.

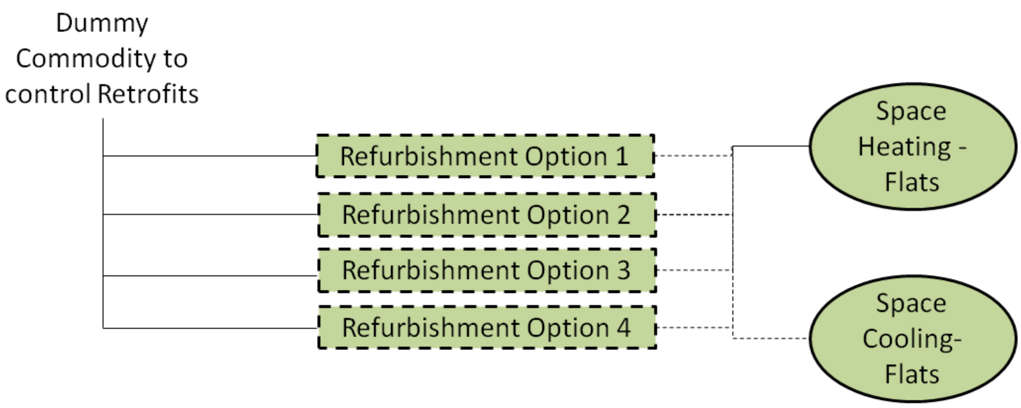


Figure 3-6: Refurbishment options for dwellings

3.I.2. Municipality Sector

The energy consumption that is attributed to the Municipality includes the following subsectors:

- Schools
- Offices
- Other Buildings
- Public lighting
- Water pumping
- Sewage pumping
- Sewage treatment plant
- Municipal small vehicles
- Municipal trucks (waste collection trucks etc.)

The first three categories, namely schools, offices and other buildings are modelled in the same way as the residential sector buildings. Each building type is associated with the demands for space heating, space cooling, lighting and other electric uses. Each of these demands is covered by a set of existing technologies and a number of future technologies (with an investment costs associated with their installation). The data regarding the existing number of buildings per type, their location in the city zones and the energy consumption were provided by the municipality of Trikala in the framework of WP4.

Water and sewage pumping demand is covered by the existing pumping motors and technology options for replacement in the future are also given. The sewage treatment plants is treated as a "black box" with an electricity consumption and the improvement options that are considered in the scenarios are modelled as alternative technologies with increased efficiencies and an associated investment cost. Details on the current consumption and operation were provided by DEYAT, which is responsible for the operation of the pumping stations and the sewage treatment plant.

Municipal transportation demand for small vehicles and trucks are treated using a demand for vehicles kilometres per year, which is derived from the annual consumption data of the base year and an estimation of distance covered per vehicle per year. The existing vehicles are considered as a generic technology, since they have almost the same energy consumption characteristics (same age and similar usage). The new technologies that are available and implemented in some of the scenarios include improved trucks (Euro 6) and gasoline small vehicles as well as electric vehicles to replace conventional small vehicles (Figure 3-7).

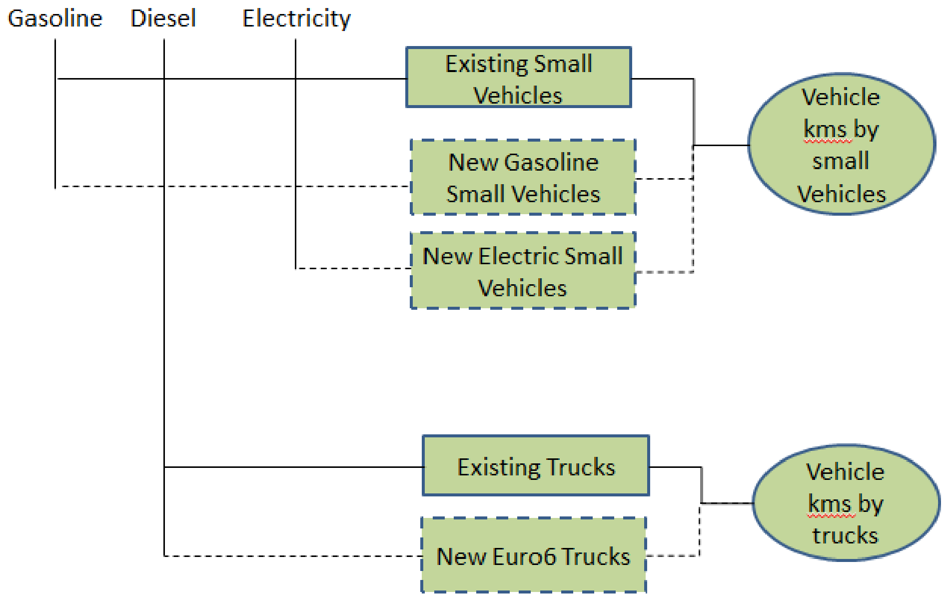


Figure 3-7: Municipality owned vehicles and transport demand

3.I.3. Transport

Following the residential sector, Transport is the sector with the second largest energy consumption. A detailed analysis of the sector was took place in WP3 with surveys and a detailed transport model, whose output is used as an input to the ESM of Trikala.

The analysis of WP3 produced tables of transportation needs (Vehicle kilometers/year) from each city zone to another using cars, motorcycles, busses and Light Duty Vehicles, for the base year, as well as future tables for the transport scenarios in 2020 and 2030. In the Trikala ESM this transport demand is connected with the dwellings and is modelled as an input demand for each type of dwellings, expressed in vehicle kilometres per dwelling per year from zone x to zone y (see for example Figure 3-8).

	Cars	Vkm/Dwelling per year																			
Dwellings		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1032	1	735	7	0	8	0	0	15	0	12	0	19	41	7	0	0	0	0	2	97	1
2601	2	3	299	0	5	0	0	18	0	18	0	7	122	2	0	0	1	0	6	17	8
374	3	222	2641	0	618	0	0	2519	0	1166	0	145	20839	63	0	0	50	41	428	553	224
859	4	213	11575	0	1203	0	0	1703	0	596	0	257	9242	100	0	0	48	35	460	617	181
82	5	506	1617	0	213	0	0	674	0	1907	0	7012	1084	204	0	0	47	80	484	1305	774
346	6	524	2617	0	814	0	0	2758	0	946	0	222	18649	135	0	0	152	86	988	878	487
441	7	21	5887	0	88	0	0	576	0	158	0	68	1227	11	0	0	10	4	65	73	31
668	8	562	1772	0	463	0	0	1093	0	2411	0	22844	892	273	0	0	72	71	1278	3855	727
1350	9	35	481	0	63	0	0	126	0	265	0	2760	545	39	0	0	6	5	150	371	40
184	10	4	29	0	5	0	0	10	0	66	0	4406	10	1	0	0	1	0	17	134	17
666	11	184	720	0	81	0	0	271	0	431	0	2524	250	139	0	0	20	27	222	675	371
1694	12	135	1192	0	113	0	0	364	0	335	0	93	5044	17	0	0	24	22	188	256	211
85	13	152	472	0	61	0	0	159	0	491	0	7725	112	41	0	0	13	22	166	470	241
48	14	608	2612	0	413	0	0	1132	0	916	0	5947	8378	138	0	0	59	93	524	2824	576
476	15	43	251	0	28	0	0	106	0	133	0	1604	134	49	0	0	6	6	71	395	132
661	16	14	1259	0	67	0	0	311	0	64	0	42	254	14	0	0	9	2	60	112	25
2286	17	1	9	0	4	0	0	8	0	13	0	11	20	6	0	0	0	337	6	77	4
720	18	31	3193	0	133	0	0	356	0	245	0	943	1827	72	0	0	18	7	392	609	82
414	19	384	1323	0	220	0	0	605	0	1850	0	14650	369	80	0	0	41	49	787	2974	673
470	20	13	841	0	19	0	0	64	0	66	0	886	206	27	0	0	3	2	36	150	76

Figure 3-8: Demand of Vkm/dwelling per year from zone x to zone y for cars.

Each dwelling in city zone x is then allocated with a demand for vehicle kilometres by car to zone y, vehicle kilometres by bus to y etc. This demand is covered by the existing stock of vehicles in the base and with new vehicles in the future years, as the demand increases and vehicles are replaced (Figure 3-9).

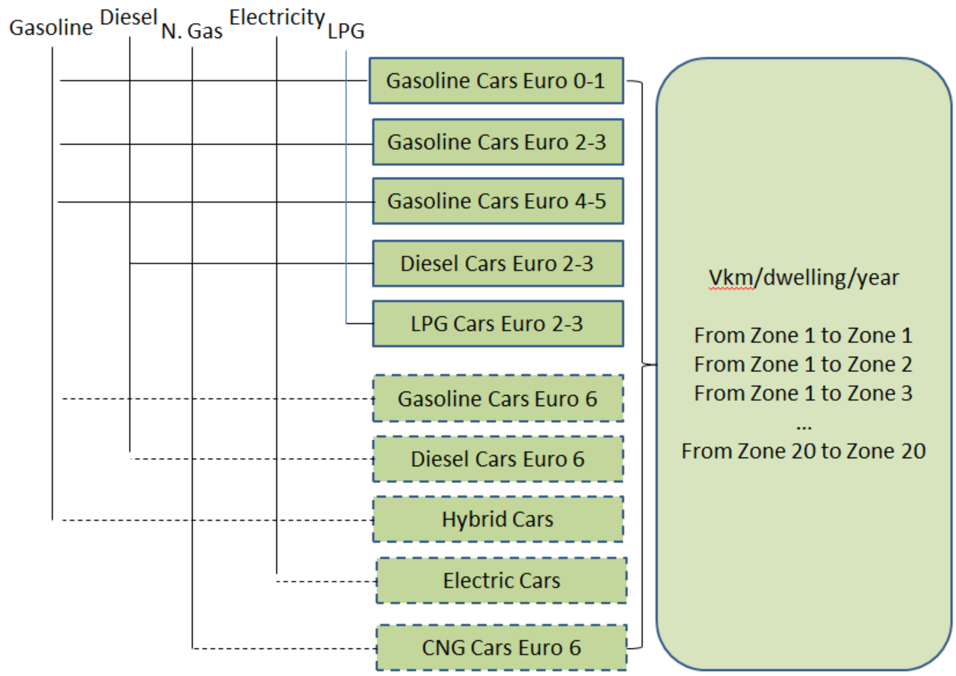


Figure 3-9: Transport by cars

3.I.4. Commercial Sector

The commercial sector includes all the other building types that are not residential or do not belong to the Municipality, namely offices, cafes and restaurants, super markets, shops etc. The commercial sector is modelled using a generic representation, using the average consumption of the existing buildings (Figure 3-10). This was considered as the most suitable approach in order to account for the commercial sector since: a) the commercial sector data availability is very limited and b) none of the scenarios analysed for Trikala focuses on the commercial sector. Further future analysis combined with targeted surveys could be used in order to cover in more detail this point. The development of the generic demand for the commercial sector in the future years is taken to be related to the assumption for the population growth in the city, since there were no other data for the probable change of activities in the sector. When the commercial sector is further analysed in a future extension then different energy demands for specific subsectors and different drivers for each energy demand could be considered.

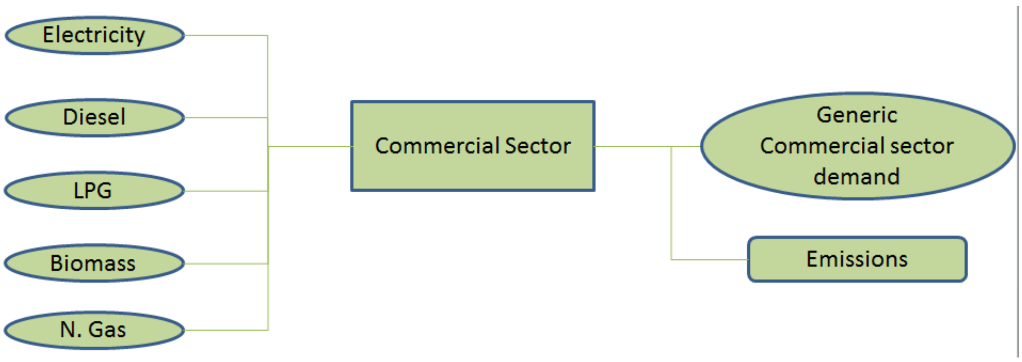


Figure 3-10: Commercial Sector Generic modelling

3.I.5. Emissions

In order to track the level of GHG and other emissions within the city limit the following GHGs and local pollutants were tracked in the analysis: CO_2, COx, CH_4, SO_2, NOx, N_2O, Particulate Matter 10, Particulate Matter 2.5, Non Methane Volatile Organic Compounds (NMVOC). An option for the inclusion of SF6 and Other Fluorocarbons exists, but it was not used in the current analysis due to lack of detailed emission coefficients. The model setup ensures that the level of emissions is tracked for each sector of energy consumption in order to be able to identify the most polluting sectors and also to identify the effect of the measures analysed in the scenarios. The emission coefficients used for each of these pollutants were derived from the UNFCCC guidelines and the total Global Warming Potential for 100 years[1] was used in order to calculate the total level of CO_2 equivalent emissions.

Stationary Sources Emissions coefficients			Fuel	
Pollutant	**LPG**	**Diesel**	**N. Gas**	**Biomass**
CO_2 (t/TJ)	65	78	56	0
CO_X (kg/TJ)	0	0	26	4000
SO_2 (kg/TJ)	0	0	0.3	11
NO_X (kg/TJ)	0	0	51	80
PM 2.5 (kg/TJ)	0	0	1.2	740
PM 10 (kg/TJ)	0	0	1.2	760

4. Description of the existing system

In a TIMES model the first step after the representation of the existing energy system with the Reference Energy System of the model, must be the calibration. This is mainly stock calibration for the base year (2012 in the case of the Trikala ESM), which means that the model reproduces the stocks of technologies in the Base Year and all the other known investments until today. Such a stock-based calibration is more important than a standard flow-based calibration for a technology-oriented model, since it determines an exogenous profile of the installed capacity in the short term. For the base year calibration of the model the input parameters required include:

- Detailed Energy balance of the base year.
- Breakdown of the energy balance per subsector of final consumption
- Allocation of energy commodity consumption to end use services demands.
- Time slice variation of end use services demands.
- Data on existing stock of dwellings.
- Average efficiencies, availability factors, lifetime, and operation cost of existing technologies.

[1] http://unfccc.int/ghg_data/items/3825.php

The data used for the base year calibration of each one of the demand sectors are presented in this chapter for reference.

4.I.1. Residential building stock and unit energy demand

The residential building stock data per typology were determined from the analysis of WP1 using the data of the survey and data from the National Statistical Office of Greece. The outcome of this analysis was a breakdown of the number of residential buildings per city zone and per typology (as defined in WP1 and WP2). The distribution of the residential buildings per city zone can be seen in Table 4-1. The typology numbers in the table correspond to the typologies presented in detail in the WP2 report for the City of Trikala (Deliverable D.2.2.).

According to the model set up described in Chapter 2, for each typology of residential buildings a demand for space heating, space cooling and hot water was assigned, based on the analysis of WP2. This demand is not differentiated per city zone, since the modelling analysis could not include such a differentiation, although the TIMES model set up could accommodate for this if it was available. These demands are presented in Table 4-2.

According to the analysis of WP2 it was calculated that there is a level of unmet demand for space hearting and hot water in the residential sector. This can be seen in the table below.

Type	% Unmet heating Demand	% Unmet Hot water demand
Flats	18%	84%
Detached	44%	83%
Semi-Detached	9%	77%

Table 4-1: Residential buildings stock distribution per city zone.

Typ.	Type	Year	Z01	Z02	Z03	Z04	Z05	Z06	Z07	Z08	Z09	Z10	Z11	Z12	Z13	Z14	Z15	Z16	Z17	Z18	Z19	Z20
1	Detached	< 1900	4	15	1	2	0	3	1	2	3	0	2	6	0	1	3	5	18	73	1	5
2	Detached	1980-2000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	139	0	0
4	Flat	<1980	595	102	0	0	0	0	0	0	0	0	0	0	0	0	0	0	155	33	0	0
5 and 5i	Flat	1980-2000	391	1207	0	0	0	0	0	0	229	11	0	0	0	0	97	134	1151	78	0	122
6	Flat	>2000	7	338	0	13	0	0	0	0	176	28	0	9	0	0	34	28	151	16	0	29
7	Detached	<1980	35	873	196	693	59	251	374	550	673	125	539	1262	75	39	287	399	740	365	327	265
7i	Semi detached	1980-2000	0	66	178	151	22	91	66	116	269	20	126	417	10	8	56	96	70	16	86	49

Table 4-2: Unit energy demand per type of residential building.

Use	Type	Construction year	TJ/ 000dwelling	Use	Type	TJ/ 000dwelling
Space Heating	Flat	1980	27.70	**Water Heating**	Flat	12.84
	Flat	1990	16.22		Detached	12.82
	Flat	2000	12.05		Semi Detached	10.28
	Detached	1900	46.40	**Space Cooling**	Flat	5.40
	Detached	1980	26.53		Detached	2.98
	Detached	1990	49.53		Semi Detached	4.93
	Semi Detached	1900	0.00			
	Semi Detached	1990	36.93			

Table 4-3: Municipal buildings stock distribution per city zone.

Area in 000m^2

Type	Z01	Z02	Z03	Z04	Z05	Z06	Z07	Z08	Z09	Z10	Z11	Z12	Z13	Z14	Z15	Z16	Z17	Z18	Z19	Z20
Schools	4.60	4.60	5.75	8.06			5.75	10.36	11.51	2.30	4.60	9.21			3.45	5.75	3.45	4.60	5.75	2.30
Offices	3.03																			
Others	15.66	1.96	0.00	1.96			5.87	0.00	1.96	0.00	0.00	1.96			0.00	0.00	11.74	3.91	1.96	1.96

4.I.2. Municipal buildings and other demands

Data related to the number and use of municipal buildings where collected directly from the Municipality of Trikala. Furthermore, energy consumption data were also collected and were used as a reference for the estimation of the useful energy demand for heating and cooling per type of building. As was mentioned in Chapter 3, the municipal buildings were divided into three categories: Offices, Schools and other buildings. The distribution of the area covered by these types of buildings per city zone can be seen in Table 4-3.

Based on the analysis of the energy consumption data and existing technologies data provided by the Municipality in WP4, the overall energy balance of the city of Trikala and national values an estimation of the useful energy demand for space heating, space cooling and water heating (where appropriate) was performed and is presented in Table 4-4.

Table 4-4: Unit useful energy demand per type of Municipal building

		TJ/000m2
Space Heating	Schools	0.012
	Offices	1.027
	Other	0.036
Space Cooling	Schools	0.004
	Offices	1.569
	Other	0.035
Water Heating	Schools	0.000
	Other	0.001

Data for the demand for public lighting in the base year were collected from the Municipality. This included the number of lightbulbs per voltage and type as well as the operational schedule (operational hours) in order to estimate the electricity consumption. The geographical distribution of the installed capacity per bulb type can be seen in Table 4-5. The electricity consumption for water pumping, sewage pumping and the operation of the sewage treatment plant were provided by DEYAT, together with the installed capacity of the motors used. These were included in the base year calibration of the model and can be seen in Table 4-6.

The transportation activities for municipal uses include light vehicles and heavy duty vehicles (truck, waste collection trucks). The fuel consumption for these vehicles was provided by the Municipality and an estimation of the required vehicle kilometres per year was performed in order to calculate the energy service demand. The average efficiency of the existing vehicles is rather low according to the Municipality data and scenarios for their replacement are included in the analysis.

Finally, the consumption in the commercial sector per city zone was estimated based on the geographical distribution of the different commercial activities and average values derived from national data.

Table 4-5: Distribution of street lighting installed capacity per bulb type

MW	Z01	Z02	Z03	Z04	Z05	Z06	Z07	Z08	Z09	Z10	Z11	Z12	Z13	Z14	Z15	Z16	Z17	Z18	Z19	Z20
Sodium Bulbs	0.03	0.04	0.08	0.20	0.01	0.06	0.04	0.14	0.11	0.01	0.09	0.25	0.03	0.01	0.02	0.03	0.05	0.07	0.06	0.02
Hg Bulbs	0.02																			

Table 4-6: Distribution of pumping electric capacity in the city zones

MW	Z01	Z02	Z03	Z04	Z05	Z06	Z07	Z08	Z09	Z10	Z11	Z12	Z13	Z14	Z15	Z16	Z17	Z18	Z19	Z20
Water Pumps			0.05									0.05	0.01			0.02		0.01		
Sewage Pumps			0.08					0.92				0.67						2.31	0.08	
Sewage Treatment Plant															0.15					

4.I.1. Transport, existing vehicle technologies and mobility

In order to model the transportation sector in the city of Trikala, the data that were collected in the framework of the survey in WP3 and the analysis performed using the transport model developed in WP3 are used as an input to the ESM-Trikala.

The first information required by the ESM is the number of vehicles per fuel and their distribution in the city zones. Information of the total number of vehicles per fuel type came from WP3 while the distribution of car ownership in the city zones was performed using the distribution of dwellings in the city zones (since more detailed data were not available). An improvement of this approach could be done through a survey that could help allocate vehicles per building typology and city zone. However for the purposes of the overall analysis at a level of the city this is not crucial. The estimated geographical distribution used in the analysis can be seen in Table 4-7.

The average efficiency of existing cars was estimated using data from the available literature and is consistent with the assumptions used in the calculations of the transport model used in WP3. Table 4-8 presents the values use in the ESM for Trikala. Similar efficiency estimations are included in the ESM for busses, mopeds and light duty vehicles.

The mobility requirements in the ESM for Trikala is expressed as vehicle kilometres per dwelling per year from zone x to zone y. These data were calculated in the framework of WP3 based on data derived from the transport surveys. These demands are included in the ESM for cars, busses, mopeds and light duty vehicles and are presented in Table 4-9 until Table 4-10 for the base year. These demands will change in the future depending on the transport scenario that is analysed. Snapshots of these demands were produced from the transport model of WP3 for 2020 and 2030 for each alternative transport scenario plus the baseline development. These are used as scenario files in the ESM, in order to represent the dynamic change of mobility demand in households per transport mode. TIMES cannot account for modal switching in transport therefore this approach was necessary in order to incorporate the analysis of a more appropriate for this purpose transport model.

Table 4-7: Distribution of cars per type and city zone.

Type	Fuel	Z01	Z02	Z03	Z04	Z05	Z06	Z07	Z08	Z09	Z10	Z11	Z12	Z13	Z14	Z15	Z16	Z17	Z18	Z19	Z20
Euro 1	Gasoline Car	999	2517	362	831	79	334	427	646	1306	178	644	1640	82	47	461	640	2213	697	401	455
	Diesel Car	7	19	3	6	1	2	3	5	10	1	5	12	1	0	3	5	16	5	3	3
Euro 2-3	Gasoline Car	599	1510	217	499	47	201	256	388	784	107	387	984	49	28	277	384	1328	418	240	273
	Diesel Car	67	168	24	56	5	22	29	43	87	12	43	110	5	3	31	43	148	47	27	30
Euro 4-5	Diesel Car	400	1007	145	333	32	134	171	259	523	71	258	656	33	19	184	256	885	279	160	182
	LPG car	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4-8: Assumed car efficiency per type and fuel.

		Efficiency	
Type	**Fuel**	**1000kms/TJ**	**lt/100km**
Euro 0-1	Gasoline Car	363	7.8800
	Diesel Car	414	6.4850
	LPG Car	478	8.1600
Euro 2-3	Gasoline Car	410	6.9850
	Diesel Car	470	5.7050
	LPG Car	478	8.1500
Euro 4-5	Gasoline Car	492	5.8200
	Diesel Car	554	4.8450
	LPG Car	480	8.1200

Table 4-9: Demand for Car vehicle kilometres per dwelling per year

	To Zone																			
From Zone	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
1	735	7	0	8	0	0	15	0	12	0	19	41	7	0	0	0	0	2	97	1
2	3	299	0	5	0	0	18	0	18	0	7	122	2	0	0	1	0	6	17	8
3	222	2641	0	618	0	0	2519	0	1166	0	145	20839	63	0	0	50	41	428	553	224
4	213	11575	0	1203	0	0	1703	0	596	0	257	9242	100	0	0	48	35	460	617	181
5	506	1617	0	213	0	0	674	0	1907	0	7012	1084	204	0	0	47	80	484	1305	774
6	524	2617	0	814	0	0	2758	0	946	0	222	18649	135	0	0	152	86	988	878	487
7	21	5887	0	88	0	0	576	0	158	0	68	1227	11	0	0	10	4	65	73	31
8	562	1772	0	463	0	0	1093	0	2411	0	22844	892	273	0	0	72	71	1278	3855	727
9	35	481	0	63	0	0	126	0	265	0	2760	545	39	0	0	6	5	150	371	40
10	4	29	0	5	0	0	10	0	66	0	4406	10	1	0	0	1	0	17	134	17
11	184	720	0	81	0	0	271	0	431	0	2524	250	139	0	0	20	27	222	675	371
12	135	1192	0	113	0	0	364	0	335	0	93	5044	17	0	0	24	22	188	256	211
13	152	472	0	61	0	0	159	0	491	0	7725	112	41	0	0	13	22	166	470	241
14	608	2612	0	413	0	0	1132	0	916	0	5947	8378	138	0	0	59	93	524	2824	576
15	43	251	0	28	0	0	106	0	133	0	1604	134	49	0	0	6	6	71	395	132
16	14	1259	0	67	0	0	311	0	64	0	42	254	14	0	0	9	2	60	112	25
17	1	9	0	4	0	0	8	0	13	0	11	20	6	0	0	0	337	6	77	4
18	31	3193	0	133	0	0	356	0	245	0	943	1827	72	0	0	18	7	392	609	82
19	384	1323	0	220	0	0	605	0	1850	0	14650	369	80	0	0	41	49	787	2974	673
20	13	841	0	19	0	0	64	0	66	0	886	206	27	0	0	3	2	36	150	76

Table 4-10: Demand for Busses vehicle kilometres per dwelling per year

	To Zone																			
From Zone	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
1	0	44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	21	0	0
2	17	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0	2
3	0	0	0	57	0	0	26	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	25	0	0	0	22	0	59	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	17	0	0	0	5	0	0	0	0
7	0	0	22	44	0	0	0	0	0	0	0	0	0	0	0	54	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0
9	0	0	0	38	0	0	0	0	0	0	0	0	0	0	0	0	25	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21	0	13	0
11	0	0	0	0	0	0	0	0	0	0	0	0	7	0	4	0	0	0	0	0
12	0	16	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	52	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	4
16	0	0	0	0	0	3	36	0	0	0	0	0	0	0	0	0	0	19	0	0
17	7	0	0	0	0	0	0	2	15	2	0	0	0	0	0	0	0	0	0	0
18	31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	0	0	0	0
19	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0
20	0	11	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0

4.I.2. Energy Balance of the Municipality

The overall energy balance of the city of Trikala was estimated for 2012 based on data from the National Statistical Service of Greece in the framework of WP1. The more detailed breakdown of the consumption of different energy commodities per sector (Table 4-11) and the breakdown of the energy consumption is uses (heating, cooling etc. as in Table 4-12) was performed using the data provided by the municipality as well as data available at a national level that are used in the TIMES model for Greece in CRES.

Table 4-11: Energy Balance of Trikala in 2012

TJ	Diesel	Gasoline	HFO	Biomass	Electricity
Residential	464			46	393
Commercial/Services	185				246
Municipal Buildings	9				29
Transport	117	719			0
Agriculture	559				138
Industry	176		46		138
Street lighting					39
Total	1510	719	46	46	983

Table 4-12: Breakdown coefficients per use

Breakdown per use - Residential	Diesel	Gasoline	LPG	HFO	Biomass	Electricity
Space Heating	0.98		0.10		0.95	0.05
DHW	0.02		0.00		0.05	0.09
Space Cooling						0.10
Cooking			0.90		0.00	0.22
Lighting						0.11
Refrigerators						0.15
Washing machine						0.06
Clothes Drier						0.00
Dishwasher						0.02
Other Electric						0.20

Breakdown coefficients per dwelling type in the residential sector.

Breakdown per dwelling type	Diesel	Gasoline	LPG	HFO	Biomass	Electricity
Flat	0.30		0.3		0.05	0.33
Detached	0.55		0.55		0.7	0.54
Semidetached	0.15		0.15		0.25	0.13

4.I.3. Potential of solar energy systems (PVs and solar water heaters).

The potential for solar applications (PV and solar water systems) was analysed in the framework of WP4 based on the availability of roof area in each typology which could be used for their installation. For the city of Trikala this information was included in the ESM in the form of three user constraints:

1) One user constraint for the maximum potential of solar water heaters per building typology and city sector, if all available space was taken by SWH (Table 4-13).
2) One user constraint for the maximum potential of PVs per building typology and city sector, if all available space was taken by PVs (Table 4-14).
3) One user constraint for the available roof surface for each building typology and city sector and the area required for the installation of a SWH unit and the area required per kW of PVs.

The combination of these three constraints gives to the optimisation model the possibility to decide how much of each of the two technologies should be installed in the limited available roof space in the city. An overall limit to the technical potential of PV installations on commercial and municipal buildings was also calculated in WP4 based on the available roof surface of these types of buildings. This was also included as a user constraint in the ESM.

Table 4-13: Potential for SWH per building type (aggregate for all city zones).

Type	Year	Potential (TJ/year)
Flats	2013	0
Flats	2035	90
Detached	2013	0
Detached	2035	10
Semi-Detached	2013	0
Semi-Detached	2035	78

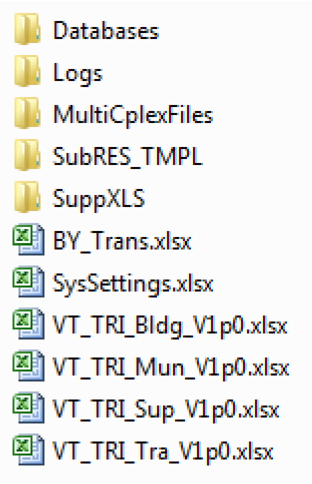
Table 4-14: Potential for PVs per building type (aggregate for all city zones).

Type	Year	Total (MW)
Flat	2013	0.0
	2015	0.0
	2035	6.4
Detached	2013	0.0
	2015	0.0
	2035	52.1
Semidetached	2013	0.0
	2015	0.0
	2035	8.8

5. Model files structure

The files that are used in ESM-Trikala follow the structure that is dictated by the TIMES model. These files include:

1) Base year and System Setting data



These files include the definitions of time slices, time periods and the other basic parameters in the model.

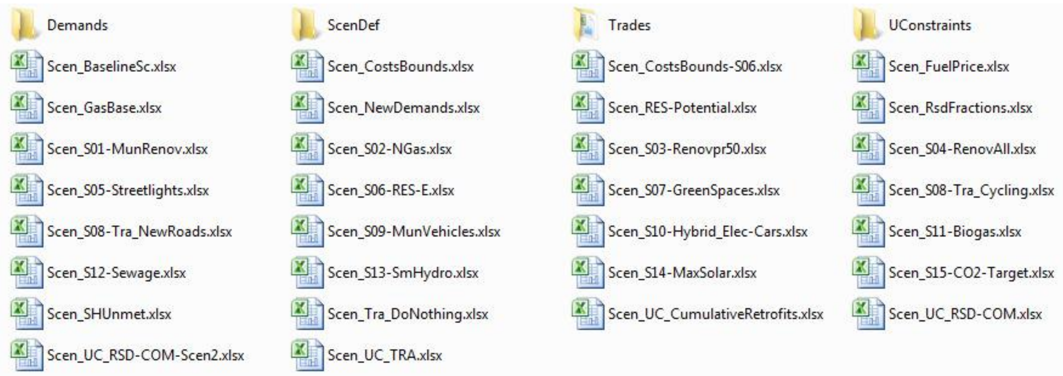
Furthermore, the base year templates cover:

- The Residential Sector (VT_TRI_Bldg_V1p0.xlsx).
- The Municipality (VT_TRI_Mun_V1p0.xlsx).
- The Transportation (VT_TRI_Tra_V1p0.xlsx).
- The Supply of energy sources to the municipality (VT_TRI_Sup_V1p0.xlsx).

as described in the previous chapter.

2) Scenario files.

This is a long list of files specific to the setup of the scenarios that are explained in the next chapter. The files are structured in such a way so that after the baseline scenario is run all the other scenarios can be run simply by including in the solution the scenario file with the corresponding name.



Some scenario files are used in the formulation of all the scenarios and these are:

Filename	Description
Scen_BaselineSc.xlsx	This includes the background assumptions of the Baseline scenario and is included in all the other scenario runs. Any alternations to the Baseline scenario assumptions are included in the other scenario files.
Scen_CostBounds.xlsx	This scenario includes an overall constraint on the available income of the households and the Municipality that can be used for

	energy related investments and operational costs.
Scen_CostBounds-S06.xlsx	This scenario includes an increased overall constraint on the available income of the households and the Municipality that can be used for energy related investments and operational costs, which is used in Scenario 6.
Scen_FuelPRice.xlsx	This file includes the assumptions for the future development of energy prices. The assumptions that were used in the National Energy model for Greece are enforced in the TIMES model for Trikala
Scen_NewDemands.xlsx	The future development of useful demands is included in this file.
Scen_GasBase.xlsx	Baseline scenario for the availability of N. Gas.
Scen_RESPotential.xlsx	This file contains the assumptions for the total potential per renewable energy sources, as was analysed in WP4.
Scen_Rsdfractions.xlsx	The distribution of the different demands within the time slices in order to create an approximate load curve is included in this file. The data for the time distribution were taken from the National TIMES model.
Scen_SHUnmet.xlsx	The implementation of the unmet demand for heating, cooling and hot water is included in this file.
Scen_UC_CummulativeRetrofits.xlsx	This file contains the user constraints that are related to the retrofits of existing residential buildings.
Scen_UC_RSD-COM.xlsx	Basic user constraints for the residential and municipal sectors related to the evolution of the share of energy commodities in the future.
Scen_UC_RSD-COM-Scen2.xlsx	Basic user constraints for the residential and municipal sectors related to the evolution of the share of energy commodities in the future used specifically in Scenario 2 (large introduction of N.Gas).
Scen_UC_TRA.xlsx	Basic user constraints for the transportation sector related to the evolution of the share of energy commodities in the future.

Scen_TRA_Donothing.xlsx	Baseline scenario development of the demand for transportation (vehicle kilometres) per city zone.
Scen_S01 – Scen_S15	These files include the specific model set up for each one of the specific scenarios corresponding to the filename.

3) New technologies repository.

The repository of new technologies that can be used in the future development of the energy system of Trikala is placed in these files.

SubRES_MunRetrofits.xlsx
SubRES_MunRetrofits_Trans.xlsx
SubRES_NewBldg.xls
SubRES_NewBldg_Trans.xls
SUBRES_NewTechs-InSmart_V01.xlsx
SubRes_NewTechs-InSmart_V01_Trans.xlsx
SUBRES_NewTechs-NewSmartBldg.xlsx
SubRes_NewTechs-NewSmartBldg_Trans.xlsx
SubRES_RsdRetrofits.xlsx
SubRES_RsdRetrofits_Trans.xlsx
SubRES_Sup.xlsx
SubRES_Sup_Trans.xlsx

These files include:

Filename	Description
SubRES_MunRetrofits.xlsx **SubRES_MunRetrofits_Trans.xlsx**	Includes the retrofit options for the Municipality buildings (schools, offices and other), the corresponding energy savings, implementation costs and constraints.
SubRES_NewBldg.xlsx **SubRES_ NewBldg_Trans.xlsx**	Includes the characteristics of the new residential and municipal buildings (unit consumption per use).
SubRES_NewTechs-InSmart_v01.xlsx **SubRES_ NewTechs-InSmart_v01_Trans.xlsx**	Includes the characteristics of all the new technologies for satisfying the different demands (heating, cooling, lighting etc.) for all the consumption sectors in Trikala.
SubRES_RsdRetrofits.xlsx **SubRES_RsdRetrofits_Trans.xlsx**	Includes the retrofit options for the residential buildings (as studied in WP2), the corresponding energy savings, implementation costs and constraints.

SubRES_Sup.xlsx **SubRES_Sup_Trans.xlsx**	Includes the characteristics of the new options on the supply side like the biogas power plant, the small hydro plant etc.

6. Scenario analysis

Two workshops were held in Trikala in the framework of the INSMART project in order to identify the key factors that should be included in the scenarios and then in order to discuss the formulation of the alternative scenarios for the development of the energy system of the city. The decision reached in these workshops was to have independent model scenarios for each one the possible interventions and developments in the city energy system on top of a Baseline scenario that will include the expected development path. Following this approach a Baseline scenario was initially formulated and then a total of fifteen alternative scenarios were created in order to examine the effects of specific actions.

6.I.1. Scenarios definitions

The definitions of the baseline scenario and the fifteen alternative scenarios for the Trikala ESM are given below.

Baseline Scenario

In the Baseline scenario the energy system of Trikala is assumed to be developed following the historical trends. The population growth rate in each city zone follows the trends of the last decade. Furthermore the scenario includes the development of one nearly zero energy school and the refurbishment of 16 municipal buildings that will be implemented under the “Exoikonomo” program. The “Exoikonomo” program focusses on the renovation of municipal buildings and covers the cost of building shell refurbishment as well as an upgrade to the systems used for heating, cooling and lighting. The other scenarios can be divided into the following broad categories based on the sectors which are focused in each scenario group:

Focus Sectors	Scenarios
Buildings	Scenarios 1,2,3 and 4
Street Lighting	Scenario 5
Renewable Energy	Scenario 6
Open Spaces	Scenario 7
Mobility	Scenarios 8R and 8C, Scenarios 9 and 10
Waste	Scenarios 11 and 12
Water	Scenario 13
Energy System Scenarios	Scenarios 14 and 15

More specifically the characteristics of each one of these scenarios are described below.

Buildings

Scenario 1.

This scenario includes the refurbishment of all the Municipal Buildings following the example of the upgrades of the 16 buildings included in the Baseline scenario. The refurbishments focus on the reduction of thermal and cooling loads and the improvement of lighting installations.

Scenario 2.

In Scenario 2, 80% of the buildings within the geographical limits of the municipality, are connected to the natural gas network by 2030. This includes both residential and non-residential buildings..

Scenario 3.

This scenario foresees the complete renovation of residential buildings that were built before 1950. The complete renovation includes all four options identified in WP2 as appropriate for the building stock in Trikala, namely replacement of windows, insulation of roofs and walls.

Scenario 4.

Scenario 4 foresees the partial renovation of all the residential building typologies following the “Exikonomisi katoikon” approach. This means that the option of windows replacement, roof insulation, walls insulation, all related combination are available, and the preferred mix is calculated by the model using the relative cost and benefits of each intervention in order to minimise the total system cost.

Street Lighting

Scenario 5

In scenario 5 the replacement of the 6000 existing sodium street light bulbs with high efficiency LED lamps is implemented.

Renewable Energy

Scenario 6.

This scenario foresees that 10% of the electricity demand in the municipality will be covered by renewable energy projects, funded by the municipality by 2030 (the share in 2020 will reach 5%).

Open Spaces

Scenario 7.

“Green Spaces” options are implemented in all the city squares and open spaces, in order to reduce the cooling demand of buildings in the city. According to relevant studies[2] it is expected that the cooling energy demand in buildings will be reduced by 5% by 2030 once Green open spaces techniques are applied in the whole of the city.

Mobility

Scenario 8.

Scenario 8 is divided into two sub-scenarios addressing mobility options analysed in WP3. These sub-scenarios are:

> **Scenario 8R** which includes the construction of the ring road around the city which leads to a reduction of the transport load through the city centre.
>
> **Scenario 8C** which includes the construction of cycling routes with a length of 2.8km in the next 2-3 years and an extra 10km in the next 10 years.

Scenario 9.

This includes the replacement of ten existing municipal small vehicles by electric cars. Furthermore, all the municipal heavy duty vehicles (trucks, refuse collection trucks etc.) will be replaced by Euro 6 vehicles in the next 15 years.

Scenario 10.

This scenario examines the effect of incentives for the promotion of hybrid or electric cars in the city centre. It is modelled through the application of an extra cost to conventional vehicles that enter into the city centre (which can be seen as a an extra parking fee for conventional cars compared to free parking spaces for hybrid or electric cars).

Waste

Scenario 11.

The landfill of Trikala can be used as an energy source according to recent studies. In this scenario the installation by 2020 of a 950kWe biogas fired power plant in the landfill is included. It is assumed that the generated electricity covers directly the demand in the city.

Scenario 12.

The sewage treatment plant is a considerable consumer in the energy system of the city (WP4 data). Based on studies that were already done the energy consumption can be reduced by at least 25% with the use of special bacteria with limited extra cost. This action can be implanted by 2019.

Water Pumping

Scenario 13.

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[2] "Thermal benefits of city parks", C. Yu, W.N. Hien, Energy and Buildings 38 (2006), pp 105-120.

The city water pumping system is another important electricity consumer. In this scenario the energy consumption is planned to be reduced through the construction of the small dam which will provide water to the municipality (without the need of pumping due to the geography) and the installation of the small hydro power plant (200kW) at this site, by 2022. There are no detailed costing and sizing studies for this intervention, therefore the scenario explores the possibility using some general assumptions and data.

Energy System Scenarios.

In the case of energy systems scenarios overall targets are imposed and the model is providing the least cost solution for achieving these targets

Scenario 14.

In scenario 14 all the available potential for solar PV and solar hot water systems will be exploited in the city of Trikala by 2030. This is equivalent to a maximum utilisation of RES scenario.

Scenario 15.

The overall target for emissions reduction which is a 20% reduction from the levels of 2012 by 2030 is implemented in this scenario in order to examine the possible options and technology combinations that can be applied.

These scenarios were run using the scenario files described in the previous chapter. The model results were analysed using a set of indicators, defined though the workshop process of WP5, and are presented in the next chapter.

7. Results

The ESM for the city of Trikala produces as an output the energy flows per energy commodity, capacities of energy technologies and pollutant emissions from the use of energy per year in a time horizon until 2030. In order to analyse and compare different scenarios a set of indicators was chosen in the project workshops which will be used in the MCDA analysis of WP5. These indicators are presented and discussed here, together with some more detailed results of the energy system model that are useful for the comparison of the different scenarios.

7.I.1. Key indicators

The indicators that will be used in the MCDA analysis as criteria in order to rank the alternative scenarios were defined in close consultation with the local stakeholders. For this reason two workshops were held in Trikala in the framework of WP5 and the following set of monitoring indicators/criteria for the scenarios were chosen:

1. **Implementation Cost (Million Euros).** This is defined as the level of investment that is required in each scenario for the energy related technologies. In order to compare the alternative scenarios, the implementation cost was expressed as the difference between the total investment cost of the Baseline scenario and the total investment cost of the scenario under consideration. In this way only the extra amount of investment required by the scenario actions will be compared. It must be noted that due to the systemic view of the model, the total investment cost in different scenarios could include other technologies and not only the specific technologies on which the scenario focusses.
2. **Energy Savings (kWh).** This indicator is defined as the difference between the total energy consumption in the baseline scenario and the scenario under consideration. In order to calculate this difference the solar energy use is not taken into account.
3. **Implementation cost efficiency (Euro/kWh).** This indicator is defined as a combination of the two previous indicators. It is calculated as the ratio of the energy savings over the implementation cost. It expresses the investment cost required per kWh of energy saved.
4. **Operation and maintenance cost (million Euros).** This is defined as the variable and fixed operational and maintenance cost of the energy system, without taking into account the cost of energy commodities. It is expressed as the difference of the total O&M costs in the baseline scenario from the same costs in the scenario under consideration. It expresses the continuous cash flow that the citizens and the municipality will have to provide in order to operate the energy system in each alternative scenario, compared to the baseline scenario.
5. **Revenue generation (million Euros).** This indicator is mainly related to the generation of energy at the city level. The main source of revenue in all the

scenarios is the generation of electricity from PVs which can be installed in the residential, commercial and municipal buildings, the generation of electricity from landfill biogas in Scenario 11 and the generation of electricity from the small hydro plant in Scenario 13. The revenue generated by each technology is calculated using the feed in tariffs that are currently available including the changes in feed in tariffs that are foreseen in the existing legislation. The indicator used in the scenario evaluation is the difference between the revenue generated in the baseline scenario from the revenue generated in the alternative scenarios.

These indicators are used for the comparative analysis across scenarios for Trikala that are presented in the next section and are used in the ranking presented in the MCDA report for Trikala ("Report on multi criteria methodology, the process and the results of the decision making" Deliverable D.5.6).

7.I.2. Comparative analysis across scenarios

An overview of the energy consumption per fuel in all the scenarios can be seen in Figure 7-1, every 5 year period. In this graph solar energy is not included, in order to be able to compare directly the energy commodities consumed and to visualise the energy savings. It is obvious from the results that Scenario 4 (renovations of all residential buildings) and Scenario 15 (optimal reduction of CO_2 emissions) correspond to the highest energy savings. In both scenarios the largest part of energy savings come from the large scale introduction of refurbishment measures in buildings and in Scenario 15 through the introduction of more energy efficient technologies in buildings and transport. This is expected because these are actions at a much larger scale compare to the other scenarios which are limited to certain technologies or very specific interventions. Scenario 1 is also exhibiting a considerable amount of energy savings which is related to the refurbishment of all municipal buildings. Overall, one can conclude that from the list under analysis, the interventions related to the existing stock buildings are those with the higher potential for energy savings.

In all the scenarios the use of biomass is increasing, mainly through the introduction of more efficient technologies like pellet stoves and boilers. The use of natural gas also increases in all scenarios, with the highest level being reached in scenario 2 where 80% of all buildings are connected to the gas grid. Scenario 15 (the reduction of emissions systemic scenario) is also showing a higher introduction of natural gas which means that this option is cost effective. The use of oil products remains high in all scenarios, covering mainly the demand for transport and space heating. The use of electricity increases, but not dramatically in the time horizon until 2030 and has the same behaviour across scenarios.

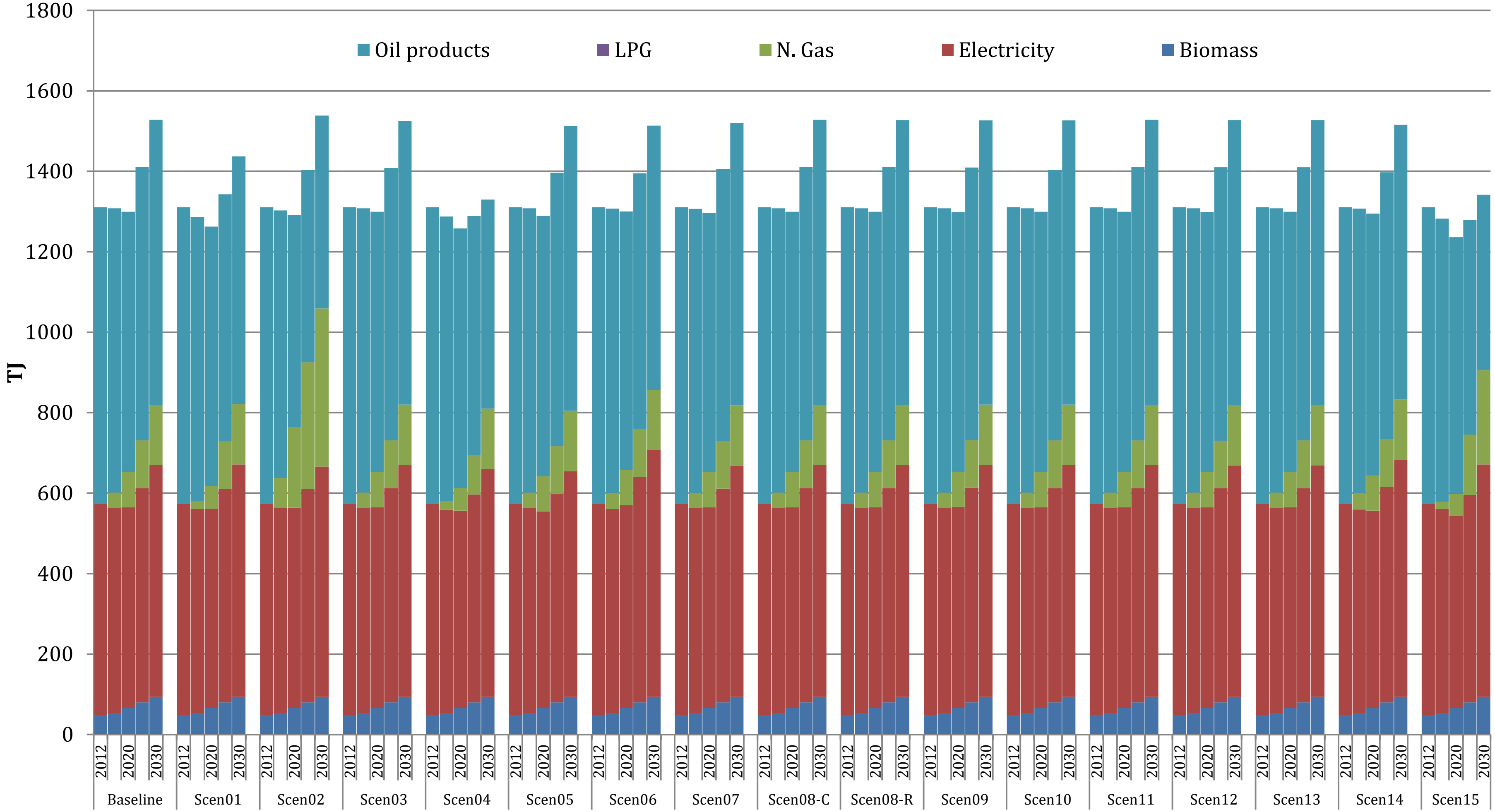

Figure 7-1: Energy Consumption by fuel for all Scenarios

Figure 7-2 compares the energy consumption in the three "systemic" scenarios, namely Baseline, Scenario 14 and Scenario 15 over five years periods. The use of solar energy appears in this graph in order to show the penetration of solar systems in the city and is related to the use of solar in PVs and SWH. We can see that the solar energy used in Scenario 15 is rather close to the maximum solar energy used in Scenario 14 (by design this is the scenario with maximum RES use). The distinct difference of Scenario 15 from the other two is the reduction of energy use (so the increased penetration of energy efficiency options) combined with the maximisation of RE, which is driven by the emissions reduction target of 20% by 2030.

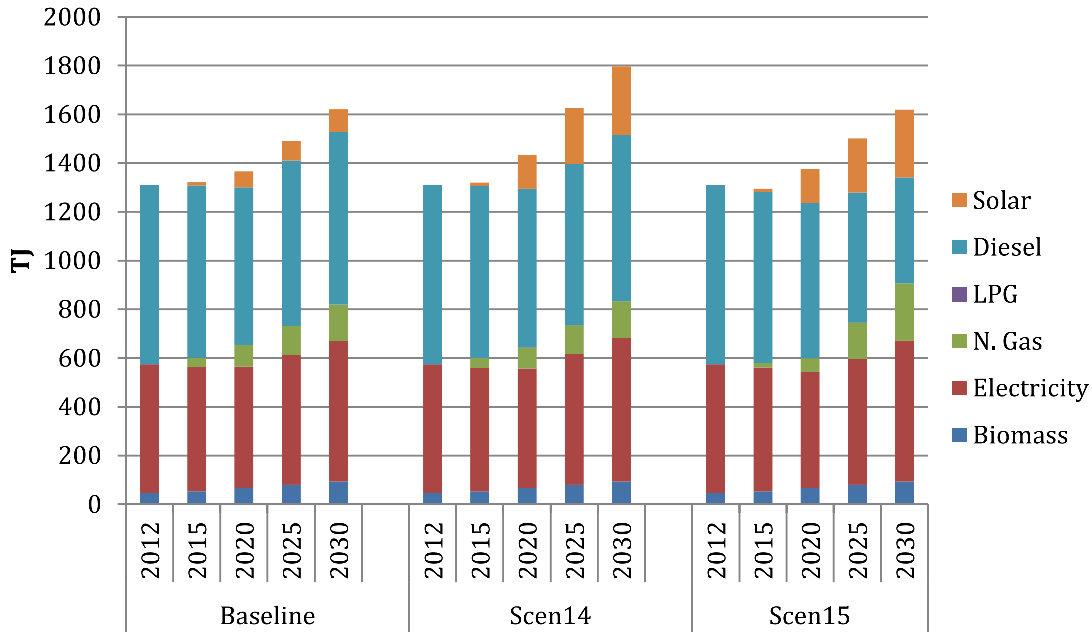

Figure 7-2: Energy Consumption by fuel for the "systemic" scenarios

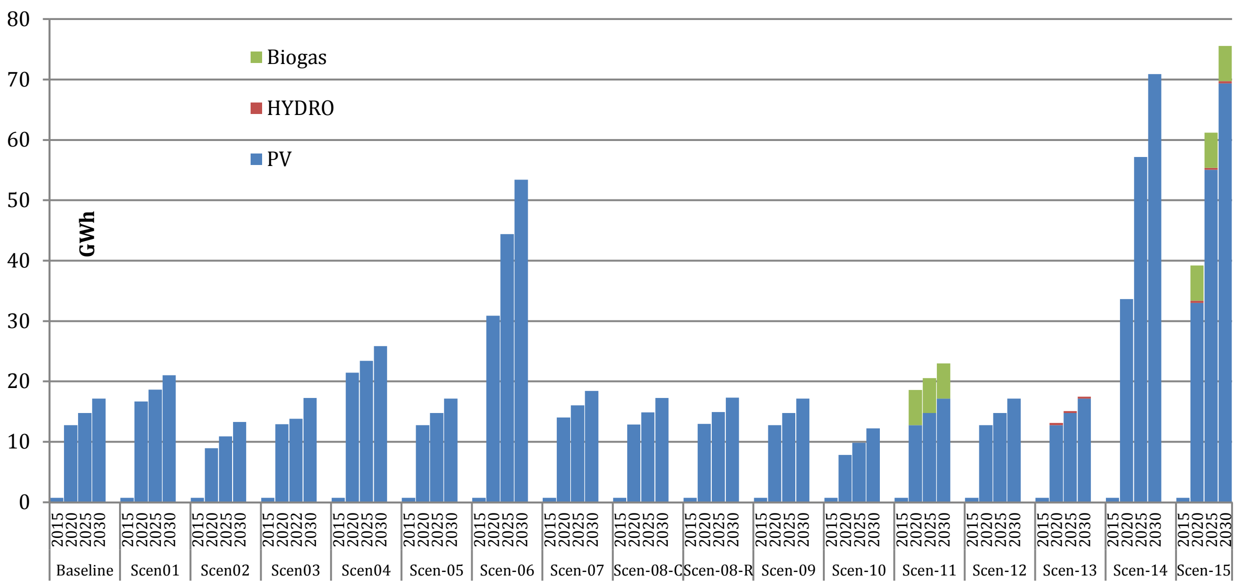

Figure 7-3: Electricity generation from RES per scenario

The electricity generation from RES in each scenario is shown in Figure 7-3. PVs are the main option for electricity generation within the city limits and they reach at different levels of generation depending on the particular characteristics of each scenario. In Scenario 6, the constraint that requests 10% of the electricity consumption in the city by 2030 to be covered by RES installations owned by the Municipality, leads to a higher contribution than all the other scenarios (apart from 14 and 15). Generation from biogas is only allowed in Scenario 11, in which case its investment costs affects negatively the investment to PVs since the available budget of the Municipality is limited. Biogas is also available in the optimisation Scenario 15 where it appears as part of the solution based on its economic merit. The small hydro power plant is also appearing in the solution of Scenario 15, since it contribute to the achievement of the emissions reduction target.

In the following pages an analysis of the indicators that are used in the MCDA is presented briefly. Looking at the implementation cost (Figure 7-4) we can see that the highest investment cost is associated with Scenario 4, which foresees the refurbishment of all the residential sector buildings that were built before 1980. The next in line is Scenario 6, in which 10% of the electricity in the Municipality is generated by RES in 2030, and it includes the investment costs of PV systems within the city.

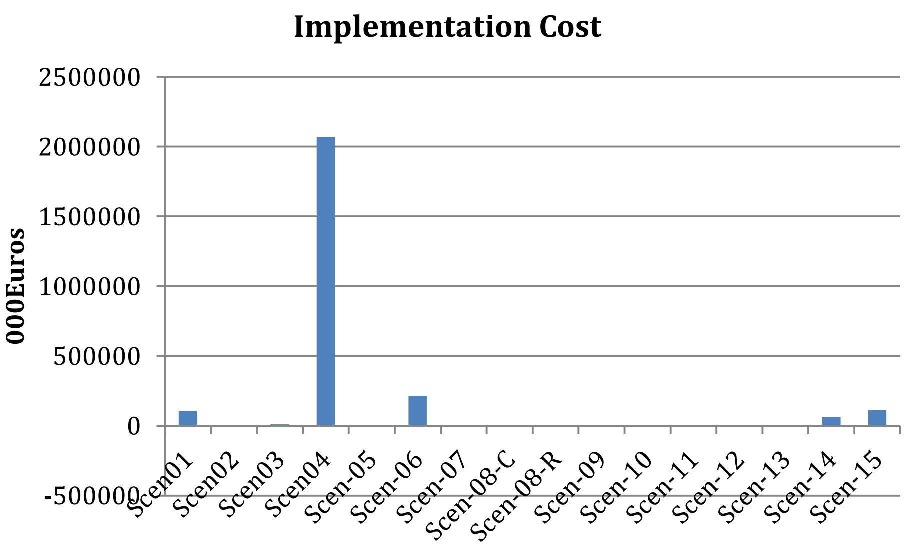

Figure 7-4: Implementation costs levels across scenarios

As was mentioned at the beginning of the chapter, Scenario 15 and Scenario 4 show the highest level of energy savings (Figure 7-5), with Scenario 1 reaching the third place. All these scenarios are associated with buildings and these results show the energy saving potential that exists in the residential and municipal buildings in Trikala.

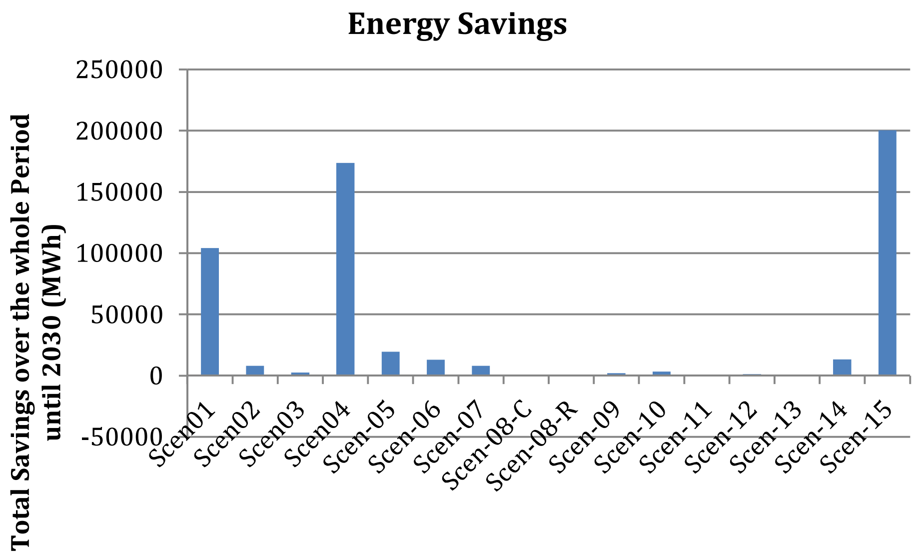

Figure 7-5: Energy savings across scenarios

When calculating the implementation cost efficiency (Euros spent per kWh saved) we can see that Scenarios 8C and 8R have negative values (Figure 7-6). This is due to the fact that the actual construction costs of the cycling routes and the ring road respectively are not included in the modelling. Therefore energy savings appear with lower costs than in the Baseline scenario.

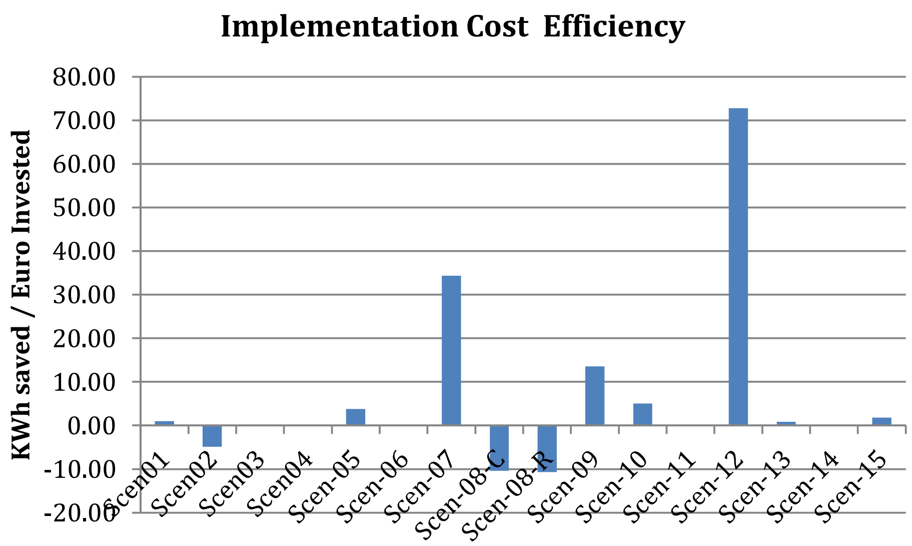

Figure 7-6: Implementation cost efficiency across scenarios

The operation and maintenance costs are comparable in all the scenarios with Scenario 6 being the only one showing higher values due to the operation of the PVs that are installed.

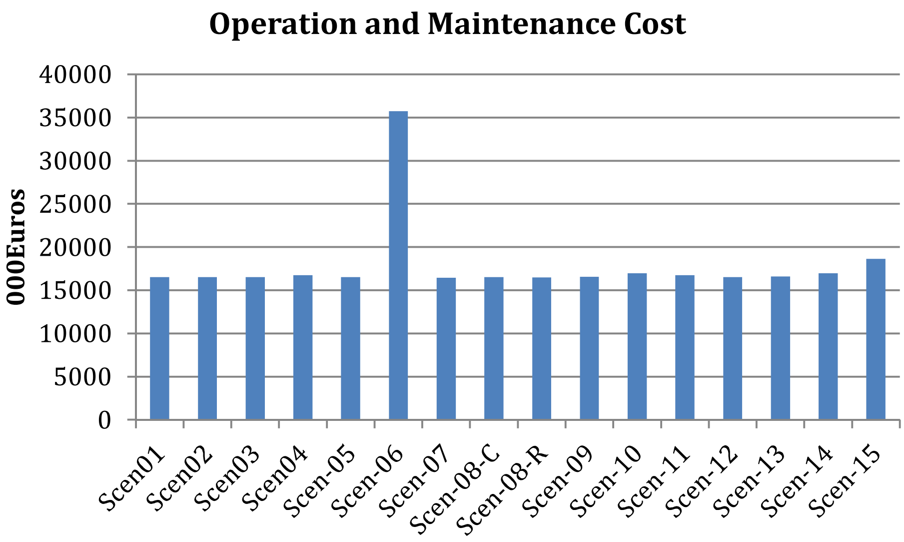

Figure 7-7: Operation and maintenance costs across scenarios

The generation of revenue at the city level are maximised in Scenarios 15 and 14 (the two systemic scenarios) and Scenario 6 which foresees the use of renewable energy to cover 10% of the electricity consumption by 2030 (Figure 7-8).

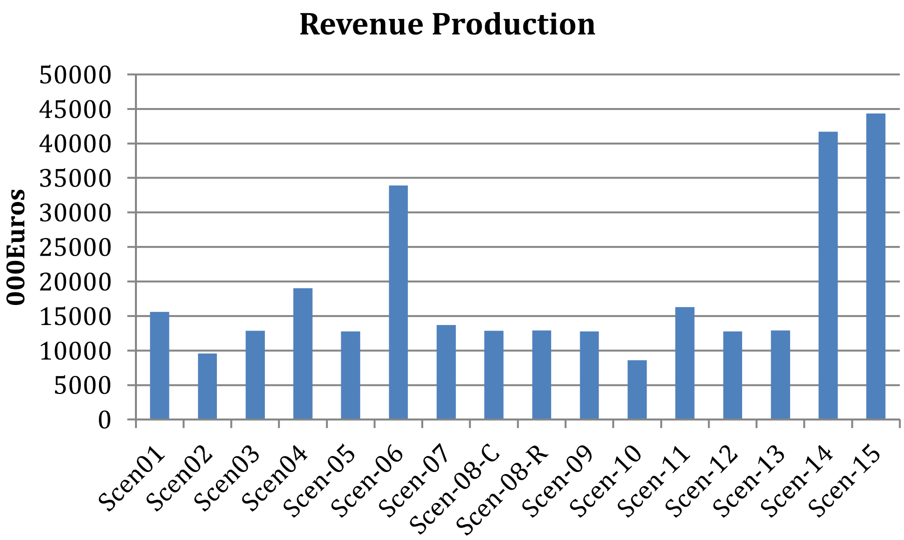

Figure 7-8: Revenue generation across scenarios

A more detailed look in the results of Scenario 15 is attempted in the next paragraphs in order to gain an insight on the characteristic of the list cost scenario for achieving the environmental targets of the municipality. Scenario 15 is the scenario in which a target of GHG emissions reduction by 20% in 2030 compared to the levels of 2012 is imposed to the solution. As can be seen in Figure 7-9 the energy consumption in the municipal sector which is currently dominated by electricity is gradually moving towards the introduction of natural gas and solar energy (mainly for electricity production since the hot water requirements are limited). Natural gas is also replacing the use of diesel for space heating, which is reduced to almost zero by 2030.

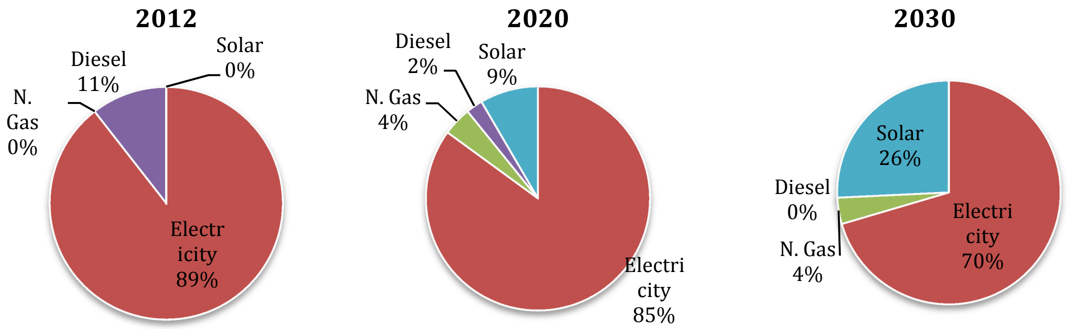

Figure 7-9: Share of different energy carriers in the municipal sector – Scenario 15.

In the residential sector, the change of the share of the different energy carriers is even more pronounced as can be seen in Figure 7-10. The contribution of natural gas increases considerably and at the end replaces almost all the diesel that is used ins space heating. Solar energy is introduced to a large extent covering the needs for hot water and generating electricity (roof top PVs). The share of biomass is stabilised to around 12-13% percent after 2020, and is mainly used is efficient installations (like pellet boilers of efficient wood stoves).

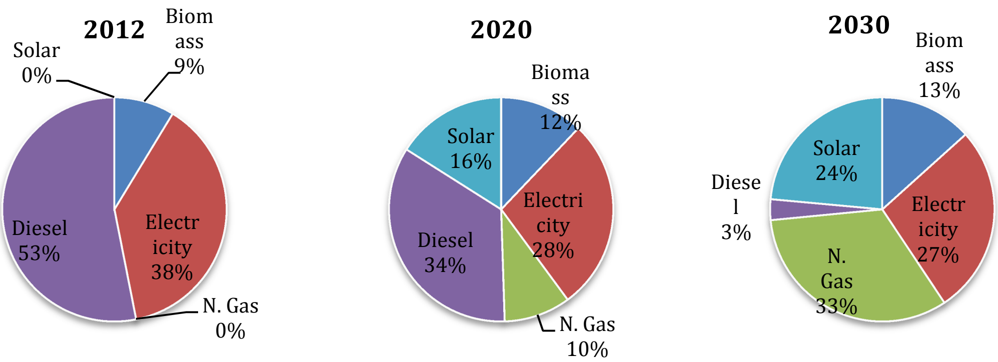

Figure 7-10: Share of different energy carriers in the Residential sector – Scenario 15.

Transportation, the second largest consumer in the city limits, changes drastically, with biofuels covering up to 23% by 2030. Electricity based transport also starts appearing in the city but reaches only up to 1% in 2030 (Figure 7-11). These changes lead to the dramatic reduction of the share of gasoline from the existing 73% in 2012 down to 45% by 2030. The low introduction of electric vehicles is mainly due to the cost considerations that were included in the model. It might be interesting to examine the implications of a scenario where the vehicle costs are reduced dramatically or a scenario in which the municipality takes very active measures for the promotion of electro-mobility (like extended charging stations infrastructure etc.).

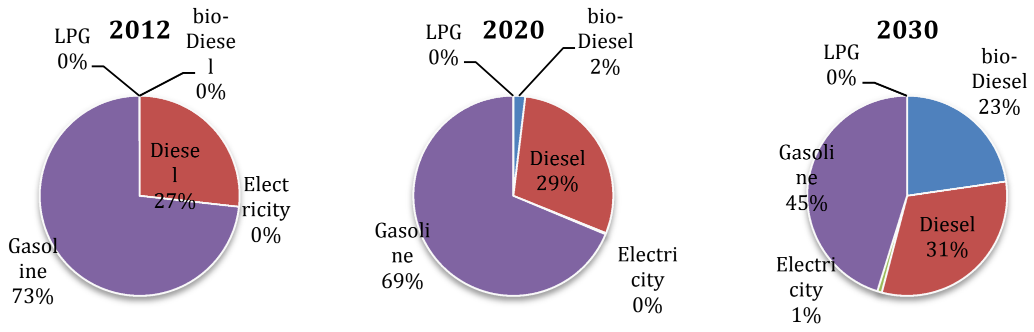

Figure 7-11: Share of different energy carriers in Transportation – Scenario 15.

7.I.3. Findings and comments

A first analysis of the quantitative results obtained from the ESM for Trikala shows that as far as energy savings are concerned, the building sector (municipal buildings and residential buildings) have the highest potential. However, these interventions are also associated with a high implementation cost, since the main actions are building shell refurbishment. In the systemic scenario (Scenario 15) it is seen that energy efficiency should play a major role in achieving the CO_2 emission reduction targets for 2030.

The estimated RES potential is adequate to cover up to 10% of the local electricity consumption by 2030 (Scenario 6), with an implementation cost that is quite below that of the building refurbishment actions, but with a higher operation and maintenance cost (related to the maintenance of the RES installations).

Looking only at the implementation cost efficiency, the most attractive scenario is Scenario 12, where the efficiency of the sewage treatment plant is increased with the use of special bacteria, an action that has low implementation costs. This is followed by Scenario 7 of the green spaces, which is an intervention that can offer significant other benefits to the city apart from those related to energy use. Scenario 9 (replacement of existing small municipal vehicle with electric vehicles) and Scenario 10 (promotion of hybrid and electric cars in the city centre) are both transport related scenarios with a high ratio of energy saved over money spent for the investment in new technologies, although the actual level of energy savings is relatively low.

These quantitative indicators are joined with a number of qualitative indicators in the MCD analysis that was performed with the participation of all local stakeholders, and is presented in the report “Multi-criteria methodology, the process and the results of the decision making for Trikala”, Deliverable D.5.7.

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InSMART Project

Coordination and support action (Coordinating Action)

FP7-ENERGY-SMARTCITIES-2012

Integrative Smart City Planning

Report on optimum sustainability pathways –ÉVORA

D-WP 5 – Deliverable D5.3

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	Name (organization)	**e-mail**
Leading participant	Sofia Simões (FCT/UNL) Luís Dias (FCT/UNL) Júlia Seixas (FCT/UNL) João Pedro Gouveia (FCT/UNL)	sgcs@fct.unl.pt luis.dias@fct.unl.pt mjs@fct.unl.pt jplg@fct.unl.pt
Contributing participants		
WP Leader (WPL)	E4SMA	
Project Coordinator (PC)	CRES	
Project Steering Committee (PSC)		

Executive Summary

This report presents the TIMES model developed for the city of Évora (TIMES_Evora) and the analysis of results using the model. These results are insights into the types of technologies and conservation measures that will be required to meet future urban energy demands in Évora. Besides describing the model details and its results, the report also presents the socio-economic visions developed for Évora, as well as the energy scenarios modelled in TIMES_Evora.

Keywords	Energy system model, sustainable energy scenarios, low-carbon options, local energy planning, TIMES model

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Acronyms and Definitions

B-Y – Base year of the TIMES_Evora (2013)

FEC - Final Energy Consumption

GHG – Greenhouse Gas Emissions

GIS – Geographic Information System

LED - Light-emitting diode lamp

LPG – Liquefied Petroleum Gas

MCDA – Multi Criteria Decision Analysis

MSW- Municipal Solid Waste

RES – Renewable Energy Sources

SEAP – Sustainable Energy Action Plan

TIMES – The Integrated Markal-EFOM System model generator of the Energy Technology System Analysis Programme of the International Energy Agency

Vkm - vehicle-kilometre representing a measure of traffic flow, determined by multiplying the number of vehicles on a given road or traffic network by the average length of their trips measured in kilometre.

WP – Working Package

1 Introduction

1.1 Overview of InSMART

The InSMART concept brings together cities, scientific and industrial organizations in order to establish and implement a comprehensive methodology for enhancing sustainable planning addressing the current and future city energy needs through an integrative and multidisciplinary planning approach.

InSMART project intends to identify the optimum mix of short, medium and long term measures for a sustainable energy future, addressing the efficiency of energy flows across various city districts, namely buildings, transport and mobility. Urban spaces, water/sewage system, waste chain and decentralized energy supply.

Each city's energy system is analysed, covering all relevant sectors and a comprehensive GIS platform including energy database was developed. Apart from being a valuable planning tool, the GIS database informs and is linked to the TIMES energy planning model. This model was used to analyse the cost-optimal mix of measures required to meet sustainable energy targets taking into account exogenous parameters (*e.g.*, environmental targets, city expansion). These measures were further assessed with respect to non-technical criteria using a multi-criteria decision making method (PROMETHEE) that addressed economic, environmental, as well as social issues.

A detailed economic analysis of the mid-term measures identified through this two stage optimisation procedure will be undertaken, identifying all relevant investment indicators. Finally, a detailed, realistic and applicable mid-term implementation plan will be developed to describe the necessary steps, required resources and monitoring procedures for each city.

1.2 Objectives of this Report

This report refers to WP5 (Tasks 5.1. to 5.2.) and it focuses the development of the TIMES model for the city of Évora (TIMES_Evora) and analysis of results presented as insights into the types of technologies and conservation measures that will be required to meet future urban energy demand. TIMES_Evora uses the data assembled in WP 1-4 to comprehensively represent the city' energy systems, focusing on energy use in buildings, transport systems and other energy uses (public lighting, industry, water and waste water and waste treatment).

Besides describing the model details and its results, the report also presents the socio-economic visions developed for Évora. The visions include a Business-As-Usual situation reflecting how the urban energy system will evolve based only on current and immediate planned measures and socio-economic trends, and alternative scenarios including sustainability targets for each city, as determined by both the city partners and stakeholders. These were set as system's constraints and the TIMES model was used to identify the optimum mix of both measures and technologies for their achievement.

The goal of WP5 are to: 1) Develop city specific energy system models, 2) Define and analyse sustainability scenarios in order to identify the economical optimum mix of measures and 3) Implement multi-criteria decision analysis (MCDA) support process in order to identify the city optimum sustainability path. This last goal regarding the MCDA is covered in a different report.

1.3 Outline of the Report

The report is organized in five chapters besides the introduction. Chapter 2 presents a brief description of the TIMES model for Évora focusing on its structure and coverage of the current urban energy system, followed by an assessment of main strengths and weaknesses. Chapter 3 presents the socio-economic visions and scenarios used in the analysis, whereas Chapter 4 focuses on the results of the modelling exercise for the city of Évora. Finally, Chapter 5 summarises the main results on the optimum sustainability pathways for the city.

2 City Energy System Model

2.1 Structure of the model and methodological approach

The TIMES_Evora model is a linear optimisation bottom-up technology model generated with the TIMES model generator from ETSAP of the International Energy Agency. More information on TIMES can be found in (Loulou, Remme, Kanudia, Lehtila, & Goldstein, 2005a, 2005b).

As in any TIMES model, the equilibrium is driven by the maximization of the discounted present value of total surplus, representing the sum of surplus of producers and consumers, which acts as a proxy for welfare in each region of the model. The TIMES_Evora model considers both the energy supply and demand sides of the energy system as depicted in Figure 1.

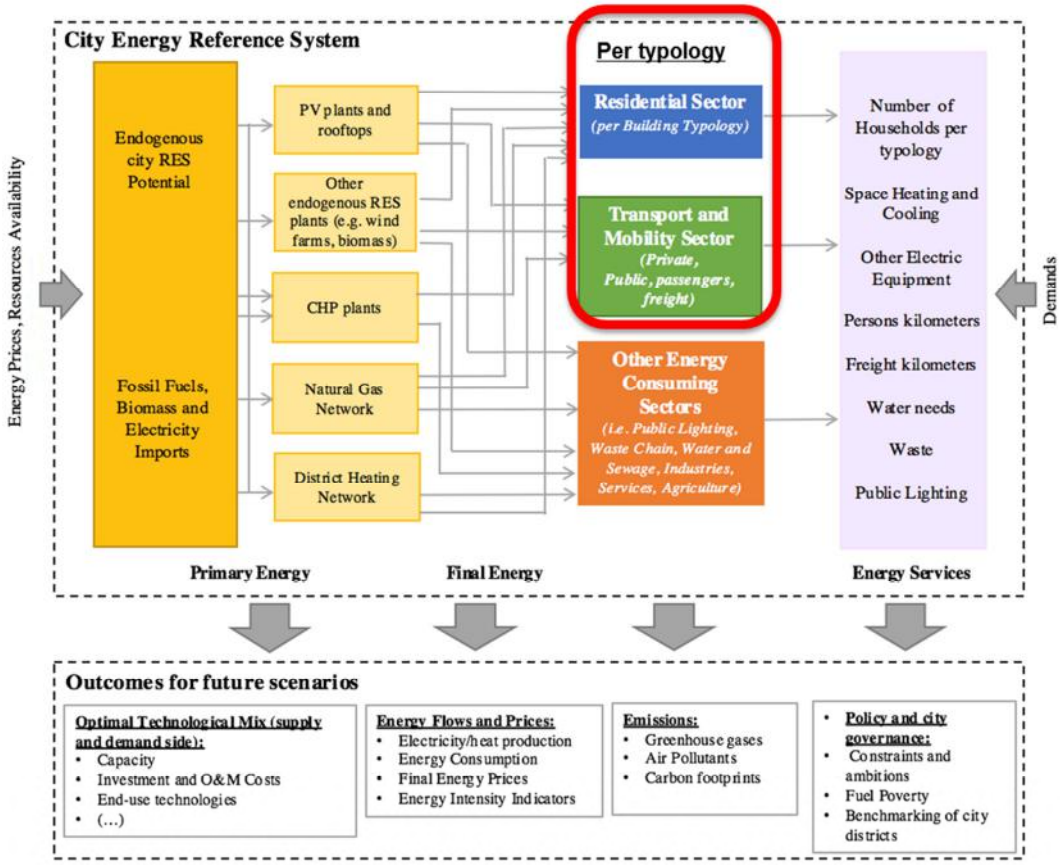

Figure 1 – Structure of the TIMES_Evora model based on the overall TIMES models structure developed for InSMART including main inputs and outputs

Regarding modelled economic sectors, the model is divided in the following sectors:

- ***Energy supply*** that covers the supply of biomass and solar energy within the municipality, as well as the energy import from outside the municipality, namely of electricity, natural gas, LPG, gasoline, diesel and fuel oil. It also include the possibility of exporting electricity generated within the municipality to the outside;
- ***Electricity generation*** which refers to the PV plants within Évora, both roof panels and plant size;

- ***Residential buildings*** disaggregated into 10 building typologies according to the analysis from WP1/WP2;
- ***Commercial buildings***, further disaggregated into non-municipal buildings (COM) and municipality-managed buildings (MUN) which include offices, storage buildings, social housing, sport related buildings, schools and culture halls and similar buildings;
- ***Public services*** further disaggregated in water supply system (WATER), sewage system (SWAGE), solid waste system (MSWSORT, MSWCOL), and public lighting (PLIG);
- ***Transport*** further disaggregated into passenger cars (TCAR), urban buses (TBUS) and interurban buses (TBIS), light duty trucks (TFL), freight trucks (TFH), trains (TT) and motorcycles (TMO);
- ***Industry***, without further disaggregation;
- ***Agriculture*** without further disaggregation.

The level of the modelling within each of the end-use sector is varied, depending on the capacity of intervention of the municipality and on the magnitude of the energy consumed in the respective sector. Therefore, whereas transport and residential buildings are modelled with substantial level of detail, commercial buildings and public services are modelled with an intermediate level of detail, and industry and agriculture are modelled as "black boxes". This means that in industry and agriculture the specific energy end-uses (process heat, machine drive, etc.) and energy consumption technology are not explicitly represented - only energy inputs in terms of final energy consumption per type of energy carrier.

In commercial buildings and public services there is a detailed representation of the existing (and future) stock of energy technologies. Finally, in passenger transport and residential sectors, not only there is a very detailed representation of the varied end-use energy services and technological detail, but also the investment decisions of the inhabitants in new transport and are modelled together. Therefore, each household in each of the 10 residential typologies has to decide how to allocate its budget among a combination of possible improvements on their transportation options or on their home energy use, as represented in Figure 2.

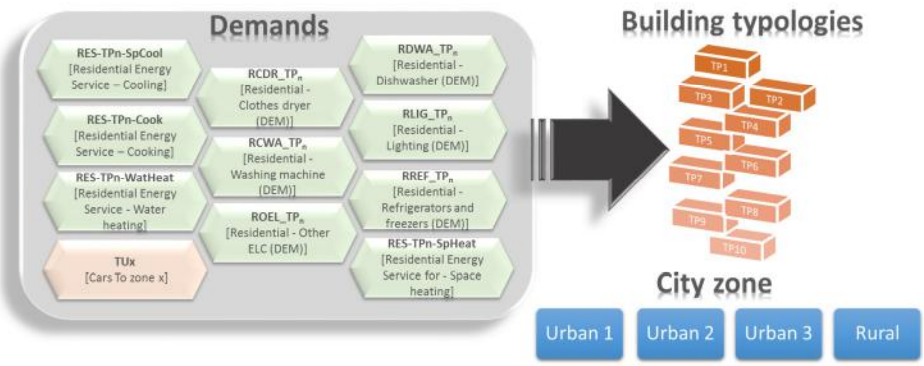

Figure 2 – Representation of modelling choices of households considering their income

2.2 Spatial and temporal coverage

The TIMES_Evora model covers 4 zones (Figure 3 and Table 1) modelled as different regions that can trade energy and waste commodities. Zone 1 covers the whole rural area of the municipality and the other 3 zones represent different parts of the city of Évora (urban areas). Zone 4 corresponds to the historic centre of the city which has a very characteristic building typology and mobility patterns as described in WP2 report.

Figure 3 –Regions of TIMES_Evora

There are flows of waste, water, wastewater, PV generated electricity and passenger.km between the regions.

Table 1 – Correspondence between considered municipality zones and TIMES_EVORA zones

TIMES zone	Municipality zone
Z1	Valverde
Z1	Sao Mancos
Z1	Nossa Sra de Machede
Z1	Azaruja
Z1	Canaviais
Z3	Bairro de Almeirim
Z3	Evora Retail Park
Z3	Aerodromo
Z3	Monte das Flores
Z3	Horta das Figueiras
Z3	Bairro Nossa sra do Carmo
Z3	Bairro De Santa Maria
Z3	Bairro dos Tres Bicos
Z3	Ceniterio de Evora
Z2	Nossa Sra da Saude
Z2	Bairro Frei Aleixo
Z2	Bacelo
Z4	Jardim Publico de Evora
Z4	Aquaduct
Z4	Universidade de Evora
Z4	Catedral de Evora

The TIMES_Evora model represents the municipality of Évora from 2013 till 2035 in five year time steps (2015, 2020, 2025, 2030 and 2035). Thus, 2013 is the base-year of the model. Each year is subdivided into 32 time slices representing day, night and peak periods of the daw for both week days (257 days) and weekends (remaining 108 days) and differentiated for each season (Summer, Winter and Interseasonal). The description of allocation of time in the model is presented in Table 2 and Table 3 and was selected considering the detailed information on residential electricity consumption obtained from the smart meters in Évora (detailed in WP2).

Table 2- Allocation of seasonal time-slices in TIMES_Evora

Name of Season	Fraction	Dates				N. of Days
Summer	0.26	21/jun	22/sep			94
Winter	0.24	22/dec	19/mar			88
Interseasonal	0.50	20/mar	20/jun	23/sep	21/dec	183

Table 3 – Allocation of daily time-slices in TIMES_Evora

Name of the period	No. of hours	Hourly period	
Day	10	08:00	17:00
Night	10	22:00	07:00
Peak	4	18:00	21:00

2.3 Greenhouse gas emissions

The Greenhouse gas emissions (GHG) considered in TIMES_Evora are only the ones from fuel combustion and are presented in Table 4. The corresponding associated emission factors are presented in Table 5 and were retrieved from the National Emission Inventories (APA, 2016).

Table 4 – GHG emissions considered in TIMES_Evora

Commodity Code in TIMES_Evora	Description
SUPCO2N	CO_2 emissions from electricity imports to Évora
SUPCH4N	CH_4 emissions from electricity imports to Évora
SUPN2ON	N_2O emissions from electricity imports to Évora
TRACO2N	CO_2 emissions from fuel combustion in the transport sector
TRACH4N	CH_4 emissions from fuel combustion in the transport sector
TRAN2ON	N_2O emissions from fuel combustion in the transport sector
COMCO2N	CO_2 emissions from fuel combustion in the commercial sector
COMCH4N	CH_4 emissions from fuel combustion in the commercial sector
COMN2ON	N_2O emissions from fuel combustion in the commercial sector
OTSCO2N	CO_2 emissions from fuel combustion in the waste, water & waste water sector
OTSCH4N	CH_4 emissions from fuel combustion in the waste, water & waste water sector
OTSN2ON	N_2O emissions from fuel combustion in the waste, water & waste water sector
INDCO2N	CO_2 emissions from fuel combustion in the industry sector
INDCH4N	CH_4 emissions from fuel combustion in the industry sector
INDN2ON	N_2O emissions from fuel combustion in the industry sector
RSDCO2N	CO_2 emissions from fuel combustion in the residential sector
RSDCH4N	CH_4 emissions from fuel combustion in the residential sector
RSDN2ON	N_2O emissions from fuel combustion in the residential sector
AGRCO2N	CO_2 emissions from fuel combustion in the agriculture sector
AGRN2ON	CH_4 emissions from fuel combustion in the agriculture sector
AGRCH4N	N_2O emissions from fuel combustion in the agriculture sector

Table 5 – GHG Emission factors considered in TIMES_Evora in kg CO_2/GJ

Emission / Fuel	Gasoline	Diesel	LPG	Natural Gas	Oil
CO_2 emission from commercial, transport, agriculture and industry sectors	97	65	78	56	Not applicable
CO_2 emission from the residential sector[1]	69	74	63	56	77.4
CH_4 emissions	0.01	0.001	0.001	0.001	0.001
N_2O emissions	0.001	0	0.004	0.001	0

The electricity consumed in Évora is generated outside the modelled zones. The corresponding GHG emission associated to its generation were considered by creating

[1] The fuels consumed in the residential sector are slightly different from the ones consumed in the other sectors, hence the different emission factors. For example, in the residential sector paraffin is consumed and grouped with gasoline.

specific emission commodities (SUPCO2N, SUPCH4N and SUPN2ON) for these imports with a CO_2eq emission factor obtained from the latest electricity statistics published the ERSE, the Portuguese electricity market regulator (ERSE, 2016) for mainland Portugal (Table 6). This roughly correspond to a share of 37% of RES electricity which is assumed constant from 2013 until 2030.

Table 6- Emission factors for imported electricity into Évora

GHG	SUPCO2N	SUPCH4N	SUPN2ON
Emission factor in kg $CO_{2.eq}$ /GJ	96.9	0.1	0.8

2.4 Description of the existing system

This section describes the key data used in the model to describe the base-year for the several modelled sectors.

2.4.1 Residential buildings

Based on the characterisation of the residential building typologies in WP1 and WP2, 10 residential building typologies are considered in TIMES_Evora (Table 7). The dwellings in Évora are all allocated to each of these typologies across the four modelled zones (Table 8). In the base year of 2013 there were 25 155 households in the TIMES_Evora model distributed across 17 972 buildings.

Table 7 – Residential building typologies considered in TIMES_Evora resulting from the analysis in WP2

Typology number	Type of house	Period of construction	Type of roof	Number of floors	Location
TP1	Detached	Until 1945	Sloped	1	Rural
TP2	Detached	Between 1946-1990	Sloped	1 to 2	Rural/Urban
TP3	Detached	After 1991	Sloped	1	Rural/Urban
TP4	Semi-Detached	Until 1945	Sloped	1	Rural
TP5	Semi-Detached	Between 1946-1990	Sloped	1 to 2	Rural/Urban
TP6	Semi-Detached	After 1991	Sloped	2	Urban
TP7	Terraced	Until 1945	Sloped	1 to 2	Rural/Urban
TP8	Terraced	Between 1946-1990	Sloped	1 to 2	Rural/Urban
TP9	Terraced	Between 1946-1990	Flat	2	Urban
TP10	Terraced	After 1991	Sloped	1 to 2	Rural/Urban

Table 8 – Number of dwellings in each model zones per typology in the base year of 2013

Typology code	Description of the typology	Model zone				Total
		Z1	Z2	Z3	Z4	

Typology code	Description of the typology	Model zone				Total
		Z1	Z2	Z3	Z4	
R_TP1	TP1 – Detached rural house, 1 floor built until 1945 with a sloped roof	510	258	102	28	**898**
R_TP2	TP2 – Detached rural or urban house, 1-2 floors built in 1946-1990 with a sloped roof	1169	1275	685	25	**3154**
R_TP3	TP3 – Detached rural or urban house, 1 floor built after 1991 with a sloped roof	641	539	293	3	**1476**
R_TP4	TP4 – Semi-Detached rural house, 1 floor built until 1945 with a sloped roof	383	120	38	53	**594**
R_TP5	TP5 – Semi-Detached rural or urban house, 1-2 floors built in 1946-1990 with a sloped roof	967	1536	732	145	**3380**
R_TP6	TP6 – Semi-Detached urban house, 2 floors built after 1991 with a sloped roof	500	721	128	10	**1359**
R_TP7	TP7 – Terraced rural or urban house, 1-2 floors built until 1945 with a sloped roof	502	467	179	2096	**3244**
R_TP8	TP8 – Terraced rural or urban house, 1-2 floors built in 1946-1990 with a sloped roof	787	2154	2749	972	**6662**
R_TP9	TP9 – Terraced rural urban house, 2 floors built in 1946-1990 with a flat roof	0	2	1175	24	**1201**
R_TP10	TP10 – Terraced rural or urban house, 1-2 floors built after 1991 with a sloped roof	518	559	1927	185	**3189**

The approach used to model the energy use in the residential sector is different from what is used in most TIMES models (see for example (Simoes et al., 2013)). Whereas in most TIMES models the model is driven by an exogenous demand for useful energy services, such as space heat or lighting, in TIMES_Evora (and in the other InSmart TIMES city models) the number of dwellings (denoted as R_TP*n* in Figure 4) drives the aggregated total useful energy demand for each dwelling per typology (Rdw_TPn in Figure 4).

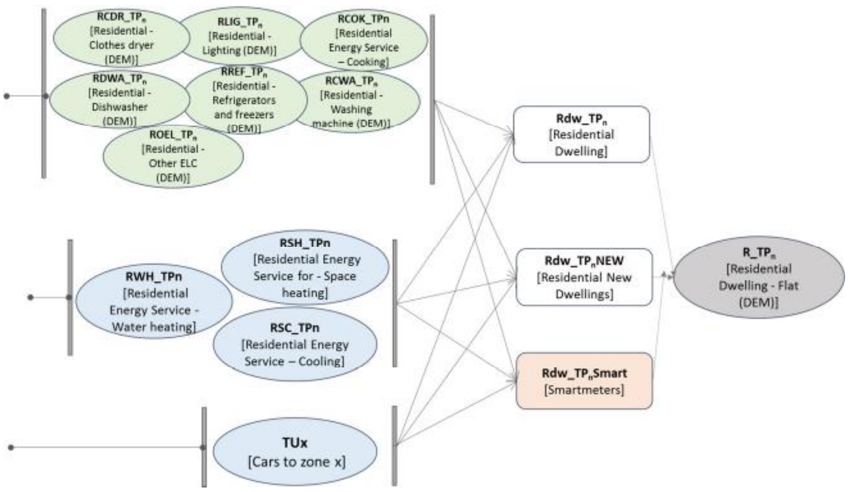

Figure 4 – Approach used to model the residential sector in TIMES_Evora. TPn denotes the building Typology (1 to 10). TUx denotes the mobility demand of passenger cars between zones in the model

This aggregated total energy demand includes useful energy needs for the following energy services also represented in Figure 4: space heating, space cooling, water heating, lighting, cooking, refrigeration, dish washing, clothes washing, clothes drying, and other electric uses. Within these energy categories of residential energy use two approaches were used in the TIMES_Evora model:

1. *Space heating, space cooling and water heating* (in blue in Figure 4) are modelled as useful energy demands in GJ that can be satisfied by different energy technologies using different final energy carriers. This means that fuel shifts are possible for these four energy services.
2. *Lighting, refrigeration, cooking, dish washing, clothes washing, clothes drying and other electric uses* (in green in Figure 4) are modelled in numbers of electric appliances that all consume electricity according to pre-defined efficiencies of the appliances. For these energy uses it is possible to have technology replacement but no fuel shifts as represented in Figure 5 for the case of lighting.

Figure 5 – Modelling approach in TIMES_Evora used for lighting which is similar for refrigeration, dish washing, clothes washing, clothes drying and other electric uses

For the first approach (*space heating, space cooling, water heating*), the number of dwellings that ultimately drives the final energy consumption in the model, is associated with an useful energy demand for each of the end-use energy services heating, cooling and water heating, based on the detailed modelling at each dwelling typology made in WP2 using EnergyPlus.

For the determination of useful energy in WP2, as close to reality possible thermal comfort conditions were considered. However, the heating and cooling gap in Portugal is very high. This means there is a difference between theoretical thermal comfort, *i.e.* heating and cooling of the whole dwelling ensuring an indoor temperature of 25ºC in winter and 18ºC in summer during the whole heating or cooling season and real comfort levels which be as high as 90% in some cases. This is found when analysing real energy consumption statistics in the residential sector, which are too low to provide the levels of comfort seen in other European countries. Dwellings in Évora (and in Portugal) were found not to be heated/cooled to the comfort levels modelled in WP2 due to a number of motives, such as high energy costs and culture factors, as found in the analysis carried following WP2. The gap was estimated based on actual/historical thermal requirements assessed based on the Évora’s energy balance breakdown as in Table 9.

Table 9 – Gap between Ideal and Real Space Heating conditions in Évora

Typology	Share of total space heating demand from WP2	Total space heating for all dwellings (GJ)		Gap (%)
		From city energy balance	Ideal thermal comfort WP2	
TP1 – Detached rural house, 1 floor built until 1945 with a sloped roof	10%	6067.54	19388.36	69%
TP2 – Detached rural or urban house, 1-2 floors built in 1946-1990 with a sloped roof	10%	5684.68	63773.91	91%
TP3 – Detached rural or urban house, 1 floor built after 1991 with a sloped roof	12%	6822.03	35801.41	81%
TP4 – Semi-Detached rural house, 1 floor built until 1945 with a sloped roof	14%	8050.56	17018.19	53%
TP5 – Semi-Detached rural or urban house, 1-2 floors built in 1946-1990 with a sloped roof	12%	6854.62	82379.46	92%
TP6 – Semi-Detached urban house, 2 floors built after 1991 with a sloped roof	11%	6457.71	31221.66	79%
TP7 – Terraced rural or urban house, 1-2 floors built until 1945 with a sloped roof	7%	4246.57	48981.54	91%
TP8 – Terraced rural or urban house, 1-2 floors built in 1946-1990 with a sloped roof	7%	4073.53	96513.14	96%
TP9 – Terraced rural urban house, 2 floors built in 1946-1990 with a flat roof	9%	5104.23	21806.43	77%
TP10 – Terraced rural or urban house, 1-2 floors built after 1991 with a sloped roof	8%	4862.54	55151.08	91%
Total	**1.00**	**58224.00**	**472035.17**	**88%**

Therefore, in TIMES_Evora was created a set of dummy processes named ***Unmet Demand*** (replicated for the different residential building technologies in the model) to reflect the gap between useful energy needed for “theoretical ideal” thermal comfort and “real” heating and cooling conditions (Figure 6).

The model has thus the possibility to model a reduction on the *unmet demand* until all households reach the optimal indoor thermal conditions. However, for the analysis carried out in this WP, the unmet demand was assumed to be maintained constant.

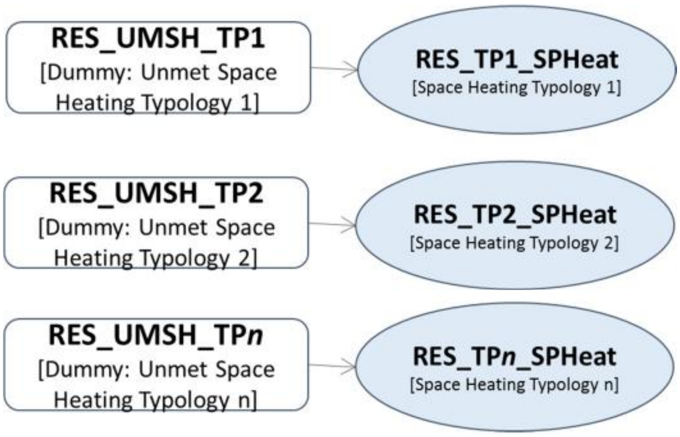

Figure 6 - Modelled approach for the unmet space heating demand

The different energy technologies stocks in the base year (B-Y) and their possible replacements are modelled explicitly considering the information gathered in Évora within WP1, and WP2 resulting in the following options:

- *Space heating*: split air conditioning units, centralized air conditioning, portable air conditioning, electric heaters, fireplaces, fireplaces with heat recovery, solid biomass and pellets burners, centralized heating gas boilers also delivering hot water, LPG stoves, heat pumps, solar centralized space & water heating with diesel / LPG / electricity backup, infiltration insulation, window insulation (double glazed) and roof insulation;
- *Space cooling*: split air conditioning units, centralized air conditioning units, fans, portable air conditioning, heat pumps, infiltration insulation and roof insulation;
- *Water heating*: centralized heating gas boilers also delivering hot water, solar centralized space & water heating with diesel / LPG / electricity backup, electric boiler, LPG furnace, gas furnace, solar thermal panels for hot water with gas / diesel / electricity backup;
- *Lighting*: incandescent, tubular fluorescent, fluorescent compact, halogen and LED;
- *Cooking*: gas stove, electric stove, biomass stoves and LPG stoves;
- *Refrigeration*: combination of refrigerators and freezers as one simplified technology divided according to energy efficiency classes (B to G, A to A+, A++, and A+++);
- *Dish washing*: electric dishwashers divided according to energy efficiency classes (B to G, A to A+, A++, and A+++);
- *Clothes washing*: electric washing machines divided according to energy efficiency classes (B to G, A to A+, A++, and A+++);
- *Clothes drying*: electric clothes dryers divided according to energy efficiency classes (B to G, A to A+, A++, and A+++);
- *Other electric uses*: simplified technology aggregation all other electric uses.

The possible new technologies that will be available in the future and can replace B-Y technologies (Figure 7 represents B-Y technologies for space-heating) are defined in detail in the model database, as exemplified for space heating in Figure 8.

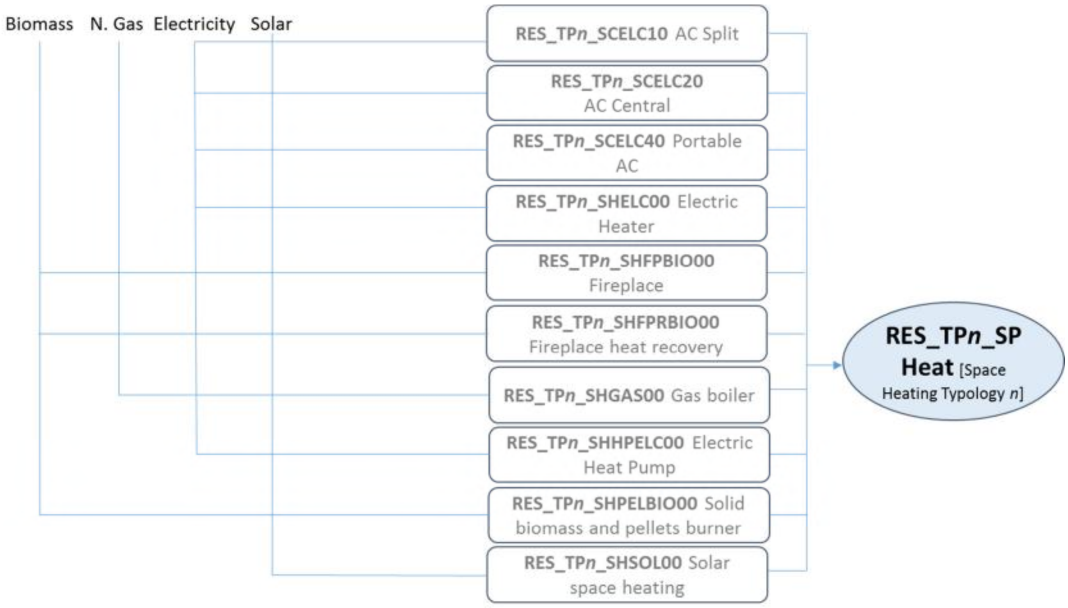

Figure 7 – Technology options for B-Y space heating in the residential buildings in TIMES_Evora.

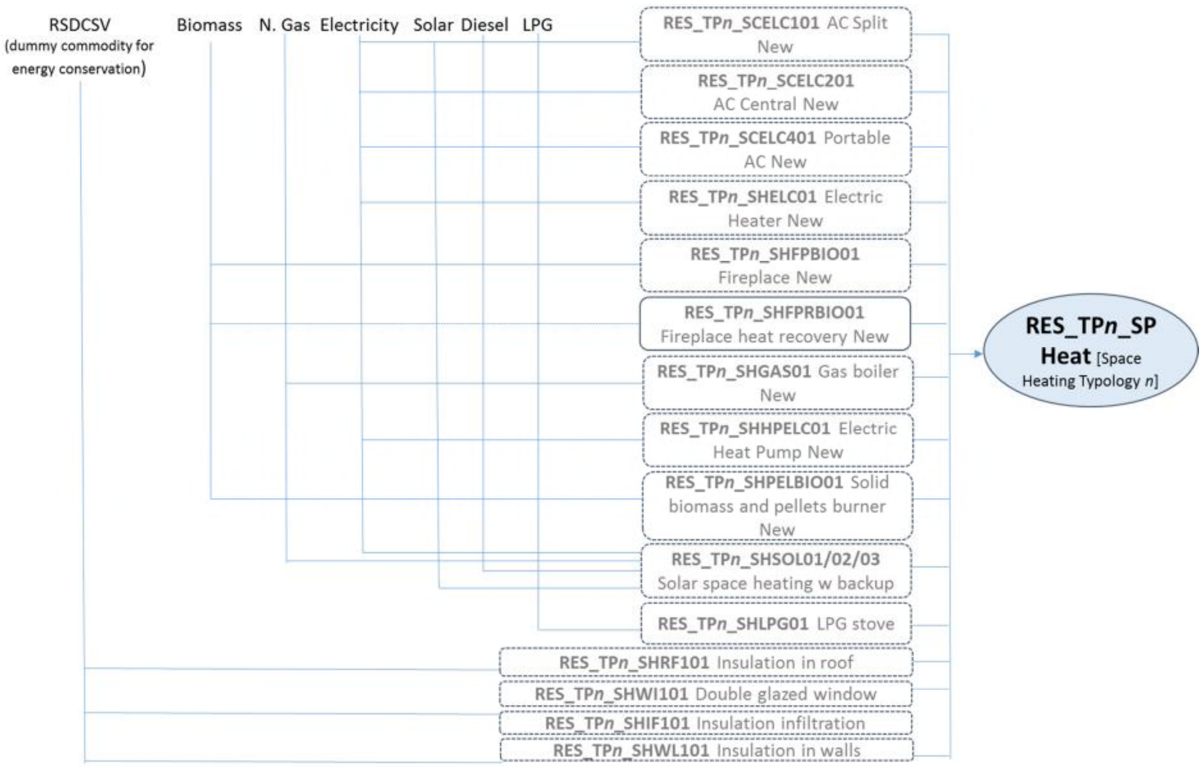

Figure 8 – New technology options that can replace B-Y technologies for space heating in the residential buildings in TIMES_Evora.

In the previous figure are also represented four possible dummy technologies (replicated per each typology) that represent the future refurbishment options for each typology and that can cover part of the space heating demand without energy consumption. The technologies closely follow the analysis done in the WP2 regarding the possible refurbishment options that can be implemented in the residential sector buildings in Évora, according to the thermal properties defined by the Portuguese Regulation for the specific climate zone:

1. Installation of external insulation on the roofs for typologies without insulation or insufficient insulation;
2. Installation of external insulation on the walls for typologies without insulation or insufficient insulation, which was found to be technically feasible only in typologies 5 and 6, more recent semi-detached houses;
3. Installation of measures to reduce air infiltration by installing some draught proofing measures;
4. Replacement of existing windows with low emissivity glazing in all external windows.

The implementation costs for each of these options was estimated based on existing market data. The expected reduction of the space heating and cooling demand vary across typology based on the calculations performed in WP2 (Table 10).

Table 10 – Energy savings per typology estimated for energy refurbishment measures considered in TIMES_Evora as % reduction of space heating useful energy demand compared to the current situation

Typology	Window Glazing	Air Infiltration	Roof Insulation	Wall Insulation
TP1 – Detached rural house, 1 floor built until 1945 with a sloped roof	6%	1%	2%	n.a.
TP2 – Detached rural or urban house, 1-2 floors built in 1946-1990 with a sloped roof	5%	1%	4%	n.a.
TP3 – Detached rural or urban house, 1 floor built after 1991 with a sloped roof	7%	2%	5%	n.a.
TP4 – Semi-Detached rural house, 1 floor built until 1945 with a sloped roof	5%	2%	9%	n.a.
TP5 – Semi-Detached rural or urban house, 1-2 floors built in 1946-1990 with a sloped roof	7%	2%	6%	50%
TP6 – Semi-Detached urban house, 2 floors built after 1991 with a sloped roof	9%	1%	3%	20%
TP7 – Terraced rural or urban house, 1-2 floors built until 1945 with a sloped roof	7%	3%	7%	n.a.
TP8 – Terraced rural or urban house, 1-2 floors built in 1946-1990 with a sloped roof	4%	1%	6%	n.a.
TP9 – Terraced rural urban house, 2 floors built in 1946-1990 with a flat roof	3%	0%	2%	n.a.
TP10 – Terraced rural or urban house, 1-2 floors built after 1991 with a sloped roof	7%	2%	4%	n.a.

n.a. – not applicable following estimates made in WP2

TIMES_Evora has thus the flexibility to choose among these available options, based on the relative cost, achieved energy savings and alternative options in the energy system.

As previously mentioned, TIMES_Evora has the possibility of limiting the available budget for new technology investments per household (i.e. dwelling) to replicate real-life conditions. Four classes of families' income expressed as per capita income in euros were considered in TIMES_Evora, per residential building typology (Table 11), based on the surveys carried out during WP2 and WP3: above 2500 euros per capita, between 1167 and 2500 euros per capita, between 500-1000 euros per capita and below 500 euros per capita.

Table 11- Distribution of typologies according to classes of income in euros per capita considered in TIMES_EVORA

Typology	>2500 euros	1167-2500 euros	500-1000 euros	<500 euros
TP1 – Detached rural house, 1 floor built until 1945 with a sloped roof	0%	0%	75%	25%
TP2 – Detached rural or urban house, 1-2 floors built in 1946-1990 with a sloped roof	0%	8%	48%	44%
TP3 – Detached rural or urban house, 1 floor built after 1991 with a sloped roof	23%	23%	31%	23%
TP4 – Semi-Detached rural house, 1 floor built until 1945 with a sloped roof	0%	6%	47%	47%
TP5 – Semi-Detached rural or urban house, 1-2 floors built in 1946-1990 with a sloped roof	0%	9%	49%	42%
TP6 – Semi-Detached urban house, 2 floors built after 1991 with a sloped roof	4%	12%	65%	19%
TP7 – Terraced rural or urban house, 1-2 floors built until 1945 with a sloped roof	5%	0%	32%	64%
TP8 – Terraced rural or urban house, 1-2 floors built in 1946-1990 with a sloped roof	0%	0%	54%	46%
TP9 – Terraced rural urban house, 2 floors built in 1946-1990 with a flat roof	0%	0%	31%	69%
TP10 – Terraced rural or urban house, 1-2 floors built after 1991 with a sloped roof	5%	17%	48%	31%
Total	**3%**	**8%**	**47%**	**43%**

Based on the relatively small sample used in the survey carried out within WP1, it was assumed that the inhabitants of most of the typologies live with an income per capita below 1000 euros. Typologies 3, 10, 6, 7 and 5 (mostly built after 1991) have a relatively higher share of wealthier inhabitants than the other typologies (Figure 9).

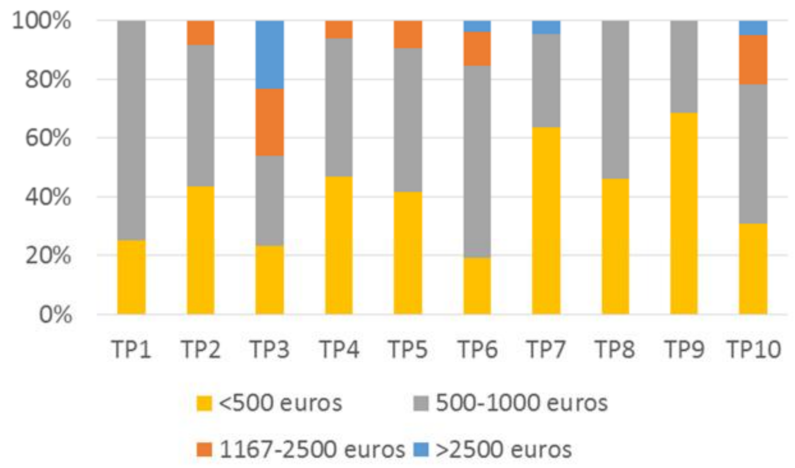

Figure 9 – Distribution of per capita income across residential building technologies in TIMES_Evora

The constraint on investment capacity was defined per residential building typology as an upper bound on annual investment in new technologies' capacity. It was assumed a weighted average annual investment amount per typology from Table 11 and assuming the following shares of savings rate per income class:

- 8.30% of weighted available annual income for typology with a per capita income above 2500 euros;
- 4.15% of weighted available annual income for typology with a per capita income below 2500 euros and 1500 euros;
- 2.08% of weighted available annual income for typology with a per capita income below 1500 euros.

This was based in the national statistics of savings of families in Portugal that were on average 8.3% of available income in 2013 (Statistics Portugal, 2015).

2.4.2 Transport

The ***passenger cars*** in TIMES_Evora are modelled as shown in Figure 10, with each dwelling in each model zone (Z1 to Z4) having associated a certain number of vehicles-km (vkm) for each of the other three modelled zones.

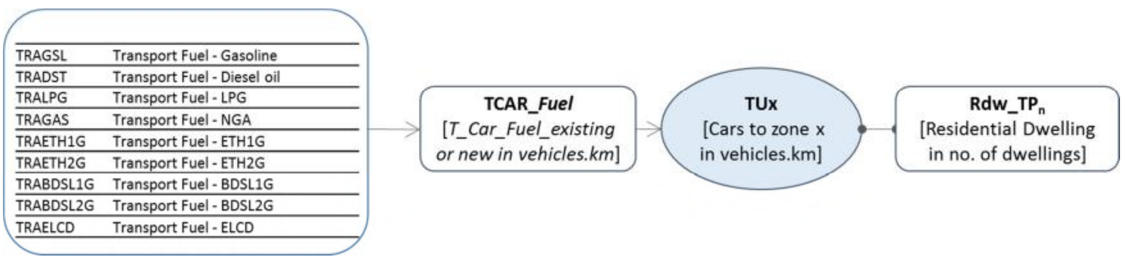

Figure 10 – TIMES_Evora model structure for passenger cars, where "x" denotes the four zones of the model 1 to 4

The vkm are the traffic flows of that dwelling to the other areas of the municipality and within the zone where the dwelling is located, based on the information collected in WP3 (Table 12). The traffic flows are supplied by the existing passenger car fleet associated to the dwellings of that particular typology and model zone based on the surveys performed in WP3 and WP2. It was assumed that the more recent cars were allocated to the typologies with higher income (from Table 11). The different passenger cars consume final energy according to their efficiency and travel patterns.

Table 12 - Demand of Vkm/dwelling per year across model zones for passenger cars

Year	Model zones	Z1	Z2	Z3	Z4
2015	TU1 (cars to Zone 1)	42.13	2.41	1.02	1.45
2015	TU2 (cars to Zone 2)	4998.20	1891.37	494.01	369.72
2015	TU3 (cars to Zone 3)	12789.28	2125.89	2576.78	1143.78
2015	TU4 (cars to Zone 4)	3652.86	444.36	200.00	550.38
2015	TU5 (cars to outside Évora)	3770.55	3098.10	3118.14	3686.55
2020	TU1 (cars to Zone 1)	42.22	2.45	1.04	1.44
2020	TU2 (cars to Zone 2)	4986.85	1877.33	502.37	368.48
2020	TU3 (cars to Zone 3)	12712.08	2134.05	2574.07	1137.61
2020	TU4 (cars to Zone 4)	3924.29	499.34	230.99	550.26
2020	TU5 (cars to outside Évora)	3801.94	3124.45	3140.86	3669.27
2025	TU1 (cars to Zone 1)	43.90	2.56	1.10	1.49
2025	TU2 (cars to Zone 2)	5185.42	1964.06	528.11	381.53
2025	TU3 (cars to Zone 3)	13218.27	2232.64	2705.97	1177.91
2025	TU4 (cars to Zone 4)	4080.56	522.41	242.83	569.75
2025	TU5 (cars to outside Évora)	3953.33	3268.80	3301.81	3799.23
2030	TU1 (cars to Zone 1)	42.08	2.51	1.09	1.42
2030	TU2 (cars to Zone 2)	4856.97	1833.40	486.35	358.64
2030	TU3 (cars to Zone 3)	12632.46	2208.67	2634.24	1103.38
2030	TU4 (cars to Zone 4)	4174.43	557.80	250.00	537.29
2030	TU5 (cars to outside Évora)	3805.24	3166.57	3213.96	3565.58

The following passenger cars are considered in TIMES_Evora:

- *diesel cars* existing in the base year further subdivided according to the following EURO Classes: I to III, IV, V and VI plus new diesel cars;
- *hybrid diesel cars* existing in the base year further subdivided according to the following EURO Classes: I to III, IV, V and VI plus new hybrid diesel cars;
- *gasoline cars* existing in the base year further subdivided according to the following EURO Classes: I to III, IV, V and VI plus new gasoline cars;
- *hybrid gasoline cars* existing in the base year further subdivided according to the following EURO Classes: I to III, IV, V and VI plus new hybrid gasoline cars;
- *hybrid plug-in gasoline cars* existing in the base year further subdivided according to the following EURO Classes: I to III, IV, V and VI plus new hybrid plug-in gasoline cars;

- *LPG cars* existing in the base year further subdivided according to the following EURO Classes: I to III, IV, V and VI plus new LPG cars;
- *electric cars* existing in the base year and new electric cars of 15-30kWh, 30-60kWh and 60kWh;
- *biodiesel cars*;
- *ethanol cars*;
- *gas cars*.

In the base-year the following vehicle stock was considered as in Table 13. A total of 30 077 passenger cars was circulating in Évora in the base-year, mostly located in zones 2 and 3, the urban zones that are not the historic centre. The passenger cars stock was allocated to each of the 10 residential dwellings typology as previously described and from there the cars travel to each of the four modelled zones and to outside the municipality of Évora.

Table 13 – Number of passenger cars considered in the base-year per type of car and modelled zone in TIMES_Evora

Type of car (code and description) / Model Zone	Z1	Z2	Z3	Z4
TCARDST10_TP1 [Diesel vehicle private - Euro I to III_TP1]	381	193	76	21
TCARDST10_TP10 [Diesel vehicle private - Euro I to III_TP10]	352	380	1309	126
TCARDST10_TP2 [Diesel vehicle private - Euro I to III_TP2]	874	953	512	19
TCARDST10_TP3 [Diesel vehicle private - Euro I to III_TP3]	274	230	125	1
TCARDST10_TP4 [Diesel vehicle private - Euro I to III_TP4]	286	90	29	39
TCARDST10_TP5 [Diesel vehicle private - Euro I to III_TP5]	722	1148	547	108
TCARDST10_TP6 [Diesel vehicle private - Euro I to III_TP6]	353	509	90	7
TCARDST10_TP7 [Diesel vehicle private - Euro I to III_TP7]	328	305	117	1370
TCARDST10_TP8 [Diesel vehicle private - Euro I to III_TP8]	588	1609	2054	726
TCARDST10_TP9 [Diesel vehicle private - Euro I to III_TP9]		1	878	18
TCARDST40_TP10 [Diesel vehicle private - Euro IV_TP10]	12	13	44	4
TCARDST40_TP3 [Diesel vehicle private - Euro IV_TP3]	68	58	31	0
TCARDST40_TP6 [Diesel vehicle private - Euro IV_TP6]	7	10	2	0
TCARDST40_TP7 [Diesel vehicle private - Euro IV_TP7]	16	15	6	65
TCARDST50_TP10 [Diesel vehicle private - Euro V_TP10]	12	13	44	4
TCARDST50_TP3 [Diesel vehicle private - Euro V_TP3]	68	58	31	0
TCARDST50_TP6 [Diesel vehicle private - Euro V_TP6]	7	10	2	0
TCARDST50_TP7 [Diesel vehicle private - Euro V_TP7]	16	15	6	65
TCARDST60_TP10 [Diesel vehicle private - Euro VI_TP10]	12	13	44	4
TCARDST60_TP3 [Diesel vehicle private - Euro VI_TP3]	68	58	31	0
TCARDST60_TP6 [Diesel vehicle private - Euro VI_TP6]	7	10	2	0
TCARDST60_TP7 [Diesel vehicle private - Euro VI_TP7]	16	15	6	65
TCARDSTHYB10_TP1 [Diesel hybrid vehicle private - Euro I to III_TP1]	1	0	0	0
TCARDSTHYB10_TP10 [Diesel hybrid vehicle private - Euro I to III_TP10]	1	1	2	0
TCARDSTHYB10_TP2 [Diesel hybrid vehicle private - Euro I to III_TP2]	2	2	1	0

Type of car (code and description) / Model Zone	Z1	Z2	Z3	Z4
TCARDSTHYB10_TP3 [Diesel hybrid vehicle private - Euro I to III_TP3]	1	0	0	0
TCARDSTHYB10_TP4 [Diesel hybrid vehicle private - Euro I to III_TP4]	1	0	0	0
TCARDSTHYB10_TP5 [Diesel hybrid vehicle private - Euro I to III_TP5]	1	2	1	0
TCARDSTHYB10_TP6 [Diesel hybrid vehicle private - Euro I to III_TP6]	1	1	0	0
TCARDSTHYB10_TP7 [Diesel hybrid vehicle private - Euro I to III_TP7]	1	1	0	3
TCARDSTHYB10_TP8 [Diesel hybrid vehicle private - Euro I to III_TP8]	1	3	4	1
TCARDSTHYB10_TP9 [Diesel hybrid vehicle private - Euro I to III_TP9]		0	2	0
TCARDSTHYB40_TP10 [Diesel hybrid vehicle private - Euro IV_TP10]	0	0	0	0
TCARDSTHYB40_TP3 [Diesel hybrid vehicle private - Euro IV_TP3]	0	0	0	0
TCARDSTHYB40_TP6 [Diesel hybrid vehicle private - Euro IV_TP6]	0	0	0	0
TCARDSTHYB40_TP7 [Diesel hybrid vehicle private - Euro IV_TP7]	0	0	0	0
TCARDSTHYB50_TP10 [Diesel hybrid vehicle private - Euro V_TP10]	0	0	0	0
TCARDSTHYB50_TP3 [Diesel hybrid vehicle private - Euro V_TP3]	0	0	0	0
TCARDSTHYB50_TP6 [Diesel hybrid vehicle private - Euro V_TP6]	0	0	0	0
TCARDSTHYB50_TP7 [Diesel hybrid vehicle private - Euro V_TP7]	0	0	0	0
TCARDSTHYB60_TP10 [Diesel hybrid vehicle private - Euro VI_TP10]	0	0	0	0
TCARDSTHYB60_TP3 [Diesel hybrid vehicle private - Euro VI_TP3]	0	0	0	0
TCARDSTHYB60_TP6 [Diesel hybrid vehicle private - Euro VI_TP6]	0	0	0	0
TCARDSTHYB60_TP7 [Diesel hybrid vehicle private - Euro VI_TP7]	0	0	0	0
TCARELC00_TP1 [Electric vehicle private_TP1]	0.13	0.07	0.03	0.01
TCARELC00_TP10 [Electric vehicle private_TP10]	0.09	0.10	0.33	0.03
TCARELC00_TP2 [Electric vehicle private_TP2]	0.20	0.22	0.12	0.00
TCARELC00_TP3 [Electric vehicle private_TP3]	0.11	0.09	0.05	0.00
TCARELC00_TP4 [Electric vehicle private_TP4]	0.07	0.02	0.01	0.01
TCARELC00_TP5 [Electric vehicle private_TP5]	0.16	0.26	0.12	0.02
TCARELC00_TP6 [Electric vehicle private_TP6]	0.09	0.12	0.02	0.00
TCARELC00_TP7 [Electric vehicle private_TP7]	0.09	0.08	0.03	0.36
TCARELC00_TP8 [Electric vehicle private_TP8]	0.13	0.37	0.47	0.17
TCARELC00_TP9 [Electric vehicle private_TP9]		0.00	0.20	0.00
TCARGSL10_TP1 [Gasoline vehicle private - Euro I to III_TP1]	224	113	45	12
TCARGSL10_TP10 [Gasoline vehicle private - Euro I to III_TP10]	207	223	769	74
TCARGSL10_TP2 [Gasoline vehicle private - Euro I to III_TP2]	513	559	301	11
TCARGSL10_TP3 [Gasoline vehicle private - Euro I to III_TP3]	161	135	73	1
TCARGSL10_TP4 [Gasoline vehicle private - Euro I to III_TP4]	168	53	17	23
TCARGSL10_TP5 [Gasoline vehicle private - Euro I to III_TP5]	424	674	321	64
TCARGSL10_TP6 [Gasoline vehicle private - Euro I to III_TP6]	207	299	53	4

Type of car (code and description) / Model Zone	Z1	Z2	Z3	Z4
TCARGSL10_TP7 [Gasoline vehicle private - Euro I to III_TP7]	193	179	69	805
TCARGSL10_TP8 [Gasoline vehicle private - Euro I to III_TP8]	345	945	1206	427
TCARGSL10_TP9 [Gasoline vehicle private - Euro I to III_TP9]		1	516	11
TCARGSL40_TP10 [Gasoline vehicle private - Euro IV_TP10]	7	7	26	2
TCARGSL40_TP3 [Gasoline vehicle private - Euro IV_TP3]	40	34	18	0
TCARGSL40_TP6 [Gasoline vehicle private - Euro IV_TP6]	4	6	1	0
TCARGSL40_TP7 [Gasoline vehicle private - Euro IV_TP7]	9	9	3	38
TCARGSL50_TP10 [Gasoline vehicle private - Euro V_TP10]	7	7	26	2
TCARGSL50_TP3 [Gasoline vehicle private - Euro V_TP3]	40	34	18	0
TCARGSL50_TP6 [Gasoline vehicle private - Euro V_TP6]	4	6	1	0
TCARGSL50_TP7 [Gasoline vehicle private - Euro V_TP7]	9	9	3	38
TCARGSL60_TP10 [Gasoline vehicle private - Euro VI_TP10]	7	7	26	2
TCARGSL60_TP3 [Gasoline vehicle private - Euro VI_TP3]	40	34	18	0
TCARGSL60_TP6 [Gasoline vehicle private - Euro VI_TP6]	4	6	1	0
TCARGSL60_TP7 [Gasoline vehicle private - Euro VI_TP7]	9	9	3	38
TCARGSLHYB10_TP1 [Gasoline hybrid vehicle private - Euro I to III_TP1]	1	1	0	0
TCARGSLHYB10_TP10 [Gasoline hybrid vehicle private - Euro I to III_TP10]	1	1	4	0
TCARGSLHYB10_TP2 [Gasoline hybrid vehicle private - Euro I to III_TP2]	2	3	1	0
TCARGSLHYB10_TP3 [Gasoline hybrid vehicle private - Euro I to III_TP3]	1	1	0	0
TCARGSLHYB10_TP4 [Gasoline hybrid vehicle private - Euro I to III_TP4]	1	0	0	0
TCARGSLHYB10_TP5 [Gasoline hybrid vehicle private - Euro I to III_TP5]	2	3	2	0
TCARGSLHYB10_TP6 [Gasoline hybrid vehicle private - Euro I to III_TP6]	1	1	0	0
TCARGSLHYB10_TP7 [Gasoline hybrid vehicle private - Euro I to III_TP7]	1	1	0	4
TCARGSLHYB10_TP8 [Gasoline hybrid vehicle private - Euro I to III_TP8]	2	5	6	2
TCARGSLHYB10_TP9 [Gasoline hybrid vehicle private - Euro I to III_TP9]		0	2	0
TCARGSLHYB40_TP10 [Gasoline hybrid vehicle private - Euro IV_TP10]	0	0	0	0
TCARGSLHYB40_TP3 [Gasoline hybrid vehicle private - Euro IV_TP3]	0	0	0	0
TCARGSLHYB40_TP6 [Gasoline hybrid vehicle private - Euro IV_TP6]	0	0	0	0
TCARGSLHYB40_TP7 [Gasoline hybrid vehicle private - Euro IV_TP7]	0	0	0	0
TCARGSLHYB50_TP10 [Gasoline hybrid vehicle private - Euro V_TP10]	0	0	0	0
TCARGSLHYB50_TP3 [Gasoline hybrid vehicle private - Euro V_TP3]	0	0	0	0
TCARGSLHYB50_TP6 [Gasoline hybrid vehicle private - Euro V_TP6]	0	0	0	0
TCARGSLHYB50_TP7 [Gasoline hybrid vehicle private - Euro V_TP7]	0	0	0	0
TCARGSLHYB60_TP10 [Gasoline hybrid vehicle private - Euro VI_TP10]	0	0	0	0
TCARGSLHYB60_TP3 [Gasoline hybrid vehicle private - Euro VI_TP3]	0	0	0	0

Type of car (code and description) / Model Zone	Z1	Z2	Z3	Z4
TCARGSLHYB60_TP6 [Gasoline hybrid vehicle private - Euro VI_TP6]	0	0	0	0
TCARGSLHYB60_TP7 [Gasoline hybrid vehicle private - Euro VI_TP7]	0	0	0	0
TCARGSLHYBPI50_TP1 [Gasoline Plug-in hybrid vehicle private - Euro V_TP1]	1	1	0	0
TCARGSLHYBPI50_TP10 [Gasoline Plug-in hybrid vehicle private - Euro V_TP10]	1	1	4	0
TCARGSLHYBPI50_TP2 [Gasoline Plug-in hybrid vehicle private - Euro V_TP2]	2	3	1	0
TCARGSLHYBPI50_TP3 [Gasoline Plug-in hybrid vehicle private - Euro V_TP3]	1	1	1	0
TCARGSLHYBPI50_TP4 [Gasoline Plug-in hybrid vehicle private - Euro V_TP4]	1	0	0	0
TCARGSLHYBPI50_TP5 [Gasoline Plug-in hybrid vehicle private - Euro V_TP5]	2	3	2	0
TCARGSLHYBPI50_TP6 [Gasoline Plug-in hybrid vehicle private - Euro V_TP6]	1	2	0	0
TCARGSLHYBPI50_TP7 [Gasoline Plug-in hybrid vehicle private - Euro V_TP7]	1	1	0	4
TCARGSLHYBPI50_TP8 [Gasoline Plug-in hybrid vehicle private - Euro V_TP8]	2	5	6	2
TCARGSLHYBPI50_TP9 [Gasoline Plug-in hybrid vehicle private - Euro V_TP9]		0	2	0
TCARGSLHYBPI60_TP1 [Gasoline Plug-in hybrid vehicle private - Euro VI_TP1]	1	1	0	0
TCARGSLHYBPI60_TP10 [Gasoline Plug-in hybrid vehicle private - Euro VI_TP10]	1	1	4	0
TCARGSLHYBPI60_TP2 [Gasoline Plug-in hybrid vehicle private - Euro VI_TP2]	2	3	1	0
TCARGSLHYBPI60_TP3 [Gasoline Plug-in hybrid vehicle private - Euro VI_TP3]	1	1	1	0
TCARGSLHYBPI60_TP4 [Gasoline Plug-in hybrid vehicle private - Euro VI_TP4]	1	0	0	0
TCARGSLHYBPI60_TP5 [Gasoline Plug-in hybrid vehicle private - Euro VI_TP5]	2	3	2	0
TCARGSLHYBPI60_TP6 [Gasoline Plug-in hybrid vehicle private - Euro VI_TP6]	1	2	0	0
TCARGSLHYBPI60_TP7 [Gasoline Plug-in hybrid vehicle private - Euro VI_TP7]	1	1	0	4
TCARGSLHYBPI60_TP8 [Gasoline Plug-in hybrid vehicle private - Euro VI_TP8]	2	5	6	2
TCARGSLHYBPI60_TP9 [Gasoline Plug-in hybrid vehicle private - Euro VI_TP9]		0	2	0
TCARLPG10_TP1 [LPG vehicle private - Euro I to III_TP1]	1	0	0	0
TCARLPG10_TP10 [LPG vehicle private - Euro I to III_TP10]	1	1	3	0
TCARLPG10_TP2 [LPG vehicle private - Euro I to III_TP2]	2	2	1	0
TCARLPG10_TP3 [LPG vehicle private - Euro I to III_TP3]	1	1	0	0
TCARLPG10_TP4 [LPG vehicle private - Euro I to III_TP4]	1	0	0	0
TCARLPG10_TP5 [LPG vehicle private - Euro I to III_TP5]	2	3	1	0
TCARLPG10_TP6 [LPG vehicle private - Euro I to III_TP6]	1	1	0	0
TCARLPG10_TP7 [LPG vehicle private - Euro I to III_TP7]	1	1	0	3
TCARLPG10_TP8 [LPG vehicle private - Euro I to III_TP8]	1	4	5	2
TCARLPG10_TP9 [LPG vehicle private - Euro I to III_TP9]		0	2	0
TCARLPG40_TP10 [LPG vehicle private - Euro IV_TP10]	0	0	0	0
TCARLPG40_TP3 [LPG vehicle private - Euro IV_TP3]	0	0	0	0
TCARLPG40_TP6 [LPG vehicle private - Euro IV_TP6]	0	0	0	0

Type of car (code and description) / Model Zone	Z1	Z2	Z3	Z4
TCARLPG40_TP7 [LPG vehicle private - Euro IV_TP7]	0	0	0	0
TCARLPG50_TP10 [LPG vehicle private - Euro V_TP10]	0	0	0	0
TCARLPG50_TP3 [LPG vehicle private - Euro V_TP3]	0	0	0	0
TCARLPG50_TP6 [LPG vehicle private - Euro V_TP6]	0	0	0	0
TCARLPG50_TP7 [LPG vehicle private - Euro V_TP7]	0	0	0	0
TCARLPG60_TP10 [LPG vehicle private - Euro VI_TP10]	0	0	0	0
TCARLPG60_TP3 [LPG vehicle private - Euro VI_TP3]	0	0	0	0
TCARLPG60_TP6 [LPG vehicle private - Euro VI_TP6]	0	0	0	0
TCARLPG60_TP7 [LPG vehicle private - Euro VI_TP7]	0	0	0	0

Most of the passenger cars are diesel cars (circa 62%) and gasoline (37%) with a substantial smaller fraction moving on LPG (0.14%) and electricity (0.01%). There no substantial differences in fuel type across zone. Most of the cars are EURO I to III classes (93-98% of the cars depending on the zones) with exception of the very few electric cars. Regarding the distribution of cars per residential building typologies, the older cars are found across all the 10 different typologies, but the more recent vehicles are more frequent owned by residents living in typologies 3, 6 and 7, respectively detached houses built after 1991, semi-detached houses built after 1991 and terraced houses built before 1945.

A very similar approach is used to model ***buses (urban and interurban)***. Existing buses are modelled using vkm and run on diesel only. However, they can be replaced by new buses fuelled by biodiesel, DME, ethanol, gas, LPG, methanol, gasoline and H_2 fuel cells. All of these are modelled as separate technologies. Additionally, there are possibilities for installing hybrid diesel buses, both conventional and plug-in. Urban buses travel within the four model zones, whereas interurban buses travel to outside Évora. The fuel consumption within the municipality is considered in TIMES_Evora.

Likewise, **freight trucks** are modelled in vkm as travelling to each of the four zones in the model and outside Évora. This can be done using diesel in the base year further disaggregated into refrigerated and conventional trucks. New freight trucks can run on diesel as well (both conventional and hybrids) and also on biodiesel, ethanol, gas, gasoline (both conventional and hybrids). The same approach is used for **light duty trucks** and for **motorcycles**, the only difference being in the range of fuels for the new technologies which are only electricity and gasoline for motorcycles and are more varied for light duty trucks (LPG, diesel, gasoline, electric vehicles of 15-30kWh, 30-60kWh and 60kWh, gasoline and diesel hybrids and plug-in hybrids, ethanol, gas and biodiesel).

2.4.3 Commercial buildings

The model considers with substantial level of detail the allocation of final energy consumption across the **buildings not managed by the municipality (COM)** which are further subdivided into: hotels (COMHOTE), restaurants (COMREST), retail (COMRETA), health care (COMHEAL), university (COMUNIV), secondary education (COMEDU), culture buildings (COMCULT) and other services buildings (COMOTHE). The energy consumption data for these buildings was obtained from the national statistics from the National Energy Directorate for the city of Évora (DGEG, 2014a, 2014b).

The **municipality-managed buildings (MUN)** are further disaggregated into: lighting of churches and monuments (MUNMON), the convent of Sª dos Remédios (MUNRMD), lighting of the historic city wall (MUNMUR), leisure buildings (MUNLEI), multifunction pavilion (MUNPAV), Garcia de Resende Theater (MUNGRS), and primary schools that are managed by the municipality (MUNEDU), city hall (CITYHALL), offices of the municipality staff (MUNTECK), buildings for storing equipment and materials (MUNMAT), social housing dwellings (MUNSOC), other sport facilities as the sports halls (MUNSPT), municipal swimming pool (MUNSWM) and other municipal buildings (MUNBLG). The energy consumption for these groups was provided by the municipality.

For both MUN and COM buildings (or areas), the energy consumption is further broken down into space heating, space cooling, water heating, lighting, cooking and other electricity used. Each of these energy services is modelled as a flexible technology with inputs of the different energy carriers in the base-year, without detailing the different technological options available to deliver it (e.g. boiler, furnace, solar thermal panel, etc.) as in Figure 11 only for the case of the culture buildings.

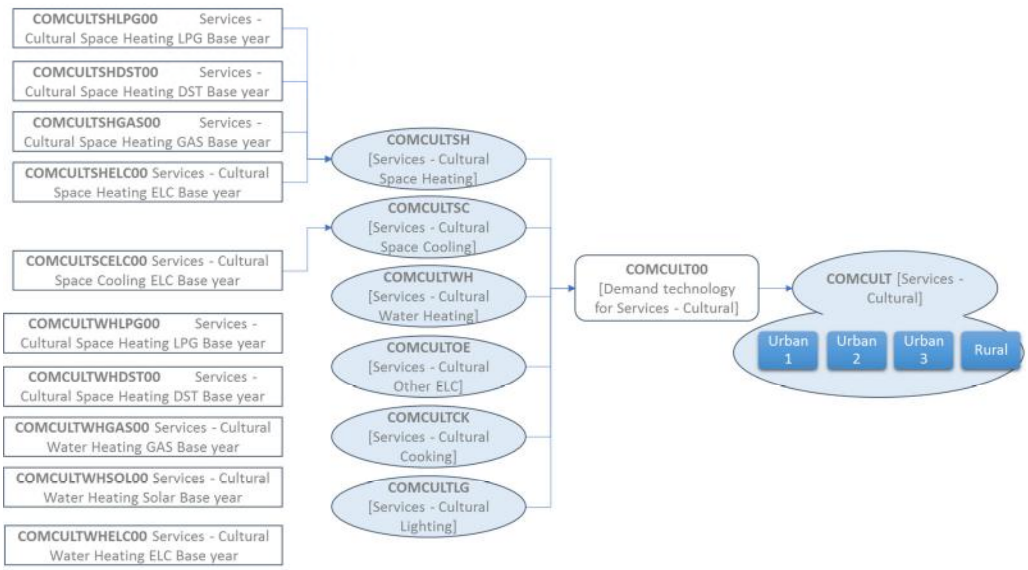

Figure 11 – Structure of the model for the services sector –example for the culture buildings

This approach was adopted due to the lack of data for this sector. Therefore, it not possible to model explicitly technology substitution for these sectors, only to introduce new fictitious generic technologies where the service is delivered with less final energy consumption. Naturally this has substantial uncertainty.

It should be mentioned that from all these sectors and activities, the most relevant ones in terms of energy consumption are the buildings not managed by the municipality in particular retail shops and schools (Table 14).

Table 14 – Overview of base-year final energy demand considered for the commercial and services buildings in GJ

		Energy consumption (GJ)			
Code	**Description**	**Z1**	**Z2**	**Z3**	**Z4**
Managed by the municipality					
MUNEDU	Public primary schools	285	427	475	617
MUNBLG	Other municipal buildings	511	511	511	511
CITYHALL	City hall building	0	0	0	768
MUNTECK	Offices of the municipality technicians	0	0	488	0
MUNLEI	Leisure buildings or areas	29	88	228	240
MUNMAT	Buildings or areas for storing equipment and materials	0	0	340	0
MUNPAV	Multifunction pavilion	0	0	380	0
MUNSWM	Municipal swimming pool	0	0	722	0
MUNSPT	Sports halls	17	52	278	0
MUNSOC	Social Housing	22	39	39	11
MUNMON	Lighting of churches and monuments	12	12	23	187
MUNRMD	Convent of Srª dos Remédios	0	0	0	316
MUNMUR	Lighting of the historic city wall	0	0	0	248
MUNGRS	Garcia de Resende Theater	0	0	0	229
Non-managed by the municipality					
COMRETA	Retail shops	16666	46664	143327	126661
COMOTHE	Other commercial and services	6298	18894	49123	51642
COMREST	Restaurant buildings	2107	3160	6321	9481
COMHOTE	Hotel buildings	0	26770	16062	10708
COMEDUC	Secondary & private education buildings	0	13561	9041	4520
COMHEAL	Health care buildings	4435	8870	15079	15966
COMCULT	Private culture buildings	0	1877	3106	1488
UNIV	University buildings	0	48	0	431

2.4.4 Public services

The public services in TIMES_Evora include the following processes according to the main services of water supply system (WATER), wastewater treatment (SWAGE), municipal solid waste collection and management (MSWSORT, MSWCOL), and public lighting (PLIG).

Regarding **water supply** the model considers the bas-year water treatment station (ETA00) as well as one generic base-year water distribution technology (WATERDISTRIB00) fuelled exclusively by electricity.

Regarding **wastewater treatment systems**, it is modelled the base-year sewage treatment plant (ETAR00) and a generic sewage collection technology (SWAGECOLLECT00) both fuelled by electricity only.

Municipal Solid Waste (MSW) is divided in undifferentiated MSW (MINMSWUND) and recycle materials (MINMSWRECY). These are each collected by specific diesel trucks: MSW_TRUCK_UND00 and MSW_TRUCK_RECY00, respectively. After collection the MSW is sent to a sorting centre (MSW_SORT00) or to a mechanical and biological treatment plant (MSW_TREAT00). Both processes are exclusively fuelled with electricity.

In all three systems (water, waste water and MSW) the processes are modelled as material mass balances, in terms of a unitary kilotons of water, waste water and MSW (differentiated or recyclable) with associated electricity consumption coefficients. The data for these was supplied by GESAMB (GESAMB, 2015) and by DGEG (DGEG, 2014a).

Finally, the **public lighting system** is modelled with explicit technological detail, detailing the different types of lighting equipment in place in the base-year and including associated electricity consumption as in Table 15, according to the information provided by the municipality of Évora.

Table 15 – Public lighting considered in the base-year

Type of public lighting equipment	**Model Zone**			
Number of equipment	**Z1**	**Z2**	**Z3**	**Z4**
Public lighting High and low pressure Sodium	3017	2895	4654	190
Public lighting Mercury	965	357	562	5
Public lighting Metal Iodates	0	7	101	1329
Public lighting LED	0	8	0	42
Public lighting Fluorescent	0	6	0	15
Energy consumption (GJ)	3577	3632	6740	1821

Taking the mercury lamps as a reference, the fluorescent lamps are modelled as 3 times more efficient, the sodium lamps are as 5 times more efficient, the metal iodates lamps are only 33% more efficient, and the LEDs lamps are 8 times more efficient.

2.4.5 Industry and Agriculture

As previously mentioned, the industry and agriculture sectors are modelled in a simplified approach as shown in Figure 12.

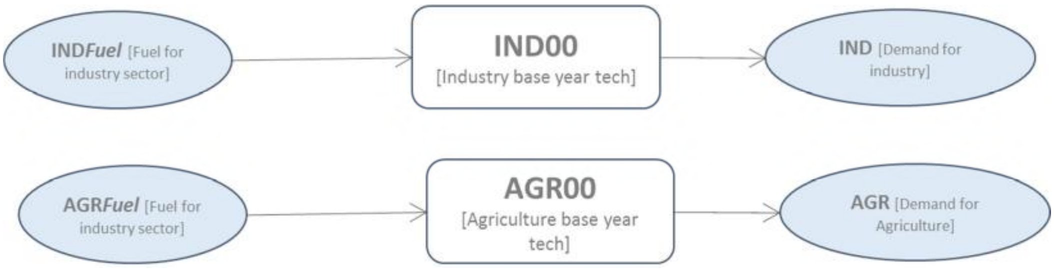

Figure 12 – Structure of the TIMES_Evora model for the industry and agriculture sectors

There is thus no possibility to model measures that will alter energy consumption in these two sectors as they are not included in the scope of the InSMART project.

2.4.6 Solar energy systems including PVs and solar water heaters

In TIMES_EVORA there is a very detailed representation of possible new solar PV applications as explicated in Table 16 which includes plant size options in Zone 1 (rural zone) and roof and facade applications in all zones, in residential, commercial, industry and agriculture buildings.

Table 16 – PV new technologies considered in TIMES_Evora

PV Technology Code	PV Technology Description
Plant-Size PV	
EUPVSOL101	PV power plant with tracking system
EUCPVSOL101	Concentrated PV power plant
Non-residential Roof	
EUPVSOLIND01	PV Mini and microgeneration applied in Industry buildings
EUPVSOLCOM01	PV Mini and microgeneration applied in Commercial buildings
EUPVSOLAGR01	PV Mini and microgeneration applied in Agriculture buildings
Residential Buildings - Roof	
EUPVSOLRSDTP*n*_01	PV Mini and microgeneration applied in residential buildings' roofs (c-Si) monocrystalline silicon
EUPVSOLRSDTP*n*_02	PV Mini and microgeneration applied in residential buildings' roofs (mc-Si) multi-crystalline silicon
EUPVSOLRSDTP*n*_03	PV Mini and microgeneration applied in residential buildings' roofs (HIT-Si) thin layer
EUPVSOLRSDTP*n*_04	PV Mini and microgeneration applied in residential buildings' roofs (3-a-Si) amorphous silicon
Residential Buildings - Facade	
EUPVSOLRSDTP*n*_05	PV Mini and microgeneration applied in residential buildings' facades (HIT-Si) thin layer
EUPVSOLRSDTP*n*_06	PV Mini and microgeneration applied in residential buildings' facade (3-a-Si) amorphous silicon

The potential for solar applications (PV and solar water systems) was analysed within WP4 based on the availability of land (for plant size PV) and roof area (for roof PV and solar water heater) in each typology which could be used for their installation. In TIMES_Evora the information on the maximum technical potentials was included in as user constraints systematised in Table 17 for PV and in Table 18 for solar water heating.

Table 17 – Solar PV maximum technical potential considered in TIMES_Evora in maximum installed capacity in MW

Technology code	Z1	Z2	Z3	Z4
Plant size PV				
EUPVSOL101	1116000	0	0	0
EUCPVSOL101	1041000	0	0	0
Residential Roofs				
EUPVSOLRSDTP1_01	1951	0	0	0
EUPVSOLRSDTP2_01	3023	4005	86	0
EUPVSOLRSDTP3_01	1777	781	0	0
EUPVSOLRSDTP4_01	1694	0	0	0
EUPVSOLRSDTP5_01	944	3264	165	697
EUPVSOLRSDTP6_01	2075	1075	140	0
EUPVSOLRSDTP7_01	1433	429	0	3493
EUPVSOLRSDTP8_01	1537	3742	4066	0
EUPVSOLRSDTP9_01	0	0	39	0
EUPVSOLRSDTP10_01	1958	1796	0	0
EUPVSOLRSDTP1_02	1530	0	0	0
EUPVSOLRSDTP2_02	2371	3142	67	0
EUPVSOLRSDTP3_02	1394	613	0	0
EUPVSOLRSDTP4_02	1329	0	0	0
EUPVSOLRSDTP5_02	741	2561	129	546
EUPVSOLRSDTP6_02	1628	843	110	0
EUPVSOLRSDTP7_02	1125	336	0	2740
EUPVSOLRSDTP8_02	1206	2936	3190	0
EUPVSOLRSDTP9_02	0	0	31	0
EUPVSOLRSDTP10_02	1536	1409	0	0
EUPVSOLRSDTP1_03	1685	0	0	0
EUPVSOLRSDTP2_03	2611	3459	74	0
EUPVSOLRSDTP3_03	1535	675	0	0
EUPVSOLRSDTP4_03	1463	0	0	0
EUPVSOLRSDTP5_03	815	2819	142	602
EUPVSOLRSDTP6_03	1792	928	121	0
EUPVSOLRSDTP7_03	1238	370	0	3017
EUPVSOLRSDTP8_03	1327	3232	3511	0
EUPVSOLRSDTP9_03	0	0	34	0
EUPVSOLRSDTP10_03	1691	1551	0	0
EUPVSOLRSDTP1_04	694	0	0	0
EUPVSOLRSDTP2_04	1075	1425	31	0
EUPVSOLRSDTP3_04	632	278	0	0
EUPVSOLRSDTP4_04	603	0	0	0

Technology code	Z1	Z2	Z3	Z4
EUPVSOLRSDTP5_04	336	1161	59	248
EUPVSOLRSDTP6_04	738	382	50	0
EUPVSOLRSDTP7_04	510	153	0	1243
EUPVSOLRSDTP8_04	547	1331	1446	0
EUPVSOLRSDTP9_04	0	0	14	0
EUPVSOLRSDTP10_04	696	639	0	0
Residential Facade				
EUPVSOLRSDTP1_05	561	0	0	0
EUPVSOLRSDTP2_05	804	0	0	0
EUPVSOLRSDTP3_05	633	0	0	0
EUPVSOLRSDTP4_05	0	0	0	0
EUPVSOLRSDTP5_05	0	0	0	0
EUPVSOLRSDTP6_05	0	0	0	0
EUPVSOLRSDTP7_05	0	0	0	0
EUPVSOLRSDTP8_05	0	0	0	0
EUPVSOLRSDTP9_05	0	0	0	0
EUPVSOLRSDTP10_05	0	0	0	0
EUPVSOLRSDTP1_06	231	0	0	0
EUPVSOLRSDTP2_06	331	0	0	0
EUPVSOLRSDTP3_06	261	0	0	0
EUPVSOLRSDTP4_06	0	0	0	0
EUPVSOLRSDTP5_06	0	0	0	0
EUPVSOLRSDTP6_06	0	0	0	0
EUPVSOLRSDTP7_06	0	0	0	0
EUPVSOLRSDTP8_06	0	0	0	0
EUPVSOLRSDTP9_06	0	0	0	0
EUPVSOLRSDTP10_06	0	0	0	0

Table 18 – Maximum technical potential for Solar Water Heating Panels in TIMES_Evora in GJ of delivered hot water

Typology of residential dwelling	Z1	Z2	Z3	Z4
TP1 – Detached rural house, 1 floor built until 1945 with a sloped roof	380	0	0	0
TP2 – Detached rural or urban house, 1-2 floors built in 1946-1990 with a sloped roof	1054	894	208	0
TP3 – Detached rural or urban house, 1 floor built after 1991 with a sloped roof	516	463	0	0
TP4 – Semi-Detached rural house, 1 floor built until 1945 with a sloped roof	264	0	0	0
TP5 – Semi-Detached rural or urban house, 1-2 floors built in 1946-1990 with a sloped roof	649	1026	400	97
TP6 – Semi-Detached urban house, 2 floors built after 1991 with a sloped roof	429	667	128	0
TP7 – Terraced rural or urban house, 1-2 floors built until 1945 with a sloped roof	287	210	0	1525
TP8 – Terraced rural or urban house, 1-2 floors built in 1946-1990 with a sloped roof	596	1781	2950	0
TP9 – Terraced rural urban house, 2 floors built in 1946-1990 with a flat roof	0	0	95	0
TP10 – Terraced rural or urban house, 1-2 floors built after 1991 with a sloped roof	504	272	0	0

The combination of these maximum potentials set as constraints allows to TIMES_Evora the possibility to decide how much of each of the technologies should be installed in the limited available land, façade and roof space in Évora.

2.5 Strengths and weaknesses

The TIMES_Evora model main strengths are the very detailed representation of the residential and transport sectors that allows explicitly representing the energy transfers in the municipality and studying more accurately the possible measures towards a more sustainable energy future.

Its main weaknesses are the lack of technological detail for the commercial and services sectors.

3 Scenario analysis

3.1 Narrative of the two visions for Évora underlying the modelled scenarios

The visions underlying each modelled quantitative scenario until 2030 were co-developed with municipal stakeholders in a series of meetings. For the development of the scenarios several aspects were taken into account considering the holist approach of the InSMART project in this for the municipality of Évora (Figure 13): known demographic scenarios for the Alentejo region where Évora is located, macro-economic drivers (only available at national level and assumed similar for Évora), planned investments in new infrastructure and business activities (mainly services and industry), and existing municipal plans. These were considered to be the "Demand Scenarios" that were at a later stage combined with "Policy scenarios" reflecting the goals of the municipality. The Demand scenarios include assumptions on the evolution of end-use energy services that are an input into TIMES_Evora regarding mobility demand (passengers and freight disaggregated per modes), energy needs in buildings (space heating and cooling, water heating, etc.), public lighting, in agriculture and in industry.

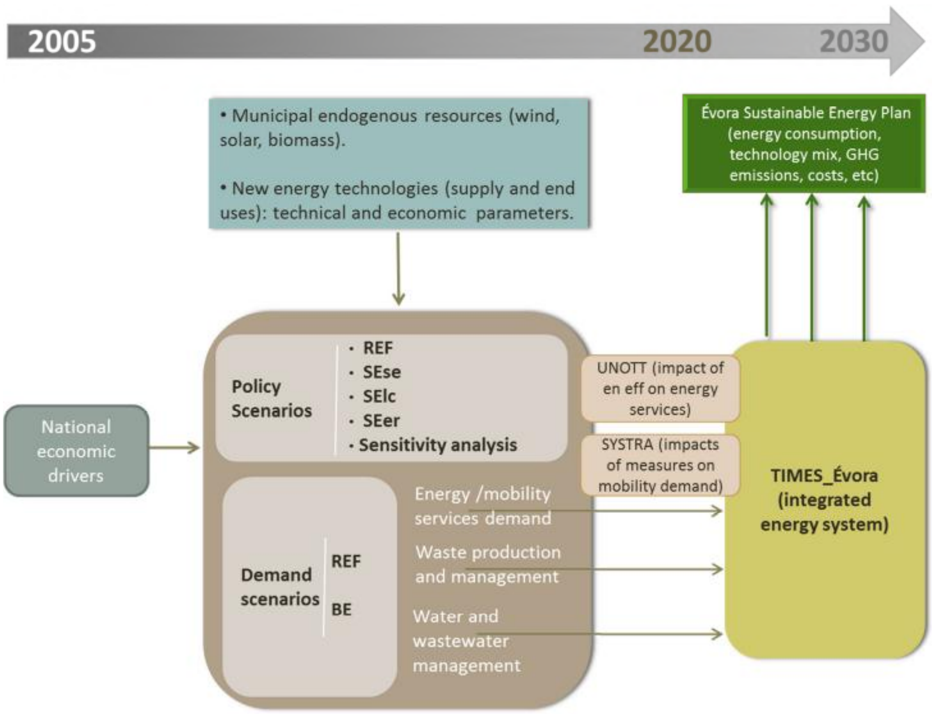

Figure 13 – Consideration of socio-economic scenarios within the InSmart approach used for Évora

During a first meeting with 7 experts from 5 Departments of the municipality: Economic Development and Planning (Director); Environment, Sanitation and Mobility (2 technicians); Operational Services (Director); Municipal Works (1 technician); Spatial Planning and urban rehabilitation (2 technicians), the following key municipal plans were taken as a starting point:

- Urban strategic development plan [PEDU]
- Urban rehabilitation action plan [PARU]
- Urban rehabilitation area [ARU]
- Mobility plan [PMOS]

Based on these, two main storylines were developed along population evolution trends:

1. ***Loosing residents***: if current trends (e.g. investment, employment, services, economic dynamics) continue to the future, there is a high probability of losing people that will move outside of Évora into bigger cities or will leave the country (specially young people);
2. ***Maintaining the number of residents***: Évora has natural and cultural capital to leverage conditions to keep its inhabitants to current population levels.

Along these population trends the following key aspects were considered crucial to work on:

- rehabilitation of the historic center into lively and modern urban conditions, including better buildings and soft mobility, and Local commerce revitalization;
- reduction of the resident population in the rural districts;
- limitation of new buildings in the external urban area outside the city wall;
- new investments in modern agriculture projects and new industrial hubs, including solar energy production and power storage.
- adapting the municipality to climate change extremes (heat waves and droughts)

Ultimately the narratives evolved into the following two main visions for Évora: Smart and Reference. In the **Reference (REF) vision** the population decreases from 56 595 inhabitants in 2011 to 48 960 inhabitants in 2030 following the expected trends from Statistics Portugal for the Alentejo region where Évora is located. There will be no changes on energy consumption profiles for the different consumers (residential, services, etc.) and likewise, no changes in current mobility patterns, except for those expected due to the ongoing construction of: (i) a new commercial mall in Bacelo e Srª da Saúde and (ii) a new sports good store. These changes were modelled by Systra in WP3. There will be no expected changes on industry and services energy consumption trends and on energy demands for public lighting.

In the **Smart Évora (Smart) vision** the population decrease till 2030 will be less evident from 56 595 inhabitants in 2011 to 54 950 inhabitants in 2030. As in REF there will be no changes on energy consumption profiles for the different consumers (residential, services, etc.) but in *Smart* it is expected that a number of soft mobility developments will take place in specific areas. Besides expected changes in mobility patterns due to the ongoing construction of the mall and sports good store, considered in REF there will be also changes due to the relocation of the municipality technical services, the construction of a new district hospital, new roads, and the expansion of the industrial park.

3.2 Quantitative description of the visions and scenarios

3.2.1 Drivers for the considered visions

The approach used to derive a quantitative estimate of the energy demand in the municipality until 2030 was based in different drivers depending on the considered sectors as explained:

- **Agriculture** – assumed a reduction of energy consumption of 1% per year similar to national scenarios for agricultural energy consumption from (Seixas et al., 2012);
- **Industry** – assumed a reduction of energy consumption of 1% per year similar to national scenarios for industry energy useful demand (Seixas et al., 2012) combined, only in the Smart scenario, with the increase in energy demand expected due to the operation of the planned factories in zone 3 from 2025 onwards[2];
- **Residential, waste, water & wastewater** – it was assumed the same evolution rate as in the population scenarios considered for Évora (see Table 19);
- **Buildings under municipality management** – since no further information was available it was assumed that the energy demand for social housing, municipal offices and other municipality managed buildings would remain constant from the base-year;
- **Commercial and services buildings** – A mixed approach was used. For *education, health, sports and retail buildings*, the demand for energy services will evolve similarly to the population scenarios and also including the expected increase due to the planned investments from 2020 onwards. These are the two new shopping malls under construction in zone 3 and in zone 2, the new sports goods store in zone 3 and, only in the Smart vision, the new district hospital in zone 3[3]. For *tourism and restaurants*, since no further

[2] This refers to the aeronautical components' factories from the companies Air Olesa, Mecachrome and Lauak. There is no detailed information on the impact of these factories on energy consumption and thus a rough assumption was made considering the available information that the current area of the industrial park will be expanded from 9 000 m^2 to 27 000 m^2. A rough industry energy consumption/m^2 indicator was built for the base year and used in the estimate for the impact of the expansion in the Évora industry sector, leading to a threefold increase from 2025 onwards.

[3] The only information available on the new commercial buildings is their planned area of 20 034 m^2 for each of the shopping malls and of 7 500 m^2 for the sports shop. An indicator of energy consumption per m^2 was considered of 564 $kWh/m^2.yr$ to estimate this future consumption, taken from (SONAE

information was available it was assumed that the energy demand for these activities will remain constant;

- **Public lighting** - since no further information was available it was assumed that the energy demand for public lighting will remain constant;
- **Transport** – the evolution of the mobility demand was obtained from the transport model for Évora developed by Systra in WP3 which considers both population and infrastructure changes.

The evolution of Évora municipality's residents until 2030 was built based on Statistics Portugal assumptions for the region of Alentejo and the inputs of the municipality described in the previous section and is presented in Table 19.

Table 19 – Population scenarios considered in TIMES_Evora

TIMES zone	Correspondence with municipality zones	Population		Reference scenario (REF)		Smart_Evora (SE)	
		2001	2011*	2020	2030	2020	2030
Z1	Valverde	2,787	2,719	2,503	2,322	2,690	2,662
	Sao Mancos	2,067	2,017	1,860	1,728	2,011	2,006
	Nossa Sra de Machede	1,965	1,917	1,768	1,643	1,914	1,911
	Azaruja	1,180	1,151	1,063	990	1,159	1,167
	Canaviais	3,528	3,442	3,163	2,930	3,378	3,314
Z2	Nossa Sra da Saude	8,233	8,589	7,958	7,433	8,130	7,695
	Bairro Frei Aleixo	2,025	2,113	1,958	1,828	2,117	2,120
	Bacelo	7,221	7,533	6,979	6,519	7,197	6,876
Z3	Bairro de Almeirim	1,366	1,461	1,355	1,267	1,474	1,487
	Evora Retail Park	71	76	70	66	77	79
	Aerodromo	363	388	359	336	394	401
	Monte das Flores	1,255	1,342	1,245	1,164	1,355	1,369
	Horta das Figueiras	3,240	3,465	3,221	3,018	3,443	3,421
	Bairro Nossa sra do Carmo	1,085	1,160	1,076	1,006	1,173	1,186
	Bairro De Santa Maria	8,093	8,656	8,085	7,614	8,264	7,890
	Bairro dos Tres Bicos	4,336	4,637	4,315	4,047	4,566	4,497
	Ceniterio de Evora	1,110	1,187	1,101	1,029	1,200	1,214
Z4	Jardim Publico de Evora	1,513	1,312	1,206	1,117	1,433	1,565
	Aquaduct	2,608	2,262	2,066	1,903	2,471	2,698
	Universidade de Evora	1,077	934	860	799	1,020	1,114
	Catedral de Evora	268	233	215	201	254	278
	Total	55,389	56,595	52,427	48,960	55,722	54,950

* last population CENSUS year for which there is information available

3.2.2 Quantitative description of the visions underlying the modelled scenarios

The previously described assumptions lead to the following quantitative description of the two visions, Reference and Smart.

SIERRA, 2012). Regarding the new district hospital it was assumed that the total annual consumption would be identical to 711 MWh based on the survey made for Portuguese hospitals by (IBM, 2010).

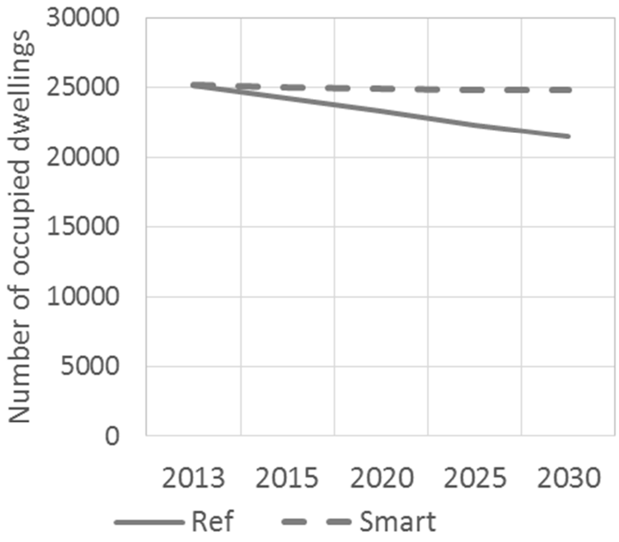

Figure 14 – Exogenous assumption on evolution of residential dwellings in TIMES_Evora

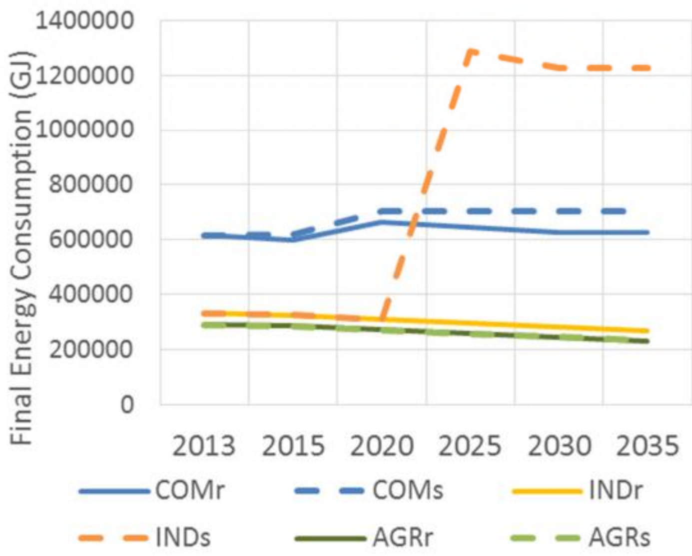

Figure 15 – Exogenous assumption on evolution of final energy consumption for agriculture, industry and commercial buildings in TIMES_Evora

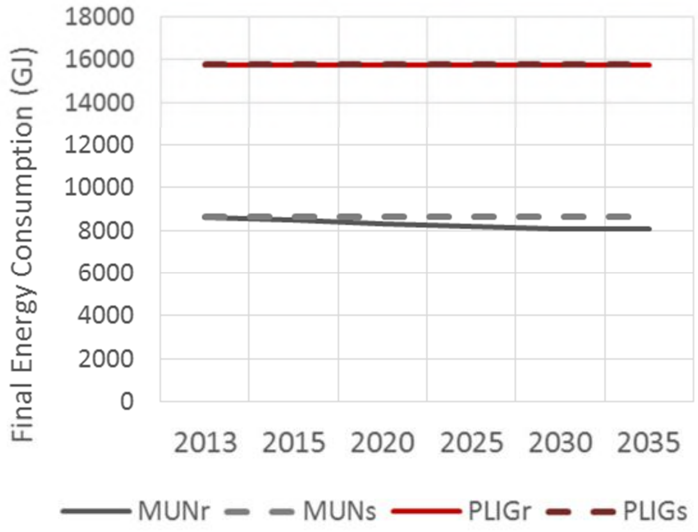

Figure 16 - Exogenous assumption on evolution of final energy consumption for public lighting and buildings managed by the municipality in TIMES_Evora

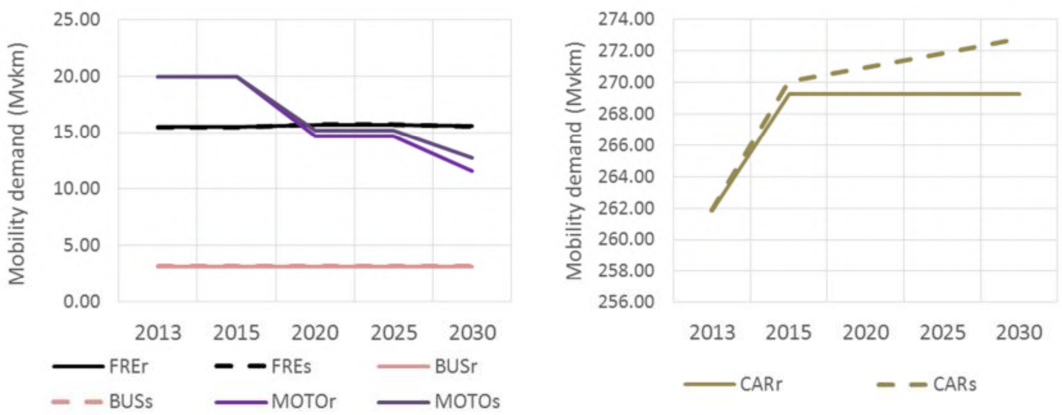

Figure 17 - Exogenous assumption on evolution of mobility demand passenger transport and freight transport in TIMES_Evora

3.2.3 Modelled scenarios

For each of these visions, the scenarios to be analysed in TIMES_Evora were decided upon together with the Évora municipality stakeholders listed in the Annex 7.1 and are summarised in Table 20. The scenarios are divided per targeted end-use sector: public lighting (2 scenarios), residential buildings (8 scenarios), waste, water & waste water (4 scenarios), and transport (9 scenarios). Some of the scenarios are simply a more or less demanding variant of a previous one, for example change 80% public lighting to LEDs with automatic control system by 2030 or change all public lighting to LEDs in that year. One of the scenarios is a more holistic one since it focus on implementing an overarching CO_2 target on all the modelled economic sectors (industry not included) with the purpose to identify which sectors are more cost-effective for CO_2 abatement. All the scenarios were modelled for the two socio-economic visions, REF and Smart.

Table 20 – Scenarios tested in TIMES_Evora for the two visions Reference and Smart

Name	Description	Code	Current status
Public lighting			
Changing luminaires with more efficient lamps	Change 80% public lighting to LEDs by 2020	PL1	0.4% of public lighting has LED in 2014
	Change all public lighting to LEDs by 2030	PL2	
Residential Buildings			
Solar Thermal	Install solar thermal hot water panels in 10% of dwellings by 2020	RSD1	0.2% of dwellings in 2014
	Install solar thermal hot water panels in 40% of dwellings in 2030	RSD2	
Solar PV	Solar PV installed corresponding to 10% of maximum feasible potential by 2020	RSD3	4% of maximum feasible in 2014
	Solar PV installed corresponding to 30% of maximum feasible by 2030	RSD4	
Insulation windows	Double glazing in 80% of dwellings by 2030	RSD6	39% of dwellings in 2014
Insulation infiltration	Small scale insulation solutions in 50% of dwellings by 2030	RSD7	10% of dwellings in 2014
Insulation walls and roofs	Wall & Roof insulation combined in 60% of dwellings by 2030	RSD8	20% of dwellings in 2014
Waste, water and waste water			
Increase recycling	Increase by 35% the share of recycled MSW after 2020	R1	7% MSW were recycled in 2014, planned 8% by 2020 (i.e. increase of 24%)
Decrease MSW production	Decrease MSW production per capita in 20% from 2013 values	R2	502 kg MSW per capita in 2013 and 6% reduction from 2009 till 2014
Energy efficiency in water system	Improve energy efficiency in water treatment plants in 50% by 2030 compared to 2009	R3	from 2009 till 2014 energy consumption in water treatment decreased 12%

Name	Description	Code	Current status
Energy efficiency in waste water treatment	Improve energy efficiency in waste water treatment plant in 30% compared to 2009 by 2030	R4	from 2009 till 2014 energy consumption in wastewater treatment decreased 12%
Transport			
Promotion of cycling	Extension of the existent 7 km cycling lanes combined with making city bikes available from 2020 onwards	TRA1	8.3 km of cycling lanes in 2014 and no city bikes
City Centre Traffic Restrictions	Duplicate parking fees in historic center from 2020 onwards	TRA2	0.7eur/hr. up to 11eur/day in 2014
	Interdiction for all type of vehicles and concerning all purposes to the Évora Acropolis from 2020 onwards	TRA3	n.a.
Speed Reductions	Speed limitation to 30km/h, for all vehicles in diverse zones from 2020 onwards	TRA4	n.a.
Electric vehicles	5% of passenger cars are electric by 2030	TRAelc	3 electric cars in 2014
Biofuel buses	All busses use biofuels by 2030	TRAbus	No biofuel buses in 2014
Increase historic center parking – concentrated	Construction of 3 parking lots with a total of 500 parking spaces for non-residents in the historic center from 2020 onwards	TRA7	215 parking spaces for non-residents in historic center in 2014
Increase historic center parking – disperse	300 new disperse parking spaces for residents in the historic center from 2020 onwards	TRA8	2019 total disperse parking spaces in historic center in 2014 of which 748 were for residents
Increase public transportation	Shift of 15% from private cars mobility to public transportation from 2020 onwards	TRA9	1029 pkm travelled by passenger car in 2014
Systemic			
CO2 emission cap	Reduction of total CO_2 emissions in 2030 of 30% from 2030 Baseline emission values, respectively for REF and Smart visions	CAP	n.a.

n.a. – not applicable

4 Results

4.1 Key indicators for a new SEAP

In this section is presented an overview of some of key variables tracked in the model and explored in the scenario analysis. The overview covers the two baseline visions for Évora (REF and Smart), as well as the several modelled scenarios reflecting the measures for sustainable energy promotion in the municipality presented before.

The key indicators for a new SEAP were selected to be able to support the Multi-Criteria Decision Analysis (MCDA) to prioritise the different modelled scenarios. These are: energy savings, CO_2 emissions reductions, and investment and operation & maintenance costs. Each of these is further detailed in the **Error! Reference source not found.**.

Table 21 – Indicators used to comparatively analyse the modelled scenarios

Name	Unit	Description
Energy Savings	TJ	Reduction between the total final energy consumption in the baseline scenario (Reference/Smart without any measure) and the scenario with the modelled measure.
CO_2 emission reductions	kt CO_2	Reduction between the CO_2 emissions in the baseline scenario (Reference/Smart without any measure) and the scenario with the modelled measure. A positive value means that there are less emission in that scenario than in the Baseline (i.e. there is a reduction).
Implementation cost	Million Euros 2015	Amount of investment necessary in each scenario for the respective energy related technologies, shown as the difference between the respective investment cost of the Baseline scenario for 2030 and the one of the scenarios with modelled measures. Therefore, only the additional investment required by the measures considered in the scenarios will be compared.
Operation and Maintenance costs	Million Euros 2015	Variable and fixed operational and maintenance costs (O&M) of the for the respective energy related technologies modelled in each alternative scenario (e.g. passenger cars, solar thermal panels, etc.), without taking into account the cost of energy commodities (e.g. electricity, gas, etc.), shown as the difference between the respective O&M cost of the Baseline scenario and the one of the scenarios with modelled measures. This translates the continuous cash flow that the citizens and the municipality will have to provide in order to operate the energy system in each alternative scenario, compared to the Baseline scenario.

These indicators are used for comparing the different scenarios modelled for Évora, as presented in the next section, and also for the ranking presented in the MCDA report for Évora ("Report on multi criteria methodology, the process and the results of the decision making" Deliverable D.5.5).

Besides these indicators used in the MCDA, a few more are included in this report for better explaining the results: share of renewable energy in total final energy consumption (%), electricity imports into the municipal energy system (TJ) and electricity generated in the municipality (TJ). All the indicators are shown as the difference from the two Baseline scenarios in the REF and Smart visions.

4.2 Overview of the Baseline scenarios for both REF and Smart visions

The evolution of Final Energy Consumption (FEC) as generated by the TIMES_Evora model for the Baseline scenarios for both the REF and Smart visions is presented in the following figures. There is a decrease in FEC of 20% in 2030 from 2013 in the REF Baseline (Figure 18) that corresponds to the assumed macroeconomic trends, with a population decrease of 13% between 2013 and 2030. The decrease in FEC is also due to the increase in energy efficiency leading to a 2030 energy consumption per capita reduction in 7% with regards to 2013, i.e. from 46.54 GJ/inhabitant in 2013 to 43.09 GJ/inhabitant 2030. This energy efficiency improvement is achieved regardless of any exogenously defined energy efficiency measures because TIMES models in general (and TIMES_Evora in particular) are perfect foresight optimisation models that minimise costs for the whole energy system, thus implementing energy efficiency measures to lower energy costs for the system.

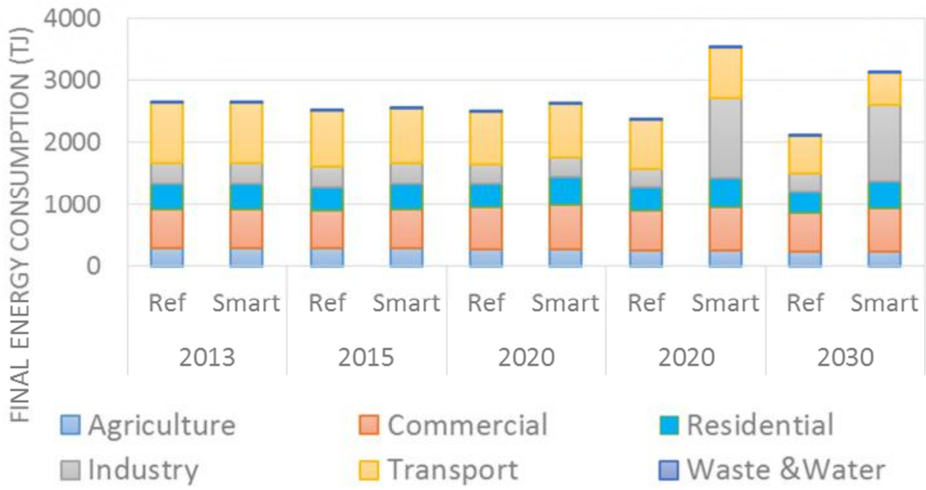

Figure 18 – Final Energy Consumption for Évora

For the Smart Baseline, there is an increase in FEC of 25% in 2030 from 2013 that corresponds to the assumed macroeconomic trends, with a population decrease of only 3% between 2013 and 2030, plus a substantial expansion of the Industry sector and other investments in the Commercial sector, as previously detailed (section 3.2.2).

Regarding the energy carrier profile of FEC in the two visions (Figure 19), in both REF and Smart Baselines, there is a gradual reduction in the relative importance of oil products (from 57% of FEC in 2013 to 54-41% of FEC in 2030), complemented by the increase in the electricity share only in Smart (from 35% of FEC in 2013 up to 45% in 2030) and of gas in both Baselines (from 5% in 2013 to 9-13% in 2030). In the Baseline scenarios the share of biomass stays roughly the same in REF (2% of total FEC), but decreases in Smart. Finally, the use of solar energy increases in both Baselines from 0.05% of total FEC in 2013 to 0.09-0.0% in 2030.

It should be mentioned that in the Baseline scenarios no CO_2 emission reductions or energy efficiency targets are considered. The shifts in energy profile are thus solely due to cost-optimisation, i.e. ensuring satisfaction of energy needs for Évora at the lowest possible cost for the whole system.

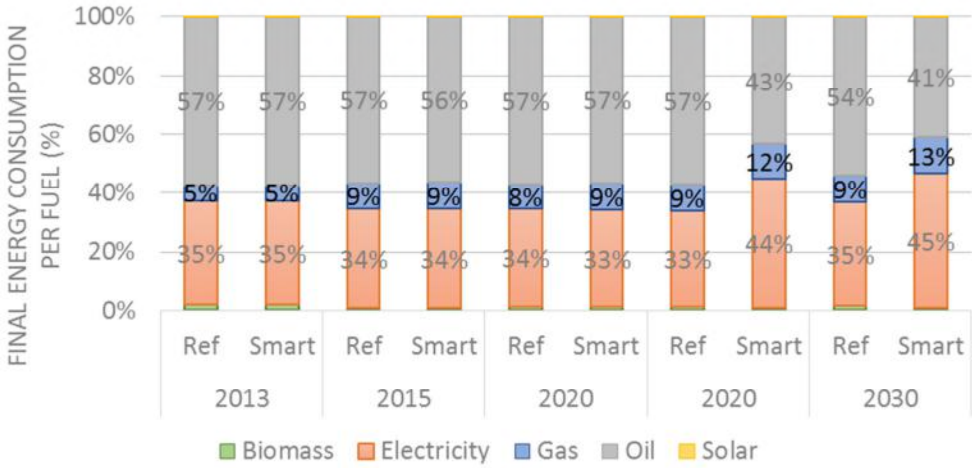

Figure 19 – Evolution of FEC from the TIMES_Evora model per type of energy carrier

None withstanding, the evolution of CO_2 emissions as generated by the TIMES_Evora model for the two Baseline scenarios shows as reduction, as presented in the following figures.

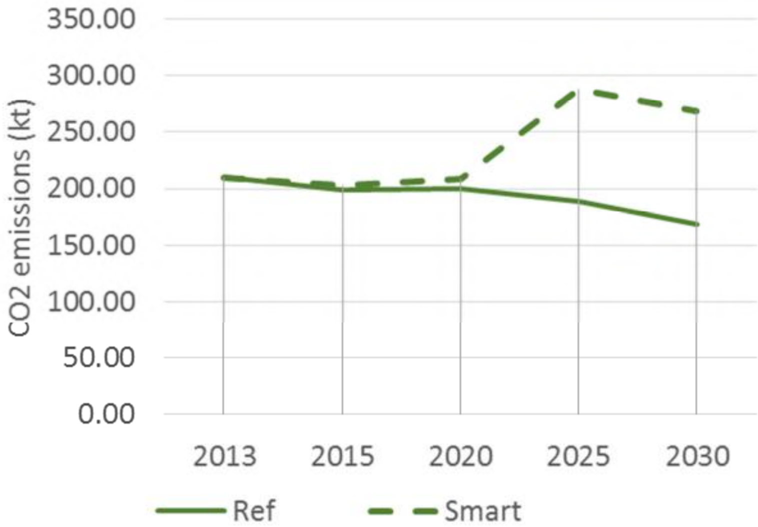

Figure 20 – CO_2 emissions generated by the TIMES_Evora model for the two Baseline scenarios

The total CO_2 emissions (Figure 20) vary from 209,937 ktCO_2 in 2013 to 167,722 ktCO_2 in 2030 for the REF Baseline (i.e. 20% less than in 2013) and to 266,740 ktCO_2 in 2030 for the Smart Baseline (i.e. 28% more than in 2013). The increase in the Baseline Smart is mostly due to the expected increase in industry activity (Figure 21).

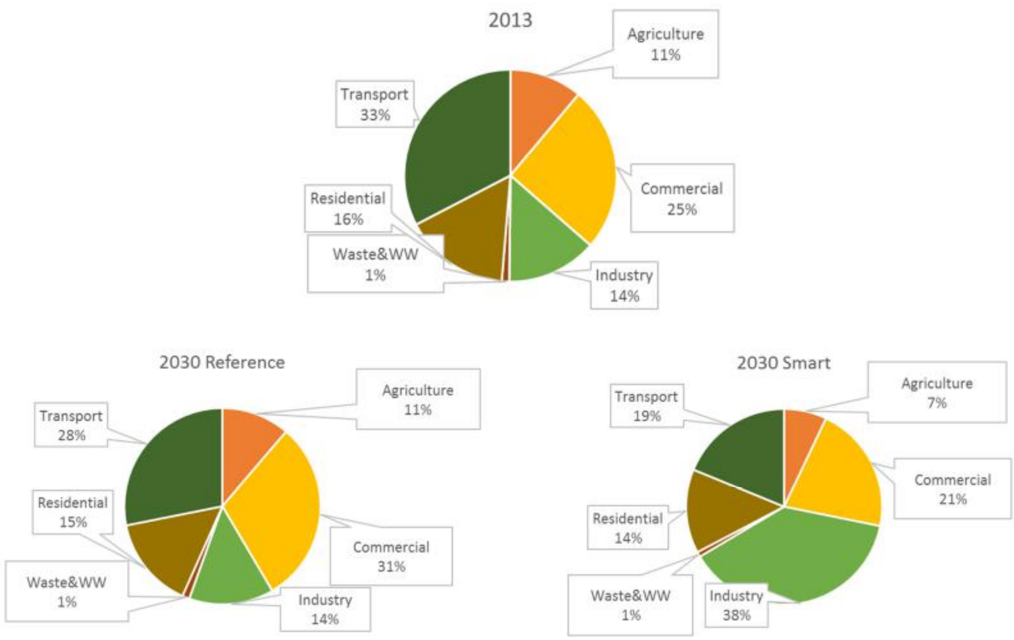

Figure 21 – Sector emissions from the TIMES_Evora model for 2013 and 2030 for the two visions

The relative importance of the other economic sectors for total CO_2 emissions stays more or less similar to the year of 2013, with a slight reduction in the share of residential buildings and transport, due to the considered population decrease (more evident in REF but also present in Smart).

The share of Renewable Energy resources (RES) in Évora's energy consumption is of 15.1% of total FEC (it is assumed that 37% of the electricity imported into Évora is RES electricity as previously described). In 2030 this share is slightly reduced to 14.7% in REF and increases to 17.9% in Smart.

In terms of electricity generated within the municipality, in the Baseline scenarios, with a decreasing population and without any CO_2 emission cap nor other sustainable energy target (including feed-in subsidies to RES electricity), it is more cost-effective to import electricity from outside the municipality than to maintain the activity of all 2013 installed capacity of PV roof panels. Thus, the value of 3.02 TJ (0.84 GWh) generated electricity in 2013 decreases to 2.21 TJ (0.61 GWh) in 2030 in the two Baselines REF and Smart.

The amount of electricity imports increases 60% in Smart from 260 GWh in 2013 to 416 GWh in 2030 and decreases 20% in REF from 260 GWh to 207 GWh. Therefore, the electricity generated in Évora represents roughly 0.1-0.3% of the imported electricity in the two Baseline scenarios.

4.3 Comparative analysis across scenarios

The results regarding the comparative analysis across the modelled scenarios described in section 3.2.3 obtained from the TIMES_Evora model are presented in the following figures.

It should be mentioned that for some of the modelled scenarios, in fact practically all the ones for the transport sector and for waste and waste water, the TIMES model was not used to estimate the associated costs. In the case of transport scenarios (except TRAelc and TRAbus), this is because the scenarios were built by inputting into the TIMES model different mobility demand assumptions than the ones considered in the Baselines scenarios, for example due to the expansion of cycle lanes. These modified mobility demands which were estimated via exogenous modelling in the Transport model developed in WP3. Therefore, for the scenarios TRA1, TRA2, TRA3, TRA4, TRA7, TRA8, TRA9 the cost estimates used in the MCDA were obtained from other sources (i.e. estimates from Évora municipality or literature) and not from the TIMES_Evora model. For the scenarios R1 and R2 regarding waste, the same applies, i.e. the municipal solid waste commodities that can be recycled and that can be collected are estimated outside the TIMES model and input into it. Thus, the costs measures were estimated using literature analysis. For R3 and R4 a similar approach was used.

Moreover, the analysis is made in parallel for the two socio-economic visions, Smart and REF. They represent two different futures for Évora and thus cannot be directly compared with each other. Instead, using the two different Baselines allows for a higher confidence on the selection of measures that can more successfully achieve a sustainable energy transition regardless of the future socio-economic situation.

The ***FEC per carrier*** in all the scenarios is depicted in

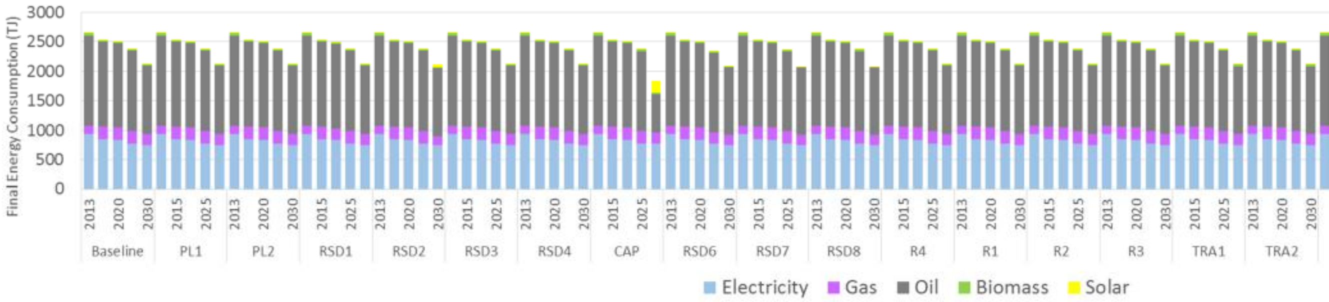

Figure 22 and in Figure 23 for the modelled period from 2013 until 2030. As expected, the magnitude of FEC is different between the REF and Smart socio-economic visions. For the modelled scenarios, **solar energy** and **biomass** still play a marginal role, with the exception of solar in the CAP scenarios for REF and Smart and of biomass for the TRAbus REF and Smart scenarios. In any case, for all scenarios (except for RSD2 and for the CAP scenarios) the use of **solar energy** for water heating in 2030 increases 43% from 2013 values due to its cost-effectiveness. In the RSD2 and in CAP scenarios solar water heating increases substantially more, following the design of the scenario for the first case and the need to reduce CO_2 emission in CAP.

The use of **natural gas** increases in all scenarios but in different amounts, depending of the REF or Smart visions. In the case of REF natural gas increases between 27-36% mainly for water heating. In this socio-economic context, the lowest increase in gas takes place in the RSD2 scenario where solar thermal panels are massively deployed, followed by the CAP scenario. In the Smart vision scenarios, natural gas increases substantially more up to 192% in 2030 from 2013 values. The increase is due to the expansion of the industrial activity which is assumed to consume natural gas (see section 3.2.2).

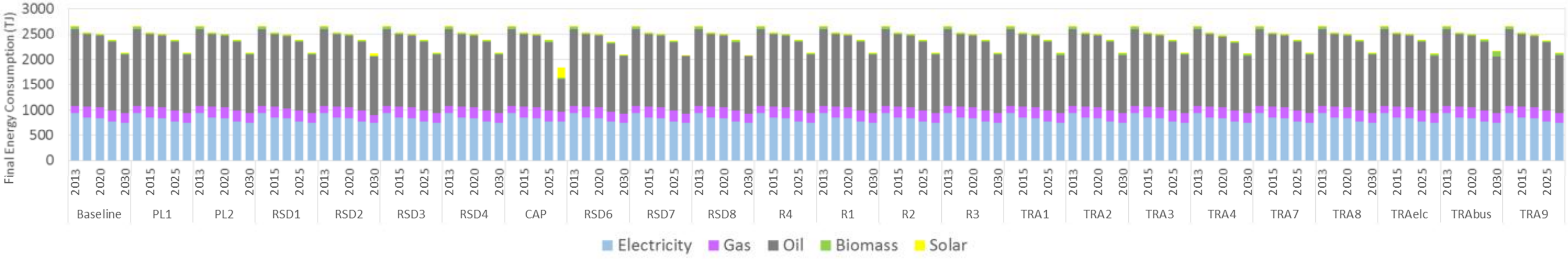

Figure 22 – Final Energy Consumption for the modelled scenarios from 2013 till 2030 – REF

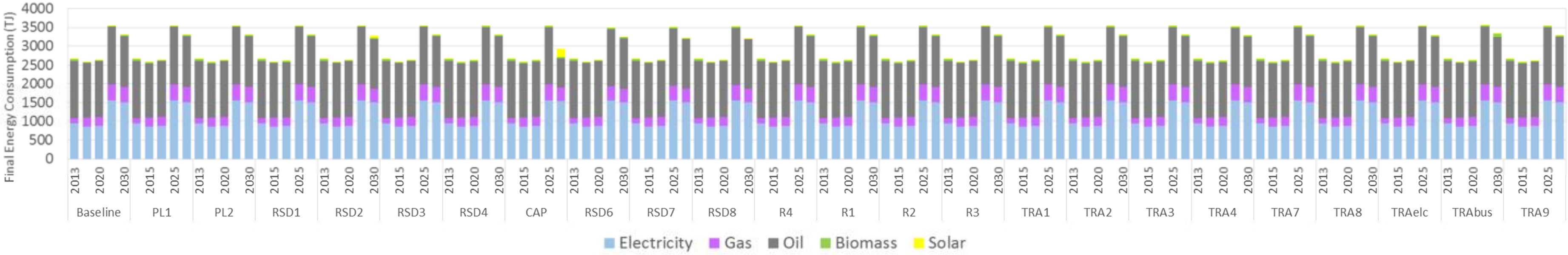

Figure 23 – Final Energy Consumption for the modelled scenarios from 2013 till 2030 – Smart

On the other hand, **oil products** consumption decreases in all scenarios around less 24-27% than in 2013 in REF scenarios and 11-13% than in 2013 in Smart scenarios. In both CAP scenarios there is a more substantial reduction of 49-56% less than 2013 in 2030, respectively for REF and for Smart. This decrease in oil products consumption is due to the gradual renovation of the relatively inefficient and rather old passenger vehicle fleet (circa 60% of the cars circulating in Évora in 2013 were more than 13 years old).

The use of **electricity** in REF scenarios decreases 20% across all scenarios, due to adoption of more efficient appliances and also due to the considered decrease in exogenous demand. In the Smart scenarios, on the contrary, electricity increases 60% in 2030 with regards to 2013 values, but mostly due to the expected increase in industrial activity. It should be noted that electricity in Évora coming from the national grid is mostly fossil and its implicit CO_2 emissions (or carbon footprint) are being considered.

Regarding ***energy savings*** (Figure 24 and Figure 25), the highest savings in both the scenarios in the REF and Smart visions are obtained using an overarching cap for a cost-optimal CO_2 reduction (CAP scenarios), followed by the renovation of specific components of the residential buildings envelope (windows, walls & roof and minimizing infiltrations) in the scenarios RSD6, RSD7 and RSD8, and finally by the introduction of speed limitations to 30km/h for all vehicles in diverse zones by 2020 (TRA4 scenario). It should be mentioned that the TRAbus scenarios leads in fact to an increase in FEC compared to the baseline, since more biofuel is needed to operate such buses than for conventional ones. This also occurs, albeit to a smaller scale, with the scenarios RSD1, RSD3 and RSD4 that lead to higher use of solar energy, and with scenarios R1 that models the increase by 35% the share of recycled MSW after 2020, thus leading to more trips made by MSW the collection trucks.

The largest part of energy savings both in CAP and RSD6, 7 and 8 scenarios is achieved via the introduction of specific refurbishment measures in residential buildings, and only for the case of CAP, also through the introduction of more energy efficient heating and cooling technologies in buildings and more energy-efficient passengers cars.

The other modelled scenarios have a relatively smaller effect in energy savings since they intrinsically consider more specific and smaller scale measures (such as replacement of public lighting, improvements on the waste water treatment plants or expansion of a specific bicycle lane).

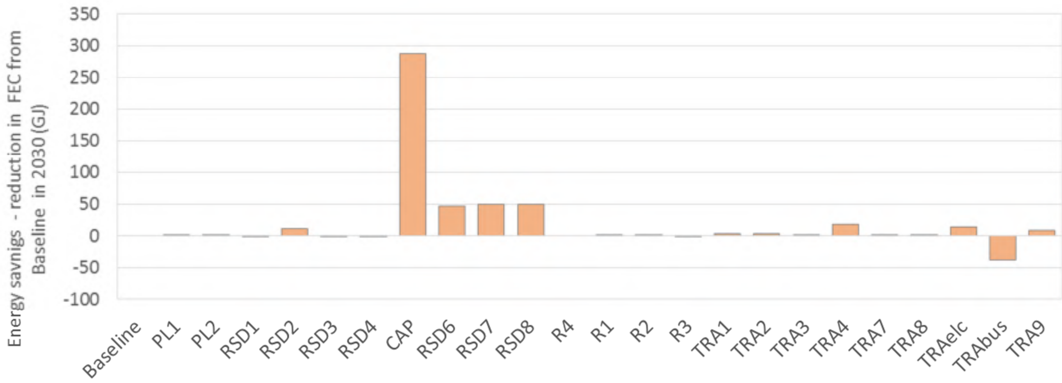

Figure 24 – Energy Savings in 2030 obtained with each modelled scenario when compared to the Baseline scenario in TJ – REF

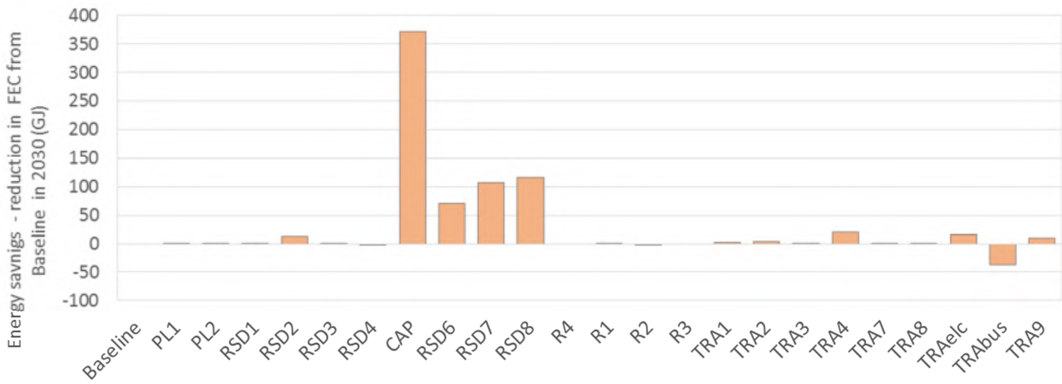

Figure 25 – Energy Savings in 2030 obtained with each modelled scenario when compared to the Baseline scenario in TJ – Smart

Regarding ***CO_2 emission*** reductions compared to the Baseline scenarios (Figure 26 and Figure 27), clearly the CAP REF and Smart scenarios have a more substantial effect with an emission reduction of 11-44% below 2013 emission levels', respectively for Smart and REF CAP's. For the other scenarios, without an explicit CO_2 emission cap, the CO_2 emissions increase 23-28% from 2013 values (from 209,937 kt CO_2 in 2013 to 259,010-268,024 kt CO_2) in the Smart scenarios and decrease 20-24% in the REF scenarios (159,785-168,747 kt CO_2).

In the two CAP scenarios the deployment of PV power plants in the rural zone of the Évora municipality contributes to the emission abatement as it lowers the need to import electricity (with associated carbon footprint) into the city.

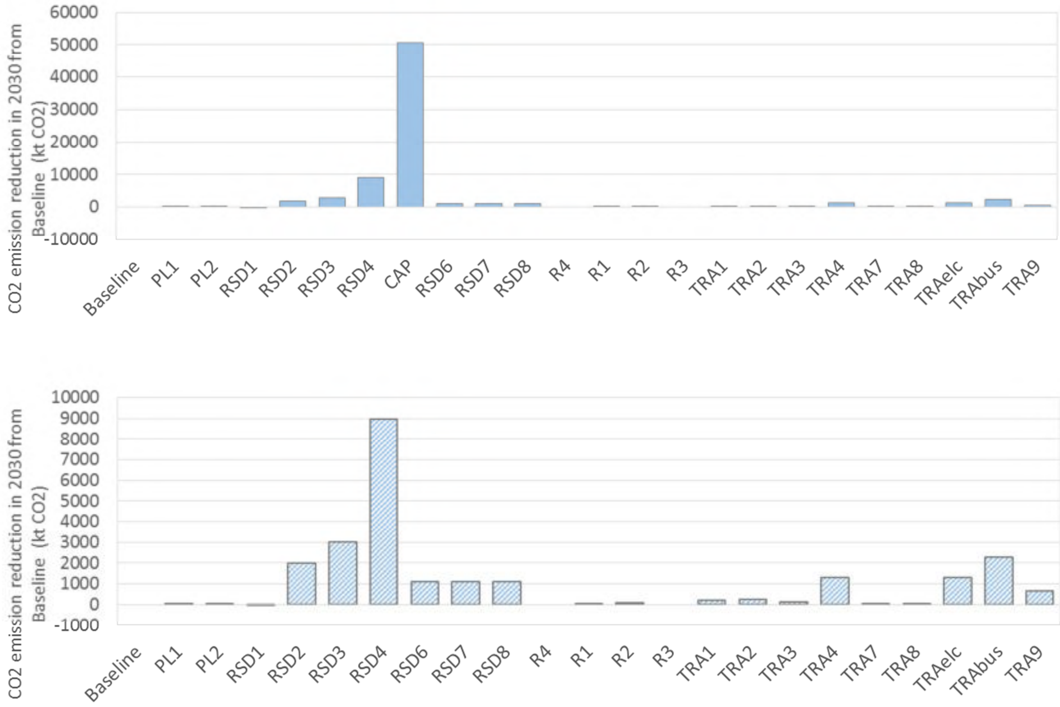

Figure 26 – CO_2 Emission Reductions in 2030 obtained with each modelled scenario when compared to the Baseline scenario with (above) and without (below) the CAP scenario – REF

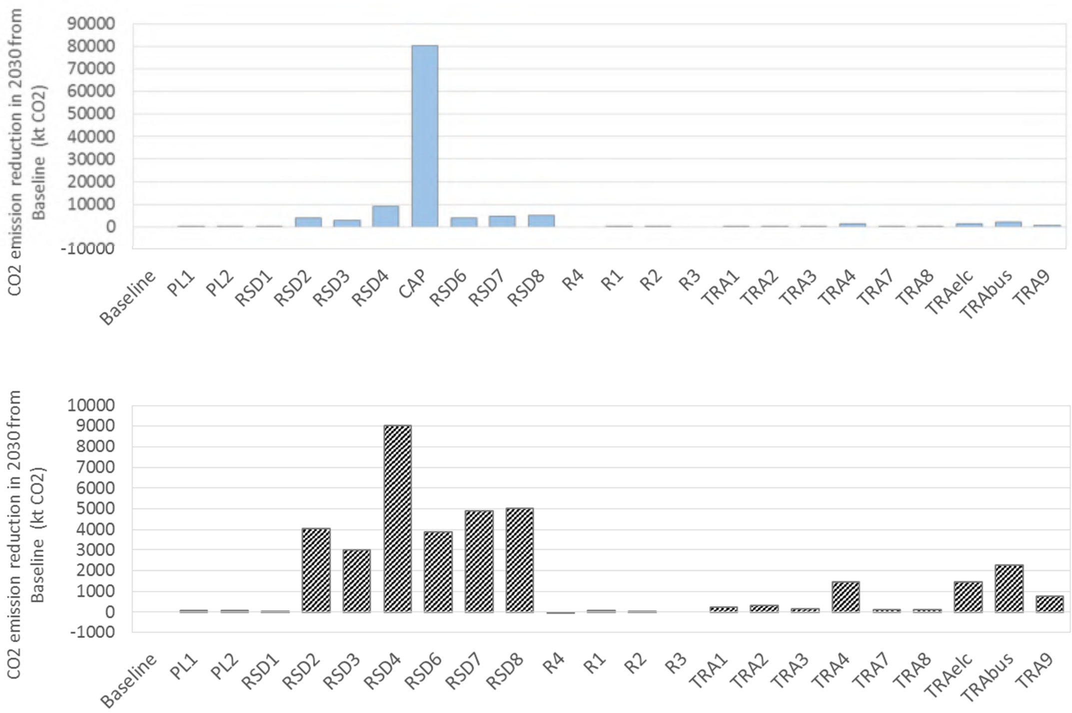

Figure 27 – CO_2 Emission Reductions in 2030 obtained with each modelled scenario when compared to the Baseline scenario with (above) and without (below) the CAP scenario – Smart

Besides the CO_2 CAP, **the most important measure for emission reduction** is the RSD4 scenario (deployment of PV roof panels up to 30% of the maximum technically feasible), both in REF and Smart visions. After this point, the importance of the measures diverges across the two socio-economic visions. For REF, the third most important measure is still the more moderate deployment of PV roof panels in RSD3, followed by solar thermal in RSD2 scenario, by biodiesel buses in TRAbus scenario and electric cars (TRAelc) as important as speed reductions (TRA4). In the Smart scenarios, the third most important measures for CO_2 mitigation are the residential buildings refurbishment options (RSD6, RSD7 and RSD8), followed by solar thermal implementation (RSD2) and the same transport measures as in the REF socio-economic vision.

This difference between REF and Smart is due to the different residential building stock considered in the two visions. Besides the number of occupied dwellings decreases further in REF, there is also a difference in the share of the different residential building typologies that remains in 2030, as the considered population decrease varies across city zones in the two visions. Therefore, in Smart in 2030 the remaining building stock is slightly more cost-effective for deploying solar thermal and insulation options than PV roof panels.

In terms of the **contribution of the different sectors for the emission abatement**, both residential and transport sectors have an equally important role in emission reduction (Figure 28 and Figure 29). The residential sector has an abatement of 25-62% less emission in 2030 than in 2013, whereas the transport sector has 35-63% less emission in 2030 than in 2013. In Figure 28 and Figure 29 is shown the relevance of the different sectors for CO_2 mitigation. The mitigation also occurs when the end-use sectors consume less imported electricity with its associated emissions. This is shown in the Figures as well in the left axis. This is simply for illustration purposes, since the implicit emissions of imported electricity are already included in the bars for each end-use sector.

In these scenarios the electricity generated within the municipality varies from the 3.02 TJ in 2013 up to 94.79 TJ (26.33 GWh) in 2030 in RSD4 for both Smart and REF. In the CAP scenarios, in 2030 the amount of PV generated electricity is substantially higher: 378.40 TJ (105.11 GWh) in CAP Smart and 149.54 TJ (41.54 GWh) in CAP REF. Whereas in RSD4 the electricity is generated by PV roof panels and no new PV plant size capacity is added to the existing already in 2013-2015, to comply with emission cap new PV plant size power plants are deployed in the municipality rural zone, practically up to the maximum technical potential.

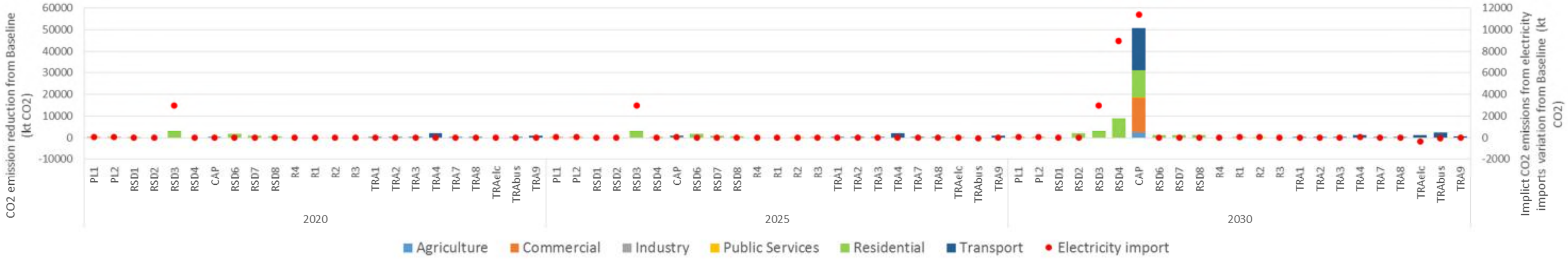

Figure 28 – CO_2 emission reductions per sector compared with Baseline per sector and implicit CO_2 emissions due to lower electricity imports (in right side axis) from 2020 till 2030 – REF

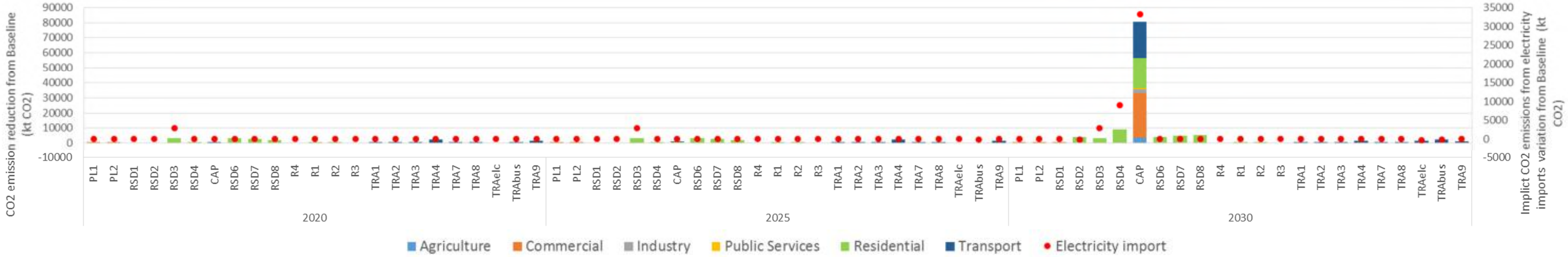

Figure 29 – CO_2 emission reductions per sector compared with Baseline per sector and implicit CO_2 emissions due to lower electricity imports (in right side axis) from 2020 till 2030 – Smart

Nonetheless, in the CAP Smart scenario, the amount of electricity imports still increases from 260 GWh in 2013 to 321 GWh in 2030, although less that in the Baseline Smart. Here, the electricity generated in Évora represents 33% of the imported electricity. In REF there is still a decrease in electricity imports from 2013 values from 260 GWh to 174 GWh in 2030. This is higher than the decrease in the Baseline REF. The electricity generated in Évora in CAP REF represents roughly 24% of the imported electricity.

The share of RES in FEC is shown in Table 22 and varies in 2030 between 13.6% for the residential “insulation” scenarios and 28% for the CAP scenarios. Most of the modelled scenarios do not have a substantial impact in increasing the share of RES, with the exception already mentioned of CAP, TRAbus and RSD2.

Table 22 – Share of RES in FEC

% RES	2013	REF	Smart
		2030	2030
Baseline REF	15.1%	14.7%	17.9%
PL1	15.1%	14.7%	17.9%
PL2	15.1%	14.7%	17.9%
RSD1	15.1%	14.7%	17.9%
RSD2	15.1%	16.1%	19.9%
RSD3	15.1%	14.7%	17.9%
RSD4	15.1%	14.7%	17.9%
RSD6	15.1%	13.7%	18.2%
RSD7	15.1%	13.6%	17.8%
RSD8	15.1%	13.6%	17.6%
R4	15.1%	14.7%	17.9%
R1	15.1%	14.7%	17.9%
R2	15.1%	14.7%	17.9%
R3	15.1%	14.7%	17.9%
TRA1	15.1%	14.8%	17.9%
TRA2	15.1%	14.8%	18.0%
TRA3	15.1%	14.7%	17.9%
TRA4	15.1%	14.9%	18.0%
TRA7	15.1%	14.7%	17.9%
TRA8	15.1%	14.7%	17.9%
TRAelc	15.1%	14.9%	18.0%
TRAbus	15.1%	17.8%	19.9%
TRA9	15.1%	14.8%	18.0%
CAP	15.1%	28.0%	28.2%

In terms of implementation and O&M costs (Figure 30), the most costly scenarios seem to be the TRAbus, where the investment to acquire the buses is substantial. In the CAP scenario there is also a substantial investment which is compensated with lower variable costs to operate the large scale PV plants. There are no major differences between REF and Smart scenarios.

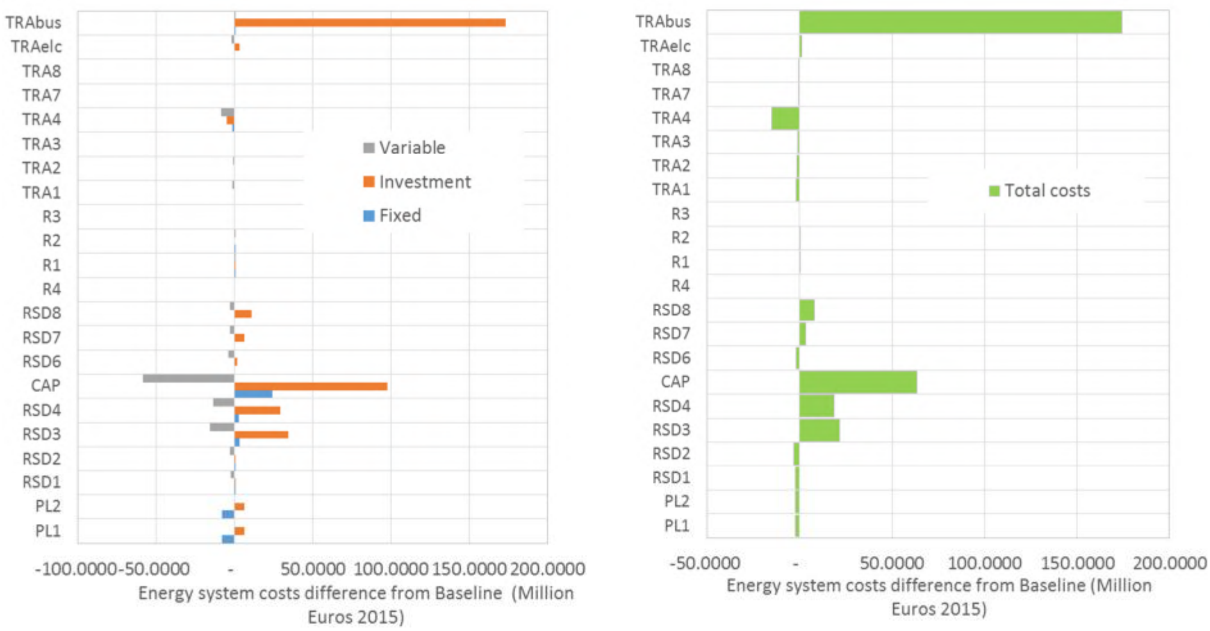

Figure 30 – Implementation costs disaggregated and total - difference with Baseline scenario - REF

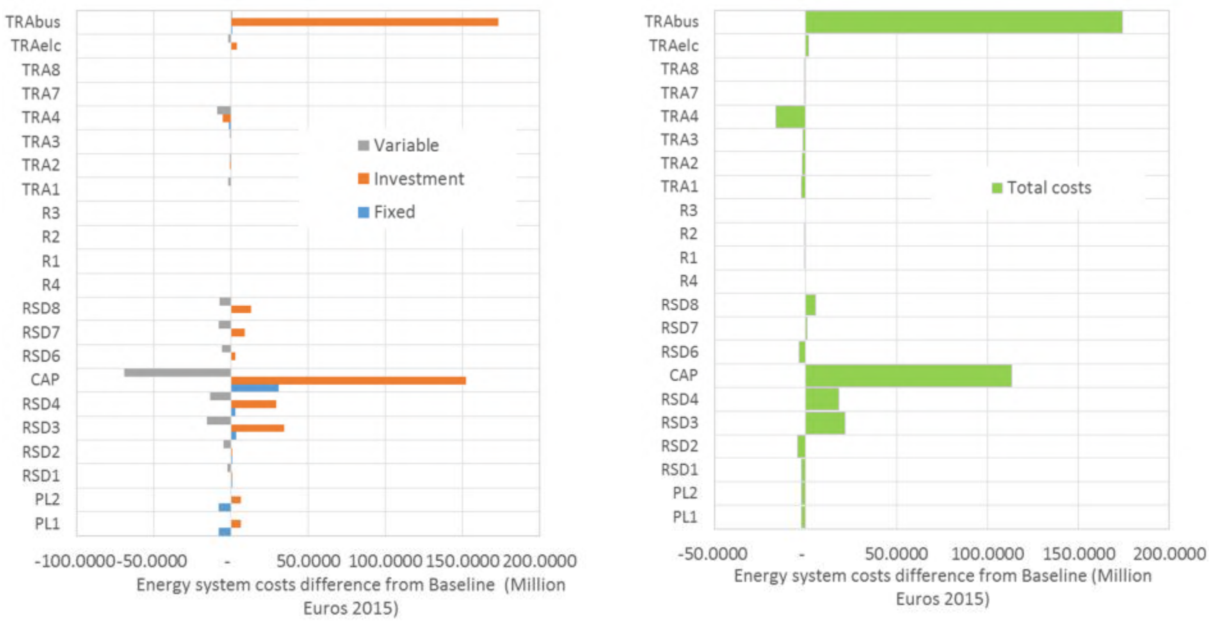

Figure 31 – Implementation costs disaggregated and total - difference with Baseline scenario - Smart

The previous figures showed the costs in terms of difference from the Baseline scenarios for the whole modelled period (2013 till 2030). Another way to assess difference in costs are the annual costs only for the year of 2030 as shown in Table 23.

Table 23 – Annual investment and operation costs for the modelled scenarios for 2030 obtained from TIMES_Evora

Scenario	Difference from Baseline in 2030 (thousand euros 2015) REF		Difference from Baseline in 2030 (thousand euros 2015) Smart	
	Investment	O&M	Investment	O&M
PL1	624.51	920.33	624.51	920.33
PL2	624.51	920.33	624.51	920.33
RSD1	16.68	1.44	16.68	1.44
RSD2	41.23	3.42	83.50	5.89
RSD3	3,869.48	357.70	3,869.48	357.70
RSD4	12,696.72	1,173.71		
RSD6	480.38	-0.37	667.65	-1.95
RSD7	2,625.65	-0.41	3,439.34	-2.14
RSD8	4,590.43	-0.38	5,510.43	-2.16
R4	-	-	-	-
R1	-	-	-	-
R2	-	-	-	-
R3				
TRA1	-	-	-	-
TRA2	-	-	-	-
TRA3	-	-	-	-
TRA4	-	-	-	-
TRA7	-	-	-	-
TRA8	-	-	-	-
TRAelc	2,309.89	213.53	2,546.49	235.40
TRAbus	4,122,984.85	762,276.98	4,122,984.85	762,276.98
TRA9	-	-	-	-
CAP	97,809.54	-34,419.37	152,199.75	-38,830.82

The Table only shows the costs obtained from TIMES_Evora as previously explained. Some measures allow saving in O&M costs as is the case of RSD6, RSD7 and RSD8.

5 Findings and comments

The modelled scenarios covered several pathways towards more sustainable energy in Évora, from more efficient equipment or technologies (i.e. PLIG1, PLIG2, TRAelc, RSD6, RSD7, RSD8), to increase use of RES (RSD1, RSD2, RSD3, RSD4, TRAbus) or adoption low carbon mobility behaviour and options (TRA1, TRA3 and TRA4 among other). It became clear from the analysis that not all option contribute equally to reduce energy savings or carbon emissions. For instance, the scenario with higher energy savings is not necessarily the scenario with higher emission reductions.

The analysis of the quantitative results obtained from the TIMES_Evora model shows that in terms of energy savings, residential buildings have the highest potential compared to the Baseline scenarios. Compared with the other modelled measures, whose costs were obtained in TIMES_Evora these interventions are not the most expensive ones. From the CAP scenario it becomes clear that investing in decentralised Res electricity (e.g. PV power plants) should play a major role in achieving the CO_2 emission reduction targets for 2030.

Considering the modelled measures, it is possible to supply up to 14-24% of the local electricity consumption by 2030 using PV panels (respectively RSD4 and CAP REF scenarios). Whereas in the latter it is not possible to assess solely the cost of the PV, since it is a systemic scenario where other measures are implemented, in the former it is seen that the PV roof panels associated costs are rather higher than of the building shell refurbishment measures, and also have a higher operation and maintenance cost.

In the sequential step of the InSMART approach, the quantitative indicators from TIMES_Evora and also from cost estimates from the municipality are integrated with qualitative indicators in the participatory MCDA analysis. This is described in the report “Multi-criteria methodology, the process and the results of the decision making for Évora”, Deliverable D.5.3.

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7 Annexes

7.1 Annex A- List of stakeholders involved in developing the scenarios analyzed

#	Organisation	Sector
1	ADRAL - Agência de Desenvolvimento Regional do Alentejo	Regional Public Authorities
2	ACDE - ASSOCIAÇÃO COMERCIAL DO DISTRITO DE ÉVORA	Business
3	GESAMB - Gestão Ambiental e de Resíduos, EIM	Regional Public Authorities
4	DianaGas	Business
5	GARE Associação para a Promoção de uma Cultura de Segurança Rodoviária	Civil Society
6	EDP	Business
7	Cycloid – Produção de Energias Renováveis Lda	Business
8	Cycloid – Produção de Energias Renováveis Lda	Business
9	ArenaTejo	Regional Public Authorities
10	NERE - Núcleo Empresarial da Região de Évora	Business

#	Organisation	Sector
11	CIMAC - Comunidade Intermunicipal do Alentejo Central	Regional Public Authorities
12	CCDRA - Comissão de Coordenação e Desenvolvimento Regional do Alentejo	Regional Public Authorities
13	Instituto da Conservação da Natureza e das Florestas / Departamento de Conservação da Natureza e Florestas do Alentejo	Regional Public Authorities
14	EDIA, S.A. - Empresa de Desevolvimento e Infraestruturas do Alqueva	Business
15	DECO - Associação Portuguesa para a Defesa do Consumidor / Delegação Regional de Évora	Civil Society
16	Fundação Alentejo / EPRAL - Escola Profissional da Região Alentejo	Civil Society
17	Colégio Fundação Alentejo	Civil Society
18	Universidade de Évora - Centro de Geofísica de Évora Escola de Ciências e Tecnologia	Civil Society
19	Universidade de Évora - Departamento de Paisagem, Ambiente e Ordenamento	Civil Society
20	União de Freguesias do Bacelo e da Senhora da Saúde	Local authorities
21	União de Freguesias de Malagueira e de Horta de Figueiras	Local authorities
22	Câmara Municipal de Évora / Divisão de Ordenamento e Reabilitação Urbana	Local authorities
23	Câmara Municipal de Évora / Gabinete de Apoio à Presidência e Vereação - Grupo de Avaliação Permanente do Espaço Público	Local authorities
24	Câmara Municipal de Évora / Gabinete de Apoio à Presidência e Vereação - Grupo de Avaliação Permanente do Espaço Público	Local authorities
25	Câmara Municipal de Évora / Divisão de Obras Municipais	Local authorities

Coordination and support action (Coordinating Action)

FP7-ENERGY-SMARTCITIES-2012

INSMART

Integrative Smart City Planning

Report on optimum sustainability pathways – Cesena

D-WP 5 – Deliverables D.5.4

Author(s): R. De Miglio, A.Chiodi, M. Gargiulo

Date: October 2016

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Report on optimum sustainability pathways – Cesena

Project co-funded by the European Commission within the Seventh Framework Programme		
Dissemination Level		
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PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Version	**Submitted by**	**Review Level***	**Date Submitted**	**Reviewed**
V01		WPL		

Editors		
	Name (organization)	**e-mail**
Leading participant	Rocco De Miglio (E4SMA) Alessandro Chiodi (E4SMA)	rocco.demiglio@e4sma.com alessandro.chiodi@e4sma.com
Contributing participants	Rocco De Miglio (E4SMA) Alessandro Chiodi (E4SMA) Maurizio Gargiulo (E4SMA) Sofia Burioli (Comune di Cesena) Elena Giovannini (Comune di Cesena) Morris Gentili (Comune di Cesena) Barbara Maggioli (Comune di Cesena) Silvia Morigi (Energie per la Citta')	rocco.demiglio@e4sma.com alessandro.chiodi@e4sma.com maurizio.gargiulo@e4sma.com est_burioli_s@comune.cesena.fc.it giovannini_e@comune.cesena.fc.it gentili_m@comune.cesena.fc.it maggioli_b@comune.cesena.fc.it mercatoenergia@energieperlacitta.it
WP Leader (WPL)	E4SMA	e4sma@e4sma.com
Project Coordinator (PC)	George Giannakidis (CRES)	ggian@cres.gr
Project Steering Committee (PSC)		

Executive Summary	
Development of the energy system model of Cesena, definition and analyses of sustainability scenarios.	
Keywords	Energy system model, planning hypotheses, scenario analysis, technologies and measures.

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Acronyms and Definitions

CHP – Combined Heat and Power

ESM – Energy City Model

GIS – Geographic information system

MCDA – Multi Criteria Decisions Analysis

O&M – Operation and maintenance

PROMETHEE – Preference Ranking Organization METHod for Enrichment of Evaluations

PV – Photovoltaic

RES – Renewable energy sources

TIMES – The Integrated MARKAL-EFOM System

1. Introduction

This report presents an application of the innovative city planning approach, developed within the EU FP7 project InSMART for the municipality of Cesena. Cesena is situated in Northern Italy within Emilia-Romagna Region. At about 15km from the Adriatic coast, the proximity to the sea ensures a moderate and temperate climate. Together with Forlì it is the capital of the Forlì-Cesena Province. Cesena itself has a population of about 97131 inhabitants (ISTAT, 2013).

The main objective of the proposed methodology is the identification of an optimum mix of applicable measures and technologies to pave the way towards the achievement of the cities' sustainable targets. On the basis of the possible space of decisions of the municipality of Cesena (which can be seen as "urban planner", as "regulator", as "provider of support and information", as "consumer" and as "supplier" of energy), and based on specific assumptions of the local decision makers, alternative planning hypotheses have been designed and tested making use of a city-energy system model and of scenario analysis. In particular, based on a data collection oriented to the preparation of decision support system tools (quantitative data gathered making use of ad-hoc surveys and local GIS-maps), a bottom-up model is used to create and explore alternative energy plans (combinations of actions and measures) for the municipality of Cesena, with a particular focus on the residential and transport sectors.

Making use of scenario analysis, the planning hypotheses are built around different themes with the aim of exploring the potential benefits (or drawbacks) of the combination of "competitive" projects, actions, standards, and targets. A "reference" development of the local system is then assumed to be modified through several different "strategic plans" aiming at representing and testing images of alternative pathways towards the sustainability.

Compared to the existing (common) planning methods, the advantage of the outputs of this approach is the fact that multiple future energy scenarios are analysed and cross-compared, and "integrated" strategies are identified.

A MCDA tool is then used in cascade to generate the final ranking on the basis of a set of elements against which the alternatives are evaluated (technological, economic, environmental and social criteria). Local stakeholders of Cesena have been engaged to participate in the design of the alternative planning hypotheses as well as in the analysis of uncertainties and of the responses of the tool (results).

2. City Energy System Model

2.1. Structure of the model and methodological approach

This section aims to describe the methodology used to represent the city energy system and the key characteristics of the model. According to the Description of Work of the project, the key outcome of the city ESM is the "*identification of an optimum mix of applicable measures and technologies that will pave the way towards the achievement of the cities' sustainable targets*". In order to assess the impact of different energy plans on the urban system, a technical economic model of the energy sector of the municipality of Cesena was built making use of the TIMES model generator (The Integrated MARKAL-EFOM System), which is a widely-applied partial equilibrium, bottom-up, dynamic, linear programming optimisation model.

Making use of the graph theory concepts (and the graph shown below), the urban area is represented in nodes ("zones") as shown in the following figure. Each zone is described as a subsystem characterized by a certain number and type of energy service demands (space heating, water heating, cooling, lighting, etc.), buildings and activities (detached, semidetached, blocks, hospitals, schools, etc.), potentials for renewables (e.g. PV solar) and by a number of zone-to-zone transport needs. Number and borders of the subsystems within the urban area are defined on the basis of homogenous zones (15 zones have been identified in Cesena for the analysis) which are suitable for the planning exercise (and are inherited by WP1, WP2 and WP3).

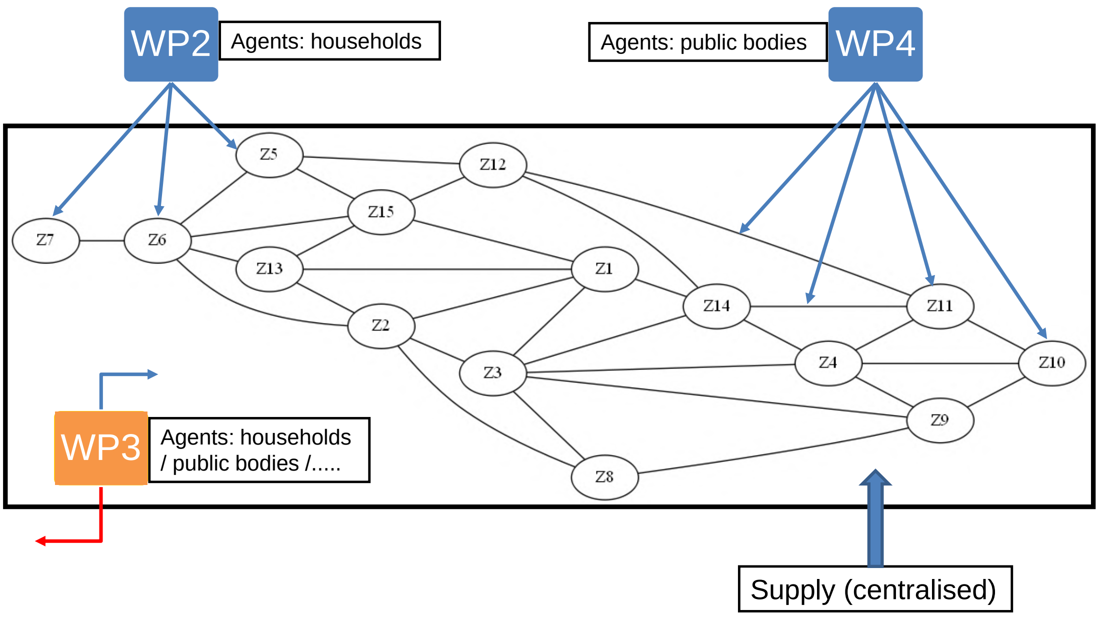


Fig. 1. Topology of the ESM for Cesena

Each zonal sub-system is characterised by stacks of "individual" behaviours (productions, consumptions, etc.) of all the agents acting in the zone. The "key" agent of the model is "virtually placed" in the dwelling (household) for which several energy needs are modelled, and to which investments decision variables (key element of the model) are assigned. Figure 2 shows the logic scheme used in the model: a generic household "demand" several energy services and use technologies to meet these demands.

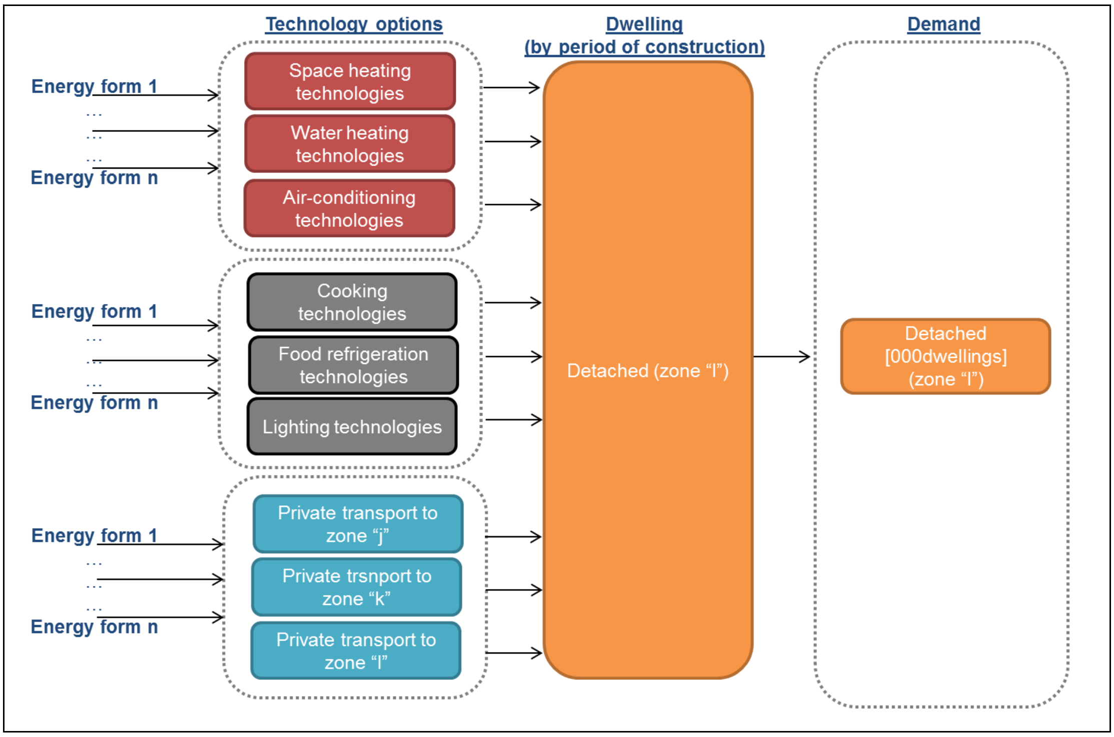


Fig. 2. End-uses demanded by household (e.g. detached)

Energy consumptions and demanded services are "decoupled": efficient technologies (boilers, refrigerators, lighting bulbs, cars, building refurbishment options, etc.) can be chosen by the final consumers to reduce the consumption and meet the same service level. Figure below shows that consumption for space heating can be reduced if retrofit measures are included.

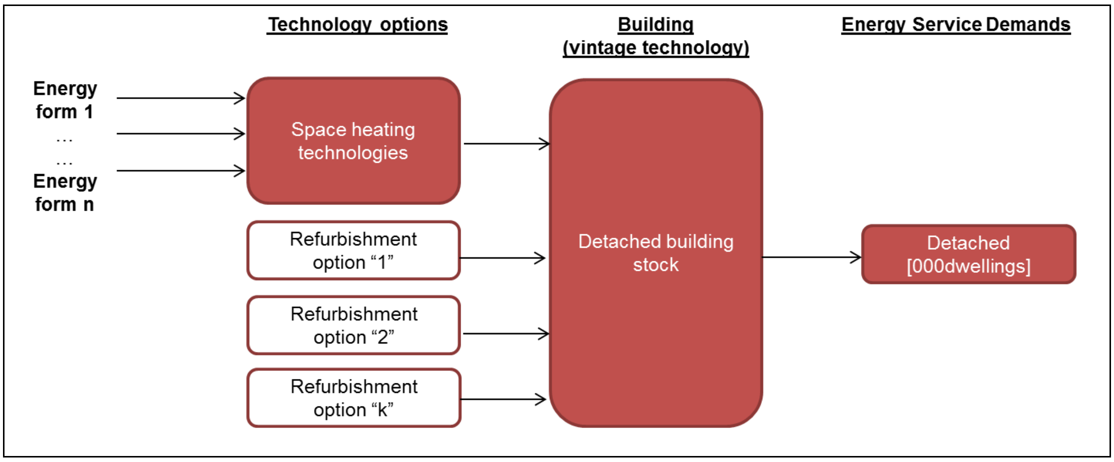


Fig. 3. Space heating technologies and refurbishment options by household (e.g. detached)

Zones of the city (15) hold different characteristics affecting the investment decisions of agents and affecting the operation of the technologies (e.g. different access to distribution systems, different PV potentials, different investments costs, etc.), therefore zone-specific developments/performances are also analysed in the framework of this research (although not included in the MCDA analysis).

Mobility demands (private) are allocated to the zones which are at the "origins" of the movements, by assuming that the corresponding investment decisions are taken by the agents located in the zone of origin. Therefore, costs, fuel consumptions and emissions are directly assigned to these zone. A matrix of movements (origin-destination) by period and by transport mode if fully inherited from the transport specific analysis (WP3). The goal of the ESM, among the others, is to provide the "optimal vehicles mix" with respect to that matrix of movements and to any possible sectorial measure/target (scenario) taking into account of the possible integrations of the transport sector with other urban system components[1]. Doing so, "urban planning" and "energy planning" are carried out together in an integrative manner as decisions taken in one area generate feedbacks from the second area.

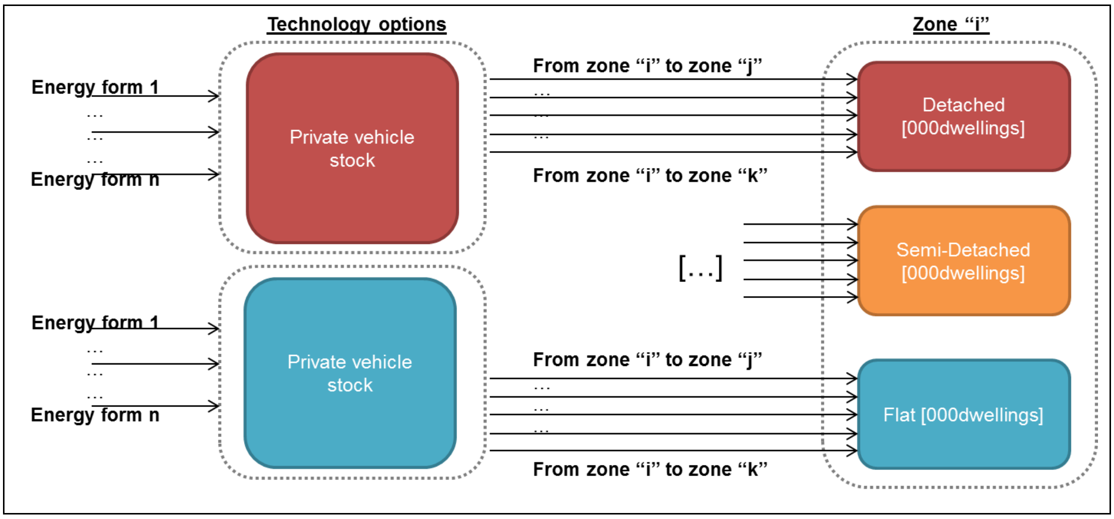


Fig. 4. Private mobility from zone "i" as demands of the households in zone "i"

The following table makes more explicit the level of detail of the city model for Cesena by reporting the key agent of the system and the corresponding variables (quantitative outcomes of the model assigned to the agent).

Key agent	Households (n-building types: detached, semidetached, blocks, by period (6) of construction).
Energy services per agent	Space heating, water heating, space cooling, lighting, entertainment, refrigeration, cloth-washing, private transport from zone "i" to zone "j".
Location	Zone 1, Zone 2, .., Zone i,, …., Zone 15.

[1] Examples of such integration are presented in the following paragraphs.

Variables	Consumption of different energy forms / sector / service, investment costs per each appliance/technology, emissions, etc.

Table 1. Basic settings of the ESM of Cesena

Other sectors and activities are also explicitly represented in the ESM of Cesena, with the same zone-specific detail. The key energy services (heating, cooling, public lighting, etc.) of schools, offices, warehouses, and other tertiary, as well as the public and good transport demands, are described to keep track of the consumption/emission level of the municipality which might be affected by specific policies and measures (municipality of Cesena is seen as a planner and regulator of the urban area). Only the industrial activities have not been included in the model.

The structure of the ESM of Cesena allows to track many types of variables which are of interest in the urban planning activity of Cesena: the savings by retrofit measure per scenario, the quantification of the savings by building type per scenario, the electricity consumption by zone and by scenario, the electricity and heat load shape by slice per scenario, the emissions by sectors and by zone, the investments costs (by zone, by agent, and by service), the penetration of decentralized production of energy, the new shape of energy consumption over the time slots, etc. As one of the most relevant planning issue of the municipality of Cesena is about the “shape” (peak, base-load) of heat demand (in particular for the public buildings), the following time granularity has been used to track the energy consumptions within the year. Specific actions can be targeted to the consumption/production of energy form in specific time-slots of the year.

Time of day	N	M	A	E	Year	
Season	N. hours	N. hours	N. hours	N. hours	N. days	Start - End
S1	7	6	5	6	31	1 Jan - 31 Jan
S2	7	6	5	6	74	1 Feb - 15 Apr
S3	7	6	5	6	76	16 Apr–30Jun
S4	7	6	5	6	62	1 Jul - 31 Aug
S5	7	6	5	6	44	1 Sept - 14 Oct
S6	7	6	5	6	78	15 Oct - 31 Dec

Fig. 5. Time granularity of the model

Section 4 of this technical note reports with more emphasis the outputs of variables and indicators used in the multi-criteria analysis. Further details of the results will be analysed in the framework of WP6 (Development of Mid-term Implementation Action Plans).

2.2. Description of the existing energy system of Cesena

Based on the data collection undertaken in WP2 and WP4, figures have been organised in a consistent framework (spreadsheets-based), and elaborated in order to:

- quantify and represent the stocks of energy demand technologies (e.g. MW of boilers, number of refrigerators, number of vehicles etc.) and distribution processes (such as gas and district heating systems) in the model,
- aggregate the information by zone,
- make consistency analyses of the key variables at zonal level (e.g. the amount of natural gas delivered, or electricity consumed, etc.) in such a way that productions and consumptions are consistent with the local statistics.

Figure 6 reports some key quantitative details of the city energy system (household sector) in 2103. Such a (static) condition of the base year evolves (dynamic) according to different conditions of the system along the period of analysis.

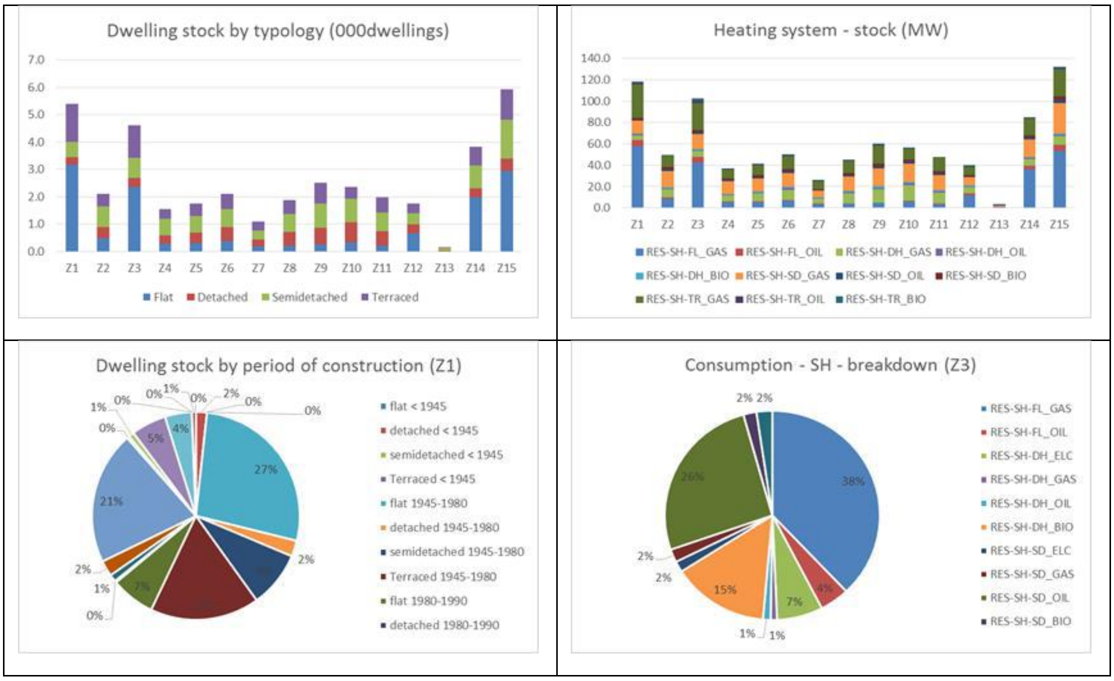
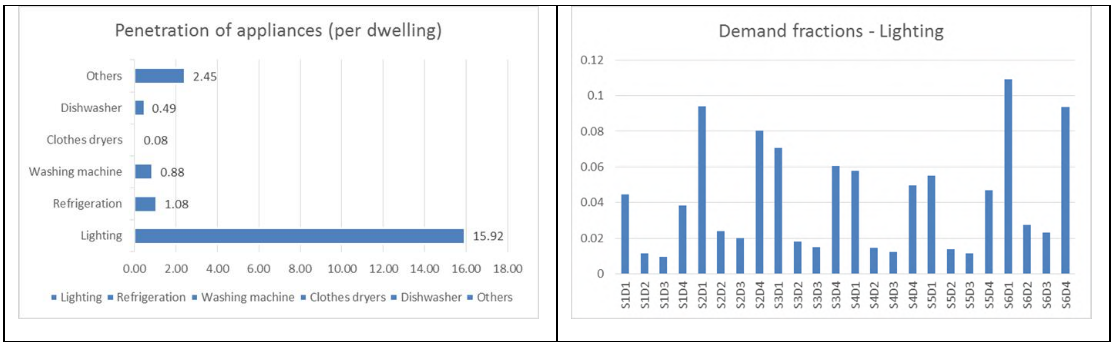


Fig. 6. Dwelling stock by typology and zone (top). Dwelling stock by period of construction (Z1) and share of heating system by fuel of Cesena (Z3)

Additional inputs to the model are used to describe the pure electrical services and technologies and the load shape (over the 24 time-slices) of consumption of electricity in the city. Figure 7 reports few important data of the base year which are assumed to be constant over the time horizon (saturation of the pure electrical services for the next 15 years).



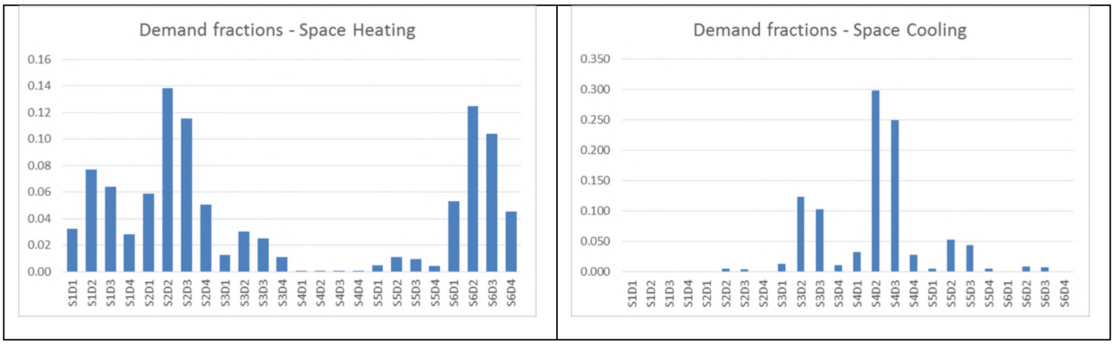


Fig. 7. Pure electrical services of the households: penetration and shapes

Energy consumptions and expenditures are calibrated "by type of dwelling" according to the information collected through local surveys for the base year of the analysis. Data on transport are fully inherited by WP3 and used in the model to project the utilisation/consumption of vehicles in Cesena.

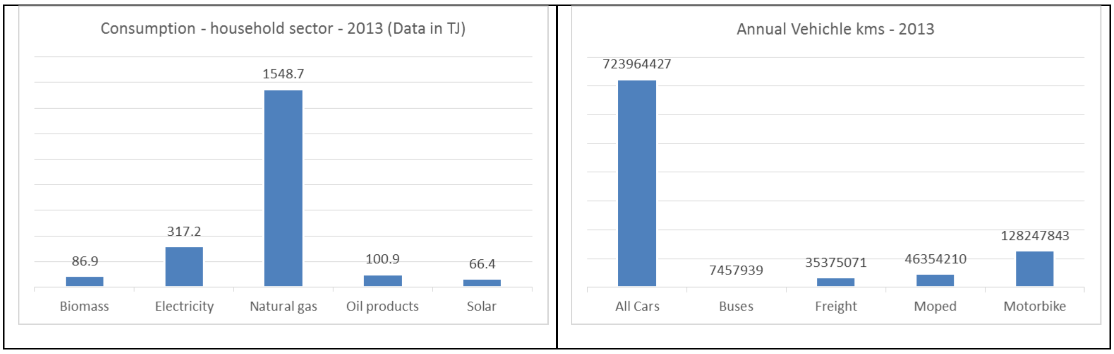


Fig. 8. Base year consumption in residential sector and transport demand by vehicle

Dwellings are explicitly represented in the model, and so are available refurbishment options (savings and the costs of the refurbishment options are calculated making use of a building stocks simulation of the existing building typologies in Cesena – WP2). Thus, per each existing building typology the heating demand, the heating consumption, and three (combinable) options of demand reductions (R1: walls, R2: roof, R3: windows) are estimated and represented in the model. Figures below show four examples of data assumed in the analysis.

T 5	**Detached house**
Use	Residential
Construction period	2006-2011
City area	Suburb
No of floors	1 floor + basement
Wall type	Reinforced Concrete

Heating Demand: 53 kWh/m2
Heating Consumption: 59 kWh/m2
Demand reduction: R1 (0%), R2 (0%), R3 (0%)

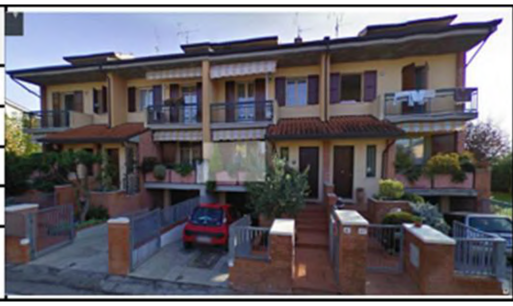
Fig. 9. Modern detached house

T 6	Semi - detached house
Use	Residential
Construction period	1946-1980
City area	City center
No of floors	2 floors
Wall type	Masonry Brick

Heating Demand: 123 kWh/m2
Heating Consumption: 162 kWh/m2
Demand reduction: R1 (9%), R2 (8%), R3 (18%)

Fig. 10. Old semidetached house

T 11	Terraced house
Use	Residential
Construction period	1981-1990
City area	Suburb
No of floors	2 floors + parking
Wall type	Reinforced Concrete



Heating Demand: 75 kWh/m2
Heating Consumption: 100 kWh/m2
Demand reduction: R1 (15%), R2 (2%), R3 (10%)

Fig. 11. Terraced house

T 17	Apartment building
Use	Residential
Construction period	2006– 2011
City area	Suburb
No of floors	3 - 5 floors
Wall type	Reinforced Concrete

Heating Demand: 74 kWh/m2
Heating Consumption: 83 kWh/m2
Demand reduction: R1 (0%), R2 (0%), R3 (4%)

Fig. 12. Modern apartment building

2.3. Key static and dynamic components of the ESM of Cesena

The ESM of Cesena has been designed with the following characteristics, with the aim to provide a flexible platform for the analysis of the scenarios proposed by the municipality (and presented in the following section) and for the exploration of many other tests which may be of interest in the future.

- The city is subdivided in zones (15 city zones for). Each zone is a subsystem (region) of the TIMES-based city ESM.
- The city ESM has a "multi-regional" structure, meaning that agents of the building sector and their demands are placed to different zones of the urban area, and that processes operate in different zones of the urban area.
- Different zones can be subject to different actions/measures.
- Buildings are classified following the typologies of the surveys (WP2).
- Each type of building is a "process" in the model, and so are refurbishment options (the number, the type, the savings and the costs of the refurbishment options are provided by WP2).
- Building construction (new demand) and demolishment are defined exogenously (WP2 and scenario design).
- Limits on refurbishment rates can be included as constraints (e.g. based on historical rates).
- The centralised supply (e.g. power plants) is not "explicitly" represented within the borders of analysis. Availabilities and prices of these supplied are part of the scenario storyline (exogenously defined). Prices can be defined by "time slot" (e.g. afternoon of season 3).
- The high requirement on local air quality can be taken into account (e.g. by banning some technologies from specific zones).
- The projection of electricity and heat needs (consumption) is completely endogenous (per each agent, per each zone).
- Model allows the representation of different actors in the same decision platform: household (i), economic activity (j), public body (k), etc.
- Model is calibrated to the latest set of available data. Calibration is meant to depict a consistent and reliable starting point for the dynamic analysis.
- Such a dynamic model deals with "feedback effects". Results capture the key features of urban dynamics, such as "price responses" and interaction with demand and supply choices per each type of "agent".
- "Behavioral-oriented" measures or phenomena like for example information campaigns, network effects, DSM and load shifting, can be considered in the model.
- The perfect foresight of the model is controlled making use of "budget constraints" aiming at simulating the maximum willingness to invest of the households.
- The details of representation of the non-residential building stock, as well as of the energy demands of the tertiary sector, is simplified (consistent with the available data collected).

3. Scenario analysis

3.1. Narrative of scenarios

Scenarios for the Municipality of Cesena are built around a number of “areas of intervention” with the aim of exploring the potential benefits (or drawbacks) of the combination of specific “competitive” projects, actions, measures, and targets. The starting point of the analysis is a reference scenario which is used as a base case (counterfactual) against which to compare the alternative planning hypotheses (oriented to the sustainability) of the city. These alternative hypotheses have been developed through a combination of actions and measures across six main areas of action, namely i) Urban regeneration, ii) Urban development, iii) Transport, iv) Behaviour and Organization, v) Renewables, and vi) System.

Forecasts vs. Scenarios

Results for the city energy system model should not be considered as forecasts for the future. Results provide insights into the impacts of a particular scenario, which considers a discrete set of input assumptions in relation to variables such as macroeconomic drivers, fuel prices, resource availability and technology costs. These assumptions should not be seen as prescriptive, but rather as a snapshot of potential outcomes that may be realized. Comparing different scenario results is where the richness lies. The objective of useful systems modelling is to provide an evidence base to inform policy decision regarding potential future energy system configurations.

3.1.1. The Reference scenario

The Reference scenario has been designed to simulate the current “reference” development of the local system. It considers all the current key policy developments and provides a basis against which to compare the alternative city planning hypotheses. The following assumptions have been assumed in the reference scenario:

- Population: the population and the number of families are assumed to stay almost constant across the horizon 2013 (base year) and 2030 (end-year simulation).
- New urban areas: all the assumptions behind new urban developments and all the energy and non-energy services are assumed in line with the current urban development plan, the PRG 2000[2] (*Piano Regolatore Vigente*). The reference scenario considers only areas which are currently approved. Within these areas limited changes are assumed relatively to the location of key service centres

[2] http://www.comune.cesena.fc.it/urbanistica/prg

(e.g. schools, shops, malls, etc.). Figure below reports the demand projections of the reference case for the four main building typologies: “Flat”, “Detached”, “Semidetached”, “Terrace”.

Year	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10	Z11	Z12	Z13	Z14	Z15
2013	3.1739	0.4813	2.3696	0.2902	0.3130	0.3805	0.1955	0.2170	0.2521	0.3405	0.2074	0.6748	0.0000	1.9883	2.9381
2020	3.1694	0.4785	2.4256	0.2825	0.3046	0.3814	0.1903	0.2112	0.2624	0.3554	0.2398	0.6759	0.0000	1.9853	2.8599
2030	3.1227	0.4622	2.3930	0.2850	0.3042	0.3748	0.1862	0.2062	0.2697	0.3537	0.2533	0.6607	0.0000	2.1964	2.7541

Year	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10	Z11	Z12	Z13	Z14	Z15
2013	0.2645	0.3990	0.3126	0.2872	0.3814	0.5150	0.2439	0.4985	0.6261	0.7302	0.5222	0.3081	0.0432	0.3251	0.4578
2020	0.2631	0.3983	0.3269	0.2857	0.3793	0.5137	0.2426	0.4958	0.6253	0.7293	0.5245	0.3084	0.0430	0.3233	0.4554
2030	0.2617	0.3973	0.3353	0.2842	0.3793	0.5125	0.2419	0.4942	0.6245	0.7275	0.5247	0.3088	0.0427	0.3231	0.4570

Year	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10	Z11	Z12	Z13	Z14	Z15
2013	0.5773	0.7603	0.7289	0.6128	0.6075	0.6511	0.3149	0.6584	0.8672	0.8485	0.7027	0.4042	0.0784	0.8210	1.4131
2020	0.5755	0.7594	0.7426	0.6108	0.6056	0.6505	0.3139	0.6564	0.8670	0.8489	0.7055	0.4050	0.0782	0.8184	1.4087
2030	0.5737	0.7580	0.7504	0.6090	0.6058	0.6500	0.3134	0.6553	0.8668	0.8483	0.7063	0.4057	0.0779	0.8174	1.4083

Year	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10	Z11	Z12	Z13	Z14	Z15
2013	1.3751	0.4562	1.2039	0.3638	0.4405	0.5724	0.3408	0.5010	0.7631	0.4296	0.5510	0.3668	0.0048	0.6895	1.1128
2020	1.3730	0.4555	1.2091	0.3633	0.4399	0.5715	0.3403	0.5002	0.7619	0.4309	0.5532	0.3682	0.0048	0.6884	1.1111
2030	1.3701	0.4545	1.2116	0.3675	0.4399	0.5713	0.3396	0.4992	0.7613	0.4310	0.5531	0.3684	0.0048	0.6880	1.1108

Tab. 2. Demand projection by zone and building typology (000 dwellings)

- New building stock: The energy standards of all new building stocks follows current national and regional building rules.
- Appliances: The substitution rates of appliances (e.g. light bulbs, washing machines, boilers, etc.) are driven by their technical obsolescence, their cost-effectiveness (i.e. no specific measure are assumed to support their substitution) and a “default” estimate of the willingness to invest of the families.
- Refurbishment of the existing stock: a smooth growth rate (driven by current rates of penetration) of retrofit measures (equivalent to 18% of the existing building stock in class E refurbished to class C. Three refurbishment options are modelled, R1, R2, R3[3]. Table below reports the investment cost (Euro/ dwelling) of the different retrofit options as used in the model. At the current stage of development of the analysis, costs are assumed to be the same across the regions, but data can be changed for future (more refined) analyses.

Type	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10	Z11	Z12	Z13	Z14	Z15
Flat-R1	4000	4000	4000	4000	4000	4000	4000	4000	4000	4000	4000	4000	4000	4000	4000
Flat-R2	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600
Flat-R3	2750	2750	2750	2750	2750	2750	2750	2750	2750	2750	2750	2750	2750	2750	2750
Detached-R1	10000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000
Detached-R2	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500
Detached-R3	10000	10500	10500	10500	10500	10500	10500	10500	10500	10500	10500	10500	10500	10500	10500
SemiDetached-R1	6667	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000
SemiDetached-R2	1667	1667	1667	1667	1667	1667	1667	1667	1667	1667	1667	1667	1667	1667	1667
SemiDetached-R3	6667	7000	7000	7000	7000	7000	7000	7000	7000	7000	7000	7000	7000	7000	7000
Terrace-R1	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000
Terrace-R2	900	900	900	900	900	900	900	900	900	900	900	900	900	900	900
Terrace-R3	4125	4125	4125	4125	4125	4125	4125	4125	4125	4125	4125	4125	4125	4125	4125

Tab. 3. Investment cost of retrofit options (Euro/ dwelling)

[3] R1: Walls: Installation of external insulation on the walls for typologies without insulation or insufficient insulation, according to the thermal properties defined by the Italian Regulation for the specific climate zone.
R2: Roof: Installation of external insulation on the roof for typologies without insulation or insufficient insulation, according to the thermal properties defined by the Italian Regulation for the specific climate zone.
R3: Windows: Replacement of existing windows, according to the thermal properties defined by the Italian Regulation for the specific climate zone.

- District heating: No further expansion of the district heating network is allowed.
- Public lighting: All newly installed lighting systems in the Municipality are high efficiency LED systems, in line with the current local directives.
- Energy prices: Energy prices are calibrated in line with the current, and for future years they follow the national projections. The future relative distance in prices between different energy sources is assumed in line to the current one. Data are reported in the following tables.

Year	Gas -Day	Gas-Night	Ele -Day	Ele-Night
2013	8.00	8.00	16.98	14.72
2020	8.78	8.78	18.67	16.19
2030	9.97	9.97	21.22	18.40

Year	Gas –Day	Gas-Night	Ele -Day	Ele-Night
2013	6.00	6.00	12.73	11.04
2020	6.60	6.60	14.00	12.14
2030	7.50	7.50	15.91	13.80

Tab. 4. Energy prices for residential and non-residential sectors (from the grid and network, Euro/GJ)

Modelling different prices of electricity allows to better keep track of the expenditures (by end use), and make possible to analyse demand responses phenomena (shift in electricity consumption in behavioural-oriented scenarios).

- Behaviour: No changes in the energy behaviour (e.g. willingness to invest of the players, load shifting) are assumed in the period of the analysis.
- Transport: All the actions of the current transport development plan, the PRIM (*Piano Regolatore Integrato della Mobilità di Cesena*)[4], have been already realised, hence included from the base-year in the model. No further actions are included in the.
- Subsidies and incentives: No national, regional and local incentives or subsidies are included in the reference scenario, given the high uncertainty around the future availability of these mechanisms. Potentials for solar PV and solar water heaters are reported in the following tables by type of technology and zone.

Type	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10	Z11	Z12	Z13	Z14	Z15
PV-Flat_Roof1	2.886	0.765	2.479	0.354	0.375	0.513	0.351	0.332	0.390	0.409	0.352	0.746	0.000	2.102	3.206
PV-Flat_Roof2	2.264	0.600	1.945	0.278	0.294	0.402	0.275	0.260	0.306	0.321	0.276	0.585	0.000	1.649	2.515
PV-Flat_Roof3	2.493	0.660	2.141	0.306	0.324	0.443	0.303	0.287	0.337	0.353	0.304	0.645	0.000	1.816	2.769
PV-Flat_Roof4	1.027	0.272	0.882	0.126	0.133	0.182	0.125	0.118	0.139	0.146	0.125	0.266	0.000	0.748	1.141
PV-Flat_Facade1	2.384	0.430	1.813	0.229	0.302	0.408	0.128	0.310	0.317	0.434	0.252	0.613	0.000	1.752	2.773
PV-Flat_Facade2	0.982	0.177	0.747	0.095	0.125	0.168	0.053	0.128	0.131	0.179	0.104	0.253	0.000	0.722	1.142
PV-Detached_Roof1	1.132	2.280	1.444	1.273	1.946	3.248	1.323	3.279	3.605	4.638	3.120	1.828	0.247	1.275	1.799
PV-Detached_Roof2	0.888	1.789	1.133	0.999	1.526	2.548	1.038	2.572	2.828	3.638	2.447	1.434	0.194	1.001	1.412
PV-Detached_Roof3	0.978	1.969	1.247	1.100	1.680	2.805	1.143	2.832	3.113	4.005	2.694	1.579	0.214	1.102	1.554
PV-Detached_Roof4	0.403	0.811	0.514	0.453	0.692	1.156	0.471	1.167	1.282	1.650	1.110	0.651	0.088	0.454	0.640
PV-Detached_Facade1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PV-Detached_Facade2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PV-SDetached_Roof1	1.528	2.131	1.783	1.563	1.795	2.320	1.058	2.204	2.846	3.251	2.373	1.537	0.336	1.974	3.258
PV-SDetached_Roof2	1.199	1.672	1.399	1.226	1.408	1.820	0.830	1.729	2.233	2.551	1.861	1.206	0.263	1.549	2.556
PV-SDetached_Roof3	1.320	1.841	1.540	1.350	1.550	2.004	0.914	1.904	2.458	2.808	2.049	1.328	0.290	1.705	2.814
PV-SDetached_Roof4	0.544	0.758	0.634	0.556	0.639	0.826	0.377	0.784	1.012	1.157	0.844	0.547	0.119	0.702	1.159
PV-SDetached_Facade1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PV-SDetached_Facade2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PV-Terrace_Roof1	2.260	0.886	2.224	0.754	1.035	1.117	0.701	1.248	1.876	1.140	1.386	0.949	0.020	1.092	2.119
PV-Terrace_Roof2	1.773	0.695	1.745	0.592	0.812	0.876	0.550	0.979	1.472	0.895	1.088	0.745	0.016	0.856	1.663
PV-Terrace_Roof3	1.952	0.766	1.921	0.651	0.894	0.964	0.605	1.078	1.620	0.985	1.197	0.820	0.017	0.943	1.830
PV-Terrace_Roof4	0.804	0.315	0.791	0.268	0.368	0.397	0.249	0.444	0.667	0.406	0.493	0.338	0.007	0.388	0.754
PV-Terrace_Facade1	1.268	0.497	1.247	0.423	0.580	0.626	0.393	0.700	1.052	0.640	0.777	0.532	0.011	0.612	1.189
PV-Terrace_Facade2	0.522	0.205	0.514	0.174	0.239	0.258	0.162	0.288	0.433	0.263	0.320	0.219	0.005	0.252	0.490

[4] http://www.comune.cesena.fc.it/pianoregolatore

Tab. 5. Potential: Solar PV potential (MW)[5]

Building	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10	Z11	Z12	Z13	Z14	Z15
Flat	1.434	0.288	1.457	0.216	0.232	0.209	0.109	0.140	0.191	0.217	0.140	0.496	0.000	1.240	1.896
Detached	0.134	0.286	0.217	0.230	0.300	0.371	0.170	0.402	0.499	0.592	0.426	0.218	0.022	0.223	0.345
Semidetached	0.263	0.484	0.404	0.451	0.439	0.478	0.220	0.505	0.624	0.640	0.525	0.311	0.057	0.518	0.929
Terrace	0.542	0.254	0.774	0.255	0.335	0.379	0.176	0.305	0.537	0.315	0.389	0.291	0.004	0.396	0.665

Tab. 6. Potential: Solar water heating potential (MW)

3.1.2. The Alternative scenarios

The alternative scenarios aim to explore possible routes for a more sustainable planning of the Municipality. These scenarios are designed to assess the implications of different integrated visions of the development of the municipality. The reference development of the local system[6] is assumed to be modified through a series of combinations of actions and measures aiming at representing *alternative planning hypotheses* of the city (oriented to the sustainability). The design of these storylines has followed a two steps approach: firstly a group of planning hypothesis and the corresponding actions by thematic areas have been identified; secondly alternative integrated plans (i.e. including "groups" / "combinations" of actions from different areas) have been composed.

Figure below presents and overview of the actions identified for the municipality. These actions are classified under a number of thematic areas; namely i) Urban regeneration, ii) Urban development, iii) Transport, iv) Behaviour and Organization, v) Renewables. A sixth area indicated as 'System' does not include any specific action, but applies a set of "top-down" emission targets to the energy system of the city. The results of this alternative will be used as benchmark in particular during the analysis of WP6, while are not used for the MCDA.

A pure "what-if" analysis is at the basis of six alternative planning hypotheses (combination of actions of different areas) for the decision makers. The first focus area is the "urban regeneration". It is oriented to the establishment of "standards" for the refurbishments of the existing building stock. It is based on the idea of supporting the refurbishment of the existing buildings rather than of changing the existing city land use (i.e. new constructions and districts).
The second policy focus is oriented to the "urban development", i.e. these planning hypotheses will assess implications of developing new districts (mainly multi-apartment buildings), including new services, activities and public infrastructures (e.g. roads, waste water systems, etc.) allowing certain numbers of families to settle in such a new area and leave old-fashioned apartments. These planning hypothesis (and the corresponding actions) have a strong impact on the demand of transport, as the resulting

[5] Roof (1,2,3,4): Monocrystalline silicon; Multicrystalline silicon; HIT (Heterojunction with Intrinsic Thin Layer); Amorphous silicon (non-transparency type). Façade (1,2): HIT-Si; 3-a-Si

[6] It is worth noting that the assumptions which underpin the reference scenario are all maintained and used as starting point for all further actions.

“zone-to-zone” movements are different compared the reference case. It makes clear the integration between urban planning, and energy and environmental cost-benefit analysis.

The third focus area is the “transport sector”. The rationale of this set of actions is to represent a possible development of the system oriented to the reorganization of the mobility system within the municipality of Cesena.

The fourth area focuses on “behavior”. The actions under this area aim to simulate the impacts of the reorganization of working and schools schedule; and of communication campaigns and information services. The latter are modelled as increased awareness and knowledge on energy efficiency and new technological options, and it is translated with an increase of the willingness to invest in new and more efficient energy technologies, as well as in the possibility to shift some electricity uses among the timeslots (based on cost-effectiveness).

Lastly the fifth area is focused to “renewables”. Actions under this section simulates the impact of a renewable development by setting minimum targets to the contribution of solar energy (PV and thermal), and/or heat pumps, in specific sectors of the municipality (supply side, and residential sector).

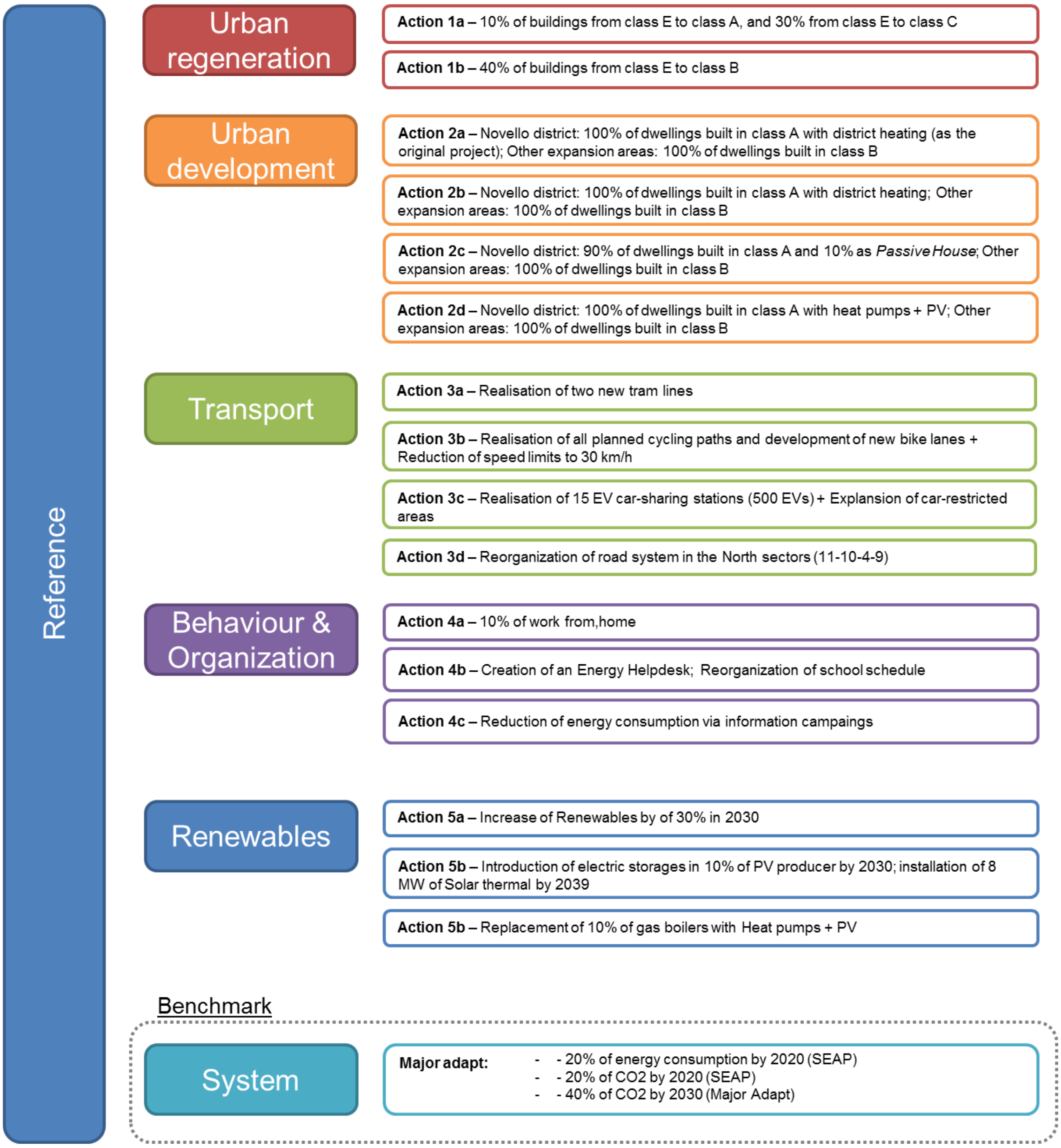


Fig. 13. Actions and measures by area

The measures[7] have been then combined to explore integrated energy action plans for a sustainable transition of the municipality of Cesena. Each of these combination has a specific focus area, as shown in the following figure.

[7] Two Urban regeneration variants have been designed and tested: 1a (moderate): 5% of buildings from class E to class A, and 15% from class E to class C; 1b (moderate): 25% of buildings from class E t class B.

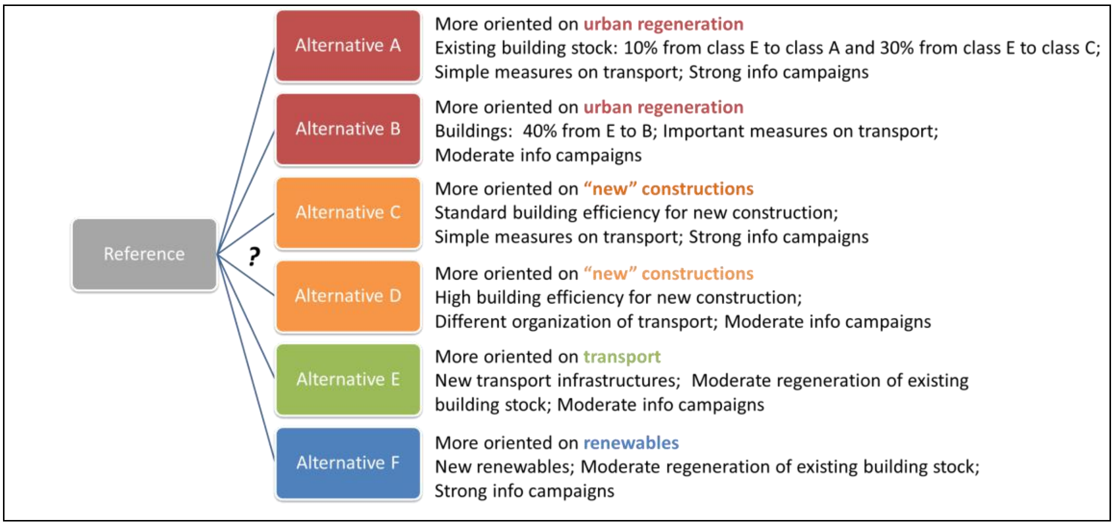


Fig. 14. Composition of the alternatives

The following assumptions have been assumed in each alternative scenario:

- **Alternative A:** Reference case + Action 1a + Action 3b + Action 4c (strong info campaign), and no specific actions on renewables.
- **Alternative B:** Reference case + Action 1b + Action 3d + Action 4c (moderate info campaign), and no specific actions on renewables.
- **Alternative C:** Reference case + Action 2a + Action 3b + Action 4c (moderate info campaign), and no specific actions on renewables.
- **Alternative D:** Reference case + Action 2c + Action 3c + Action 4c (strong info campaign), and no specific actions on renewables.
- **Alternative E:** Reference case + Action 1a (moderate) + Actions 3a, b, c, d + Action 4c (moderate info campaign), and no specific actions on renewables.
- **Alternative F:** Reference case + Action 1b (moderate) + Action 4c (strong info campaign) + Action 5a.

One more option is also simulated for a further benchmark (Alternative G), it makes use of the system and goal-oriented approach[8]. Urban system is subject to target constraints (rather than actions/projects constraints) with the aim to unveil the cost-effective room for the emission reduction in the urban area. Thus, both the reference case as well as the system and target-oriented scenario can be used to assess the quality ("distance with the benchmark") of the six actions-oriented alternatives.

All the alternative hypotheses have been designed with the involvement of the municipality of Cesena, to directly respond their needs of knowledge about potential impacts of different development of the local system.

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[8] Results of this scenario are not reported in this deliverable but are meant to be useful elements for the finalisation of the strategy in WP6.

4. Results

4.1. Key indicators for a new SEAP

The key outcome of such a city energy system model (city-ESM) is the identification of an optimum mix of applicable measures and technologies that will pave the way towards the achievement of the sustainable targets of Cesena. To support the municipality in the explorations of different strategies, model aims to be a test-bed for assessing the impacts of different urban actions and measures in terms of new energy technology mix and corresponding environmental-economic performances.
In agreement with the experts of the municipality of Cesena, some indicators have been chosen to "measure" the performances of the alternative planning hypotheses:

- Energy consumption in the building sector.
- Total CO_2 emissions.
- Total particulate emission.
- Investments (and maintenance) costs.
- Onsite production of energy.
- Indicator of private vehicles (cars, moto) dependency.

Many other indicators can be generated for Cesena making use of the city ESM. Among the most interesting: the emissions by sectors and by zone, the investments costs (by zone, by agent, and by service), the penetration of decentralized production of energy, the new shape of energy consumption over the time slots, etc.

4.2. Comparative analysis across scenarios

Results of the modelling exercises can be combined in different ways to create several types of indicators: "*static*" (to compare the performance of one scenarios with respect to other scenarios in one point of the time and/or in a cumulative manner) or "*dynamic*" (to track the evolution of a variable in the three milestone years of the model, 2013, 2020, 2030 and compare the different trend across scenarios). As the inputs for the MCDA model (which is used in cascade with the ESM) are "static", the response of the model to the different stories are presented in one point of the time (2030, the ending year of the analysis) or in terms of cumulative figures (sum over the 17 years of analysis, from 2013 to 2030).

By looking at the first set of results (Fig. 15) is clear that different planning hypotheses depict very different response of the model (quantitative image of the local system). For instance, indicators of emissions show that the transport-oriented strategy would move the city towards the minimisation of the private transport demand and of the emissions (both the CO2 and particulate); on the other side the simulations oriented to the "urban development" show the highest level of emissions. Looking at the emissions, it's also worth noting that the renewable-oriented simulation (which boosts the penetration of solar technologies in the medium term) employs a large amount of budget which cannot be used for lowering the emissions in the most critical sector (transport)[9]. The urban regeneration oriented scenarios (in particular hypothesis "A") look quite well-balanced options as they perform quite well in "all" the criteria (but in particular in the energy consumption of the building sector).

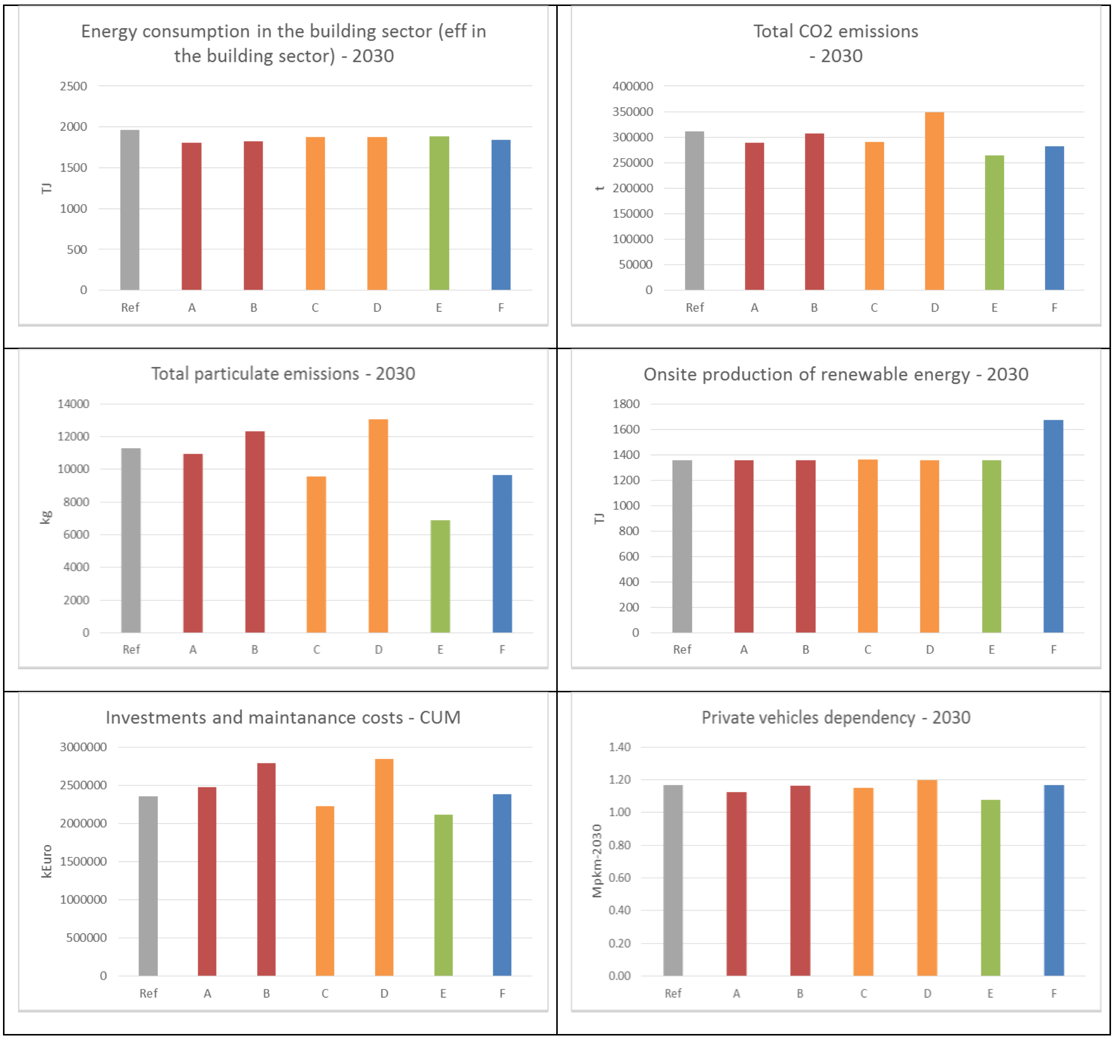

Fig. 15. Results: static indicators from MCDA

By analysing the trends (dynamics) of important indicators, it is possible to track the actual evolution of the city-system from the existing configuration to the new one depicted by the model for the medium term (2030). The two most interesting outputs shown in Fig,16 are:

- the quantification of the impacts of the actions on "buildings" (all the six scenarios include building-related actions) which are able to lower the consumption trend of the reference (up to 200 TJ of reduction), and

[9] Only direct emissions are taken into consideration. Indirect emissions (for centralised production of electricity) are excluded from the analysis as the decisions associated to bulk generation do not fall into the group of players placed in the municipality.

- the estimation of the emissions (CO_2) in case of new urban development which are always above the reference profile. All the alternatives generate a decreasing emission pattern, but only alternative E and F report evident reductions at the end of the period of analysis.

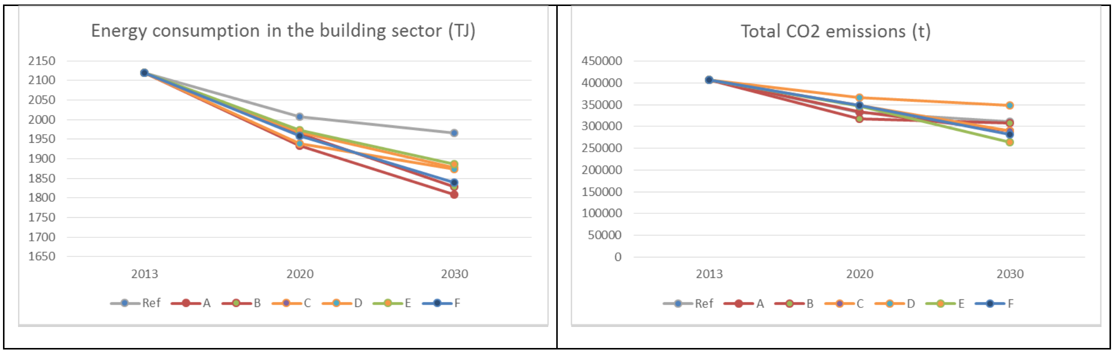

Fig. 16. Results: time dependent indicators

Results analysis can go deeper, looking at specific services, technologies, energy commodities, zones, and time slots. Many details can be extracted from the ESM to investigate the response of the simulations in the main areas of interest.

One of the key component of the alternative planning hypotheses (and of the model) is the detailed representation of the dwelling stock of Cesena and of the available retrofits measures. Figures below provide some details "by scenario", "by retrofit type", and "by zone" of the energy savings. In 2030 more than 140 TJ can be saved if the urban regeneration-oriented plans are assumed. In particular, results suggest that the most cost-effective retrofit measures are "R1" (for terrace houses built before 1980) and "R3" (for semidetached buildings built before 1980), and that the largest number of interventions can be concentrated in zones 1, 15 and 3.

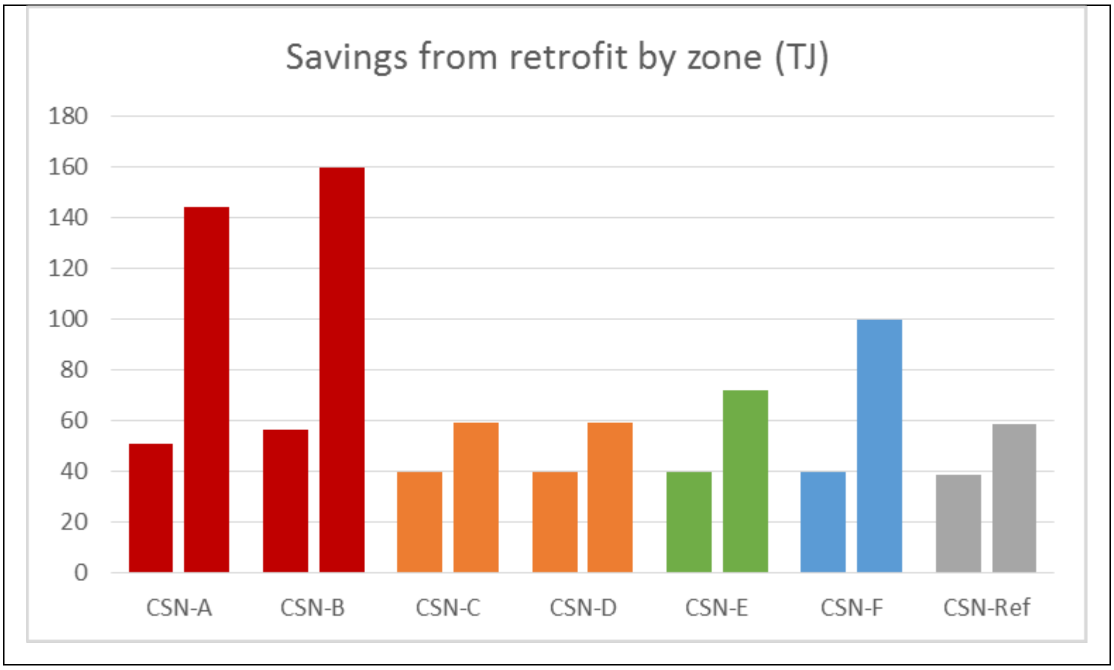

Fig. 17. Results: savings from retrofits in 2020/2030

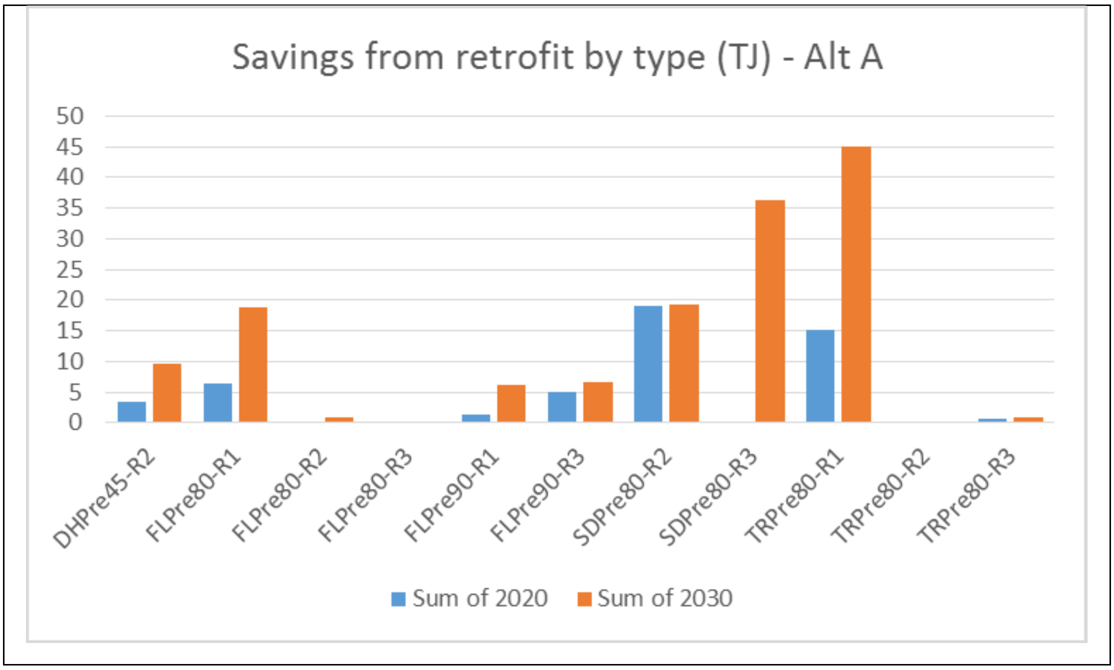

Fig. 18. Results: savings by retrofit type in 2020/2030 - Alternative A

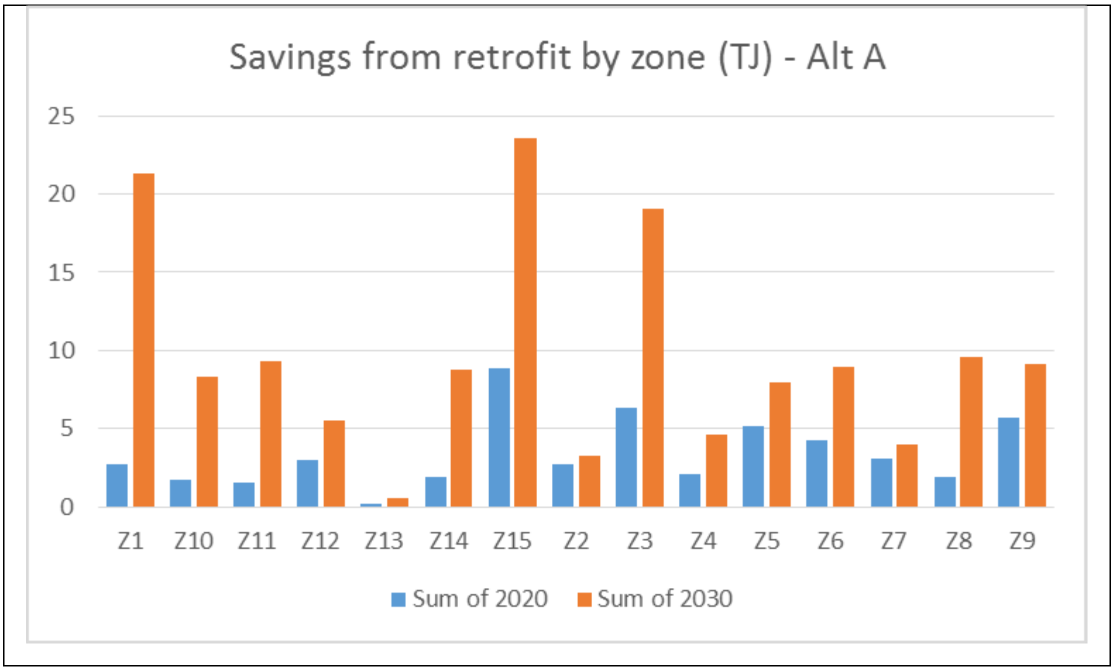

Fig. 19. Results: savings from retrofit by zone in 2020/2030 - Alternative A

A complete set of results (.xls), of the whole set of scenarios, has been shared with the experts of the Municipality of Cesena to let them check and find all the details of interest.

5. Findings and comments

Results show significant trade-offs among the key indicators reported, and different configurations of the system based on the specific simulation. The decision about the most promising planning hypothesis (and about the specific actions included) is therefore subject to a multi-criteria analysis.

Compared to the existing city Strategic Energy Action Plans of Cesena (mainly based on the downscaling of the national/regional planning approaches), such a new method allows to explore multiple future energy scenarios of the “integrated” urban system (explicitly modelled) and to engage the local stakeholders in all the steps of the decision problem. Table below summarizes the key differences and highlight the novelty of the method proposed to the municipality of Cesena in the framework of the INSMART project.

	Existing SEAP approach	**INSMART approach**
Approach	Top-down. Downscaling of national targets, policies and measures.	Bottom-up. Driven by urban specific needs and integrated with the urban planning.
Sectors (coverage)	Residential, Commercial, Public Administration (very limited analysis of agriculture and industry). Transport is not included.	Residential, Transport, Public Administration.
Emissions (location)	Direct (within the urban area) and indirect (e.g. due to the generation of electricity consumed in the urban area).	Direct (within the system). All the emissions “directly” generated by the players of the system (e.g. households) are taken into consideration.
Emissions (type)	CO_2	CO_2, particulate
Measures	Simulation. Cost-benefit analysis of individual stand-alone measures.	Optimisation/Simulation (what-if analysis). Integrated system approach.

Tab. 7. Overview of the differences between the existing and the new planning method

6. References

InSMART (2015a) InSMART Internal report 3 Task 1.2 – Survey of city energy data (housing) Typologies, methodology and results – Nottingham. Available at http://www.insmartenergy.com/wp-content/uploads/2014/11/I.R.3-WP1-T1.2.Building-Survey-Nottingham.pdf. Accessed: 28 January 2016

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InSMART (2015c) InSMART Deliverable D3.4 Transport Base Year Report Cesena. Available at: http://www.insmartenergy.com/wp-content/uploads/2015/10/D.3.4.v2.-Transport-Base-Year-Cesena.pdf

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Acknowledgements

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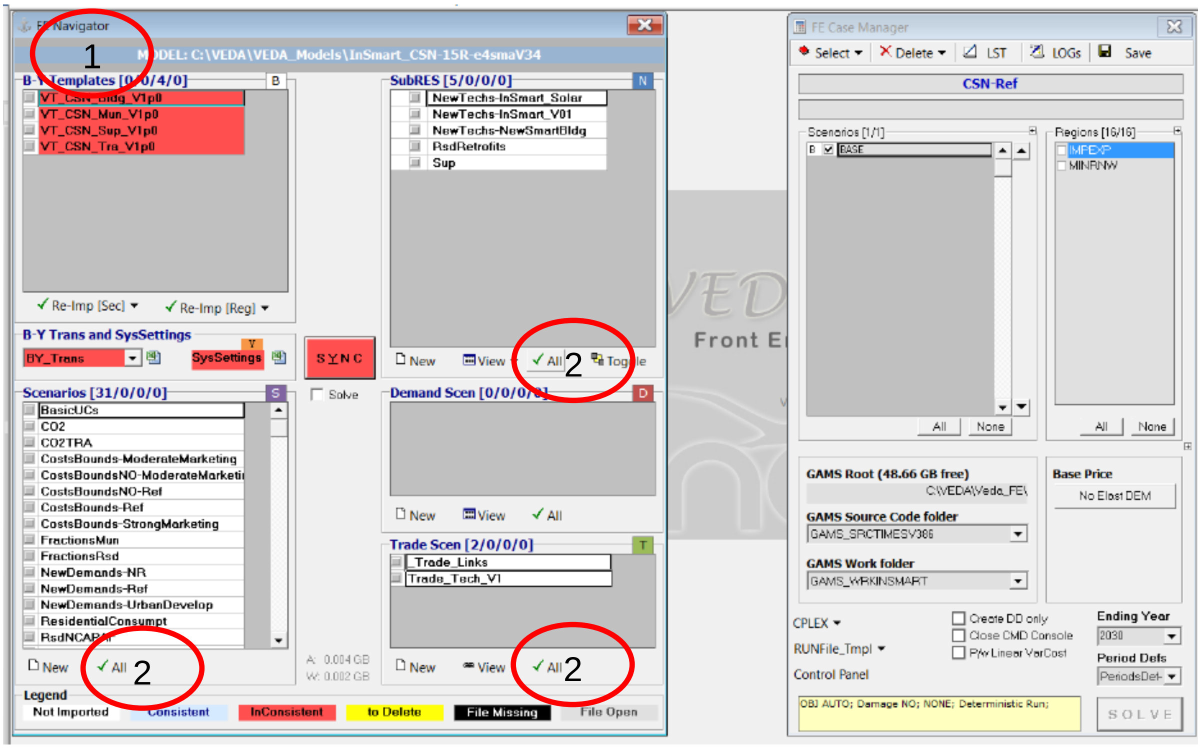
Appendix I: How to run the energy city model of Cesena

This appendix briefly describes the process that should be followed in order to run the ESM of Cesena. More details about the operation of the VEDA-FE and VEDA-BE can be found in the document "Getting Started with TIMES-VEDA" v. 2.7, May 2009[10].

1) Start VEDA-FE, from VEDA-FE Navigator call the model (double click on the horizontal bar) to be imported. You will get a window similar to the one shown below.

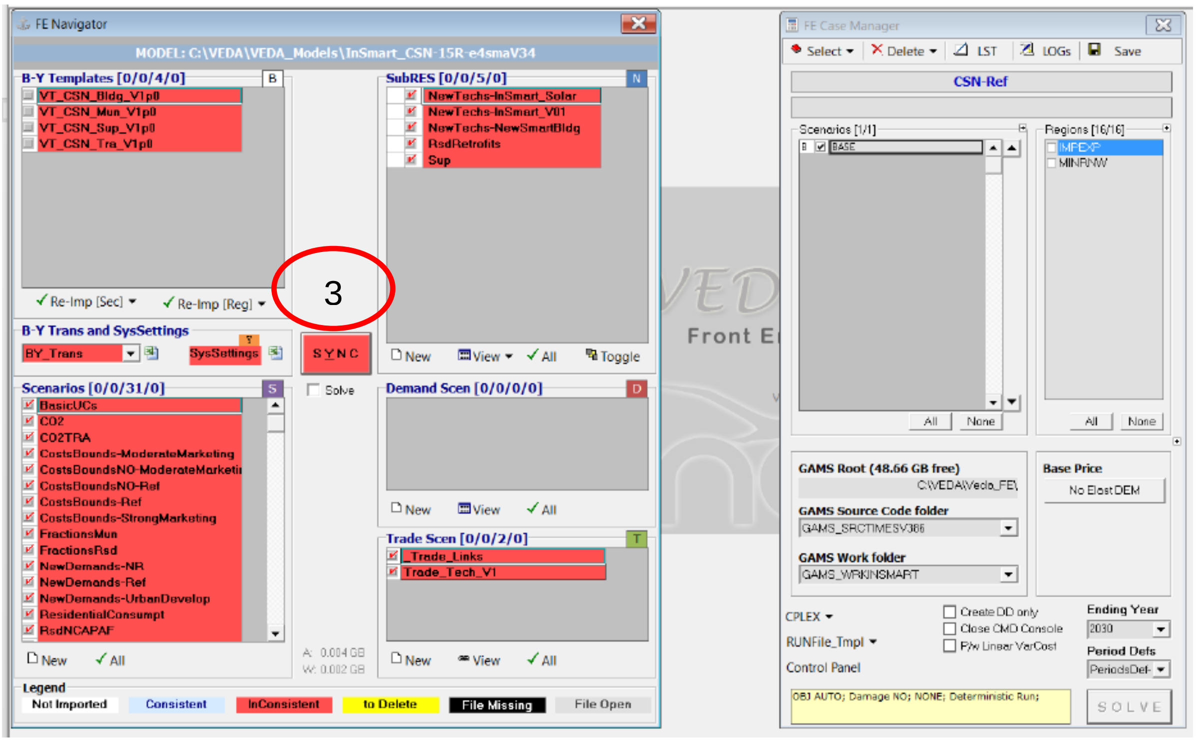


- *B-Y Templates (upper-left corner of the FE Navigator)* comprise the base year calibration templates with the data depicting the energy balance and current system composition.
    - organized by sector;
    - may contain some default time-dependent constraints (e.g. demolition rates for buildings).
- *System Files (center-left in the FE Navigator)* corresponding to the base year (B-Y_Trans) and overall (SysSettings) system settings (e.g. adjustment factors, definition of time periods, time horizon, interpolation/extrapolation rules).
- *SubRes files (upper-right corner of the FE Navigator)* contain data specification and transformation for new technologies to be added to the B-Y system (e.g. new demand devices, alternative decentralized generation technologies, etc.).

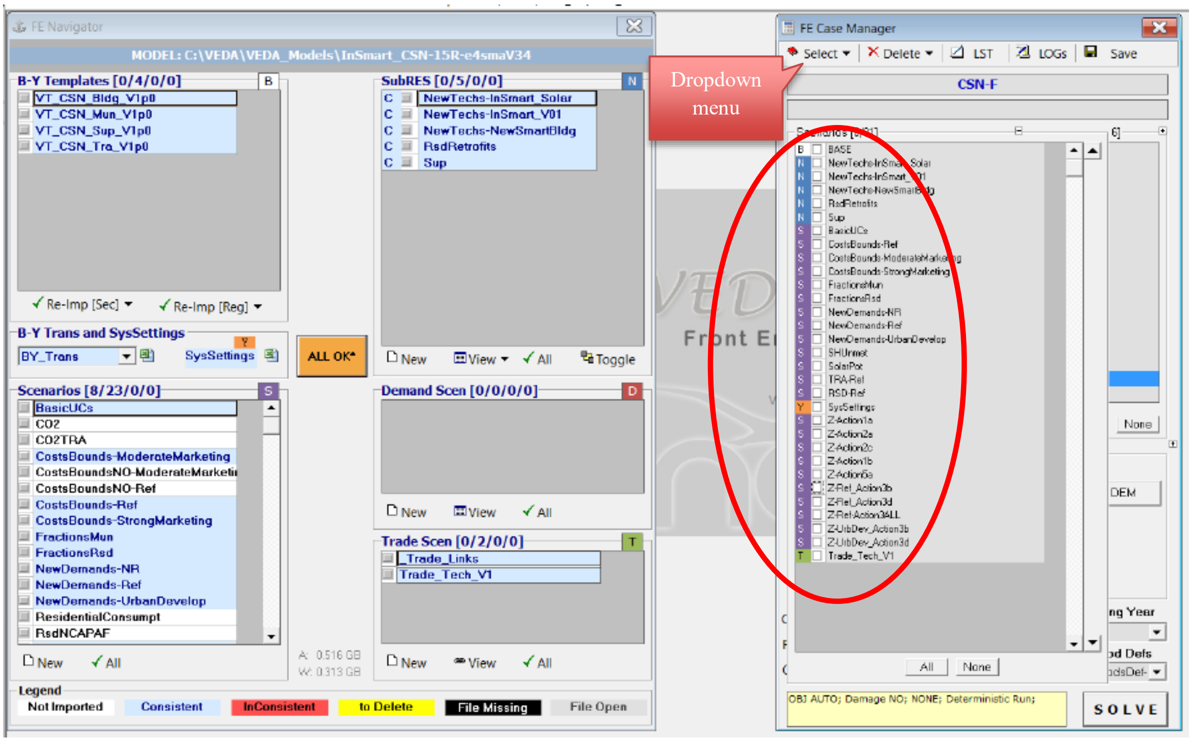
[10] http://www.iea-etsap.org/web/docs/Files_Times_Tutorial.zip

- *Scenarios (lower-left corner of the FE Navigator)* consisting of the various modifications to the underlying energy system for the purpose of changing input data or introducing policy and other constraints on the system.

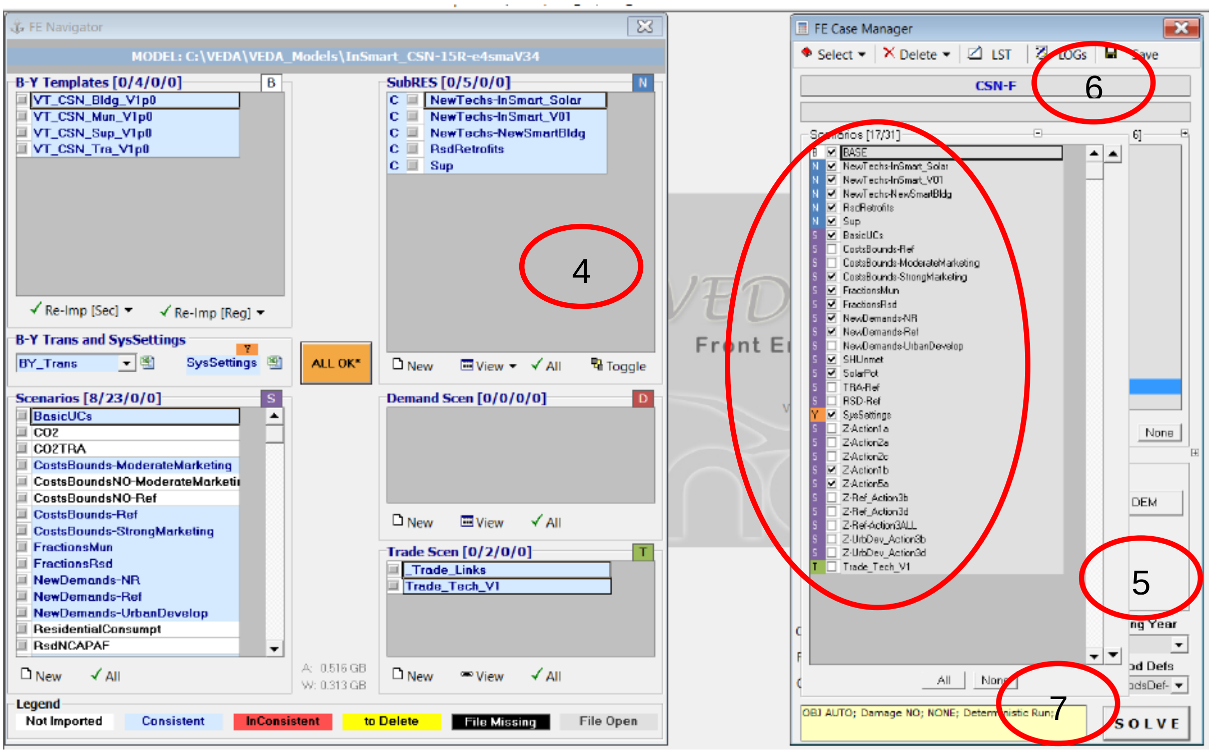
2) Select all (click on "All") the other files, or at least the subset of files required for the run. Once the selected files are viewed as "inconsistent" (as in the figure below), then synchronize the files.



3) Click on "SYNC" to import the content of the input files (.xls) in a VEDA DataBase, and to make the files "consistent" (light blue, see figure below). At the end of this stage, all the imported files (scenario files and SubRes files) will be listed under the FE Case Manager (right view of the screen).



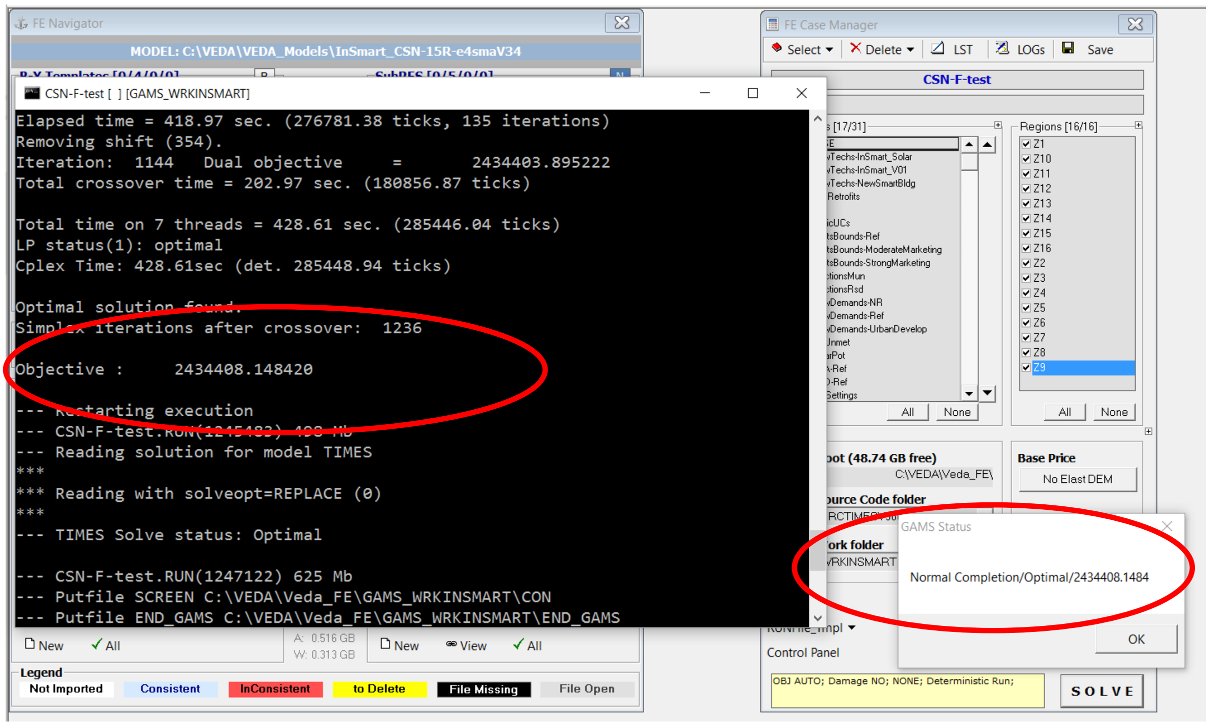
4) Make sure to select a consistent set of files, and to sort them in the appropriate order, before running the model (see the dropdown menu of the case manager to select predefined combinations of scenarios).



5) Select the Ending Year according to the type of test to be launched (by default the end of time horizon).

6) Type a name for the scenario under investigation (you will get the results in a DB with the same name!). *Hint*: to compare different scenarios, make sure to change the name of the alternative cases in order to save different sets of results.

7) Click to “SOLVE” and wait for the solution.
Objective function will be displayed together with some additional information (statistics and comments) about the solution.



<u>Overview of the key settings/assumptions of the ESM of Cesena</u>

Space granularity: Zone/District level (15)

Time granularity: 24 intervals within the year, End of Horizon: flexible, until 2030-(2035)

Base Year of the analysis: 2013

Level of detail of the building stock: 17 building typologies in the base year

Demands: constant number of total dwellings over the time horizon (driving energy service demands); transport demands (by transport mode and scenario dependent) inherited by the transport specific analysis.

Centralised supply: (exogenous) controlled by quantities/prices. Not explicitly modelled.

Decentralised supply: (endogenous) controlled by solar potential and costs of solar technologies.

Retrofit measures: mainly driven by scenario hypotheses (“what-if” analysis). But such a model component can be turned into a pure cost-effectiveness based mode.

Non-Residential: simplified representation (partially endogenous).