Coordination and support action (Coordinating Action)

FP7-ENERGY-SMARTCITIES-2012

INSMART

Integrative Smart City Planning

Report on optimum sustainability pathways – Cesena

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Report on optimum sustainability pathways – Cesena

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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).

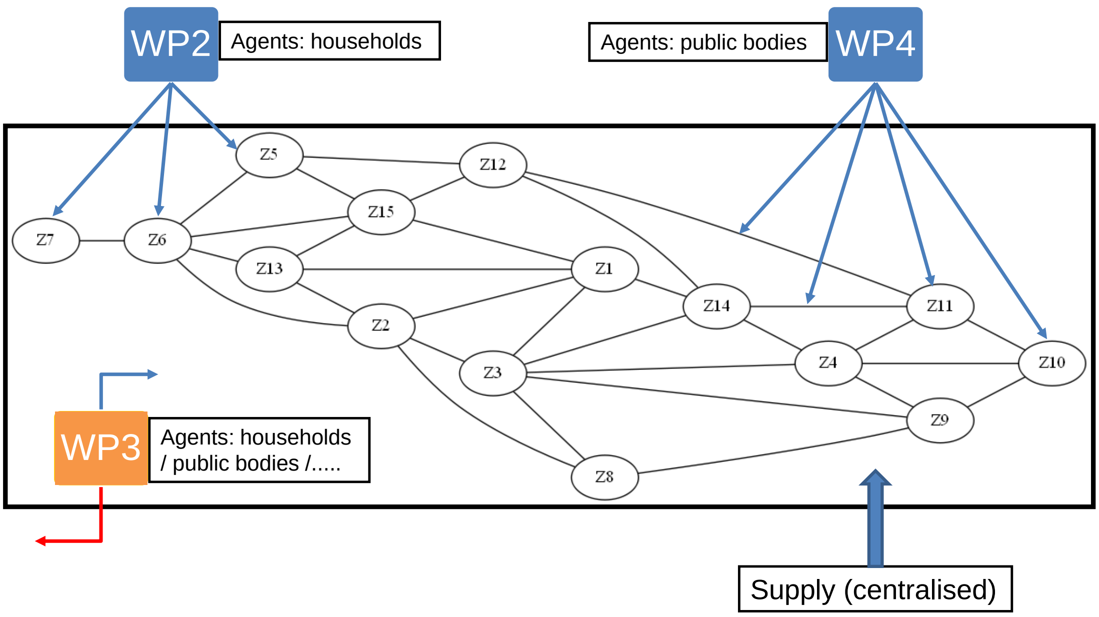


Fig. 1. Topology of the ESM for Cesena

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.

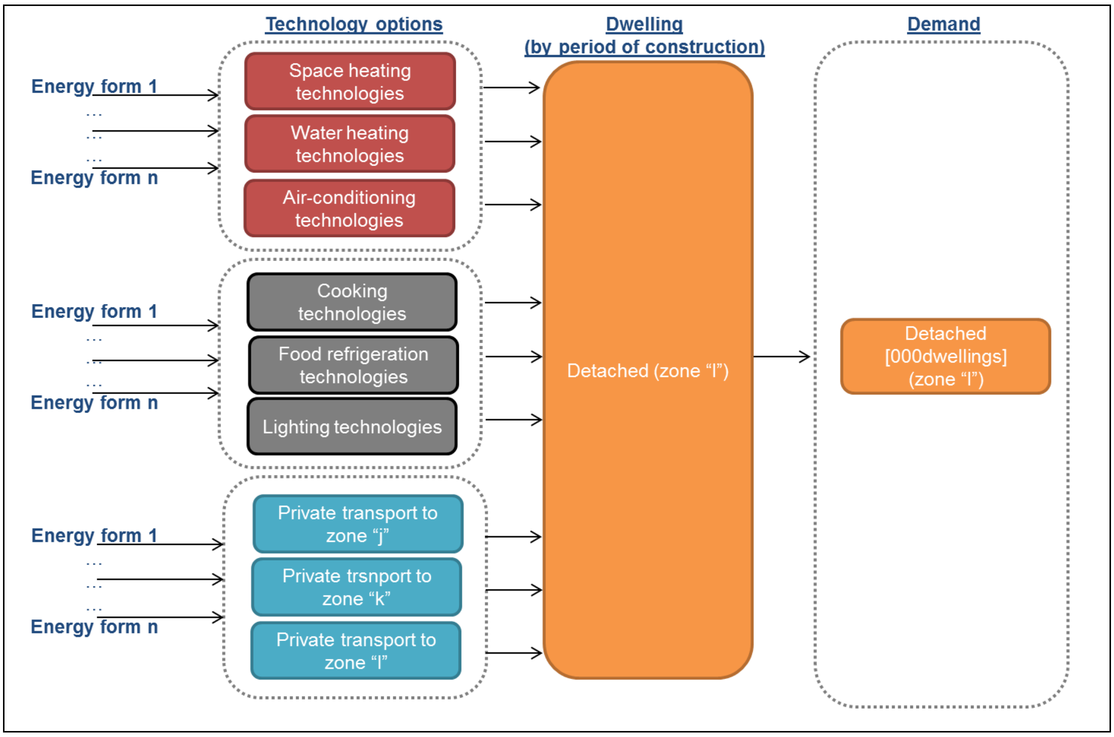


Fig. 2. End-uses demanded by household (e.g. detached)

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.

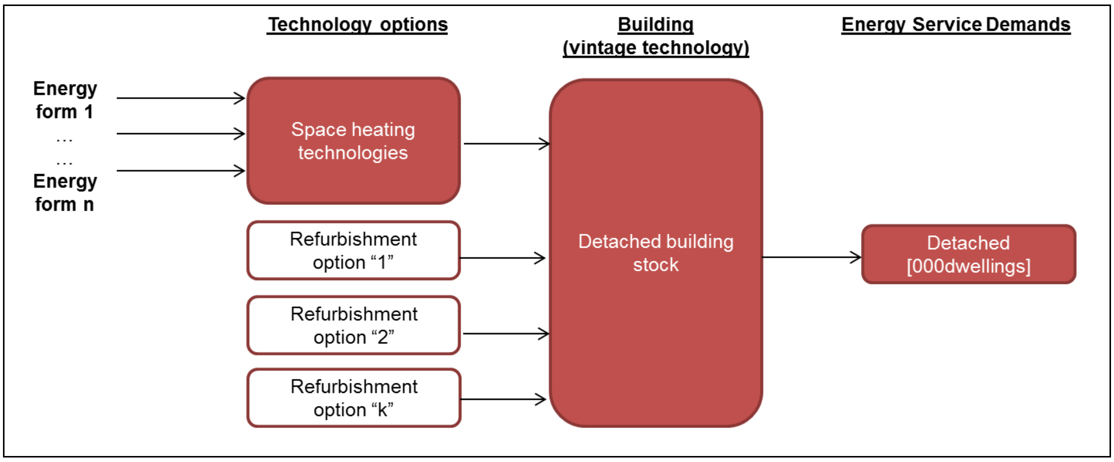


Fig. 3. Space heating technologies and refurbishment options by household (e.g. detached)

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.

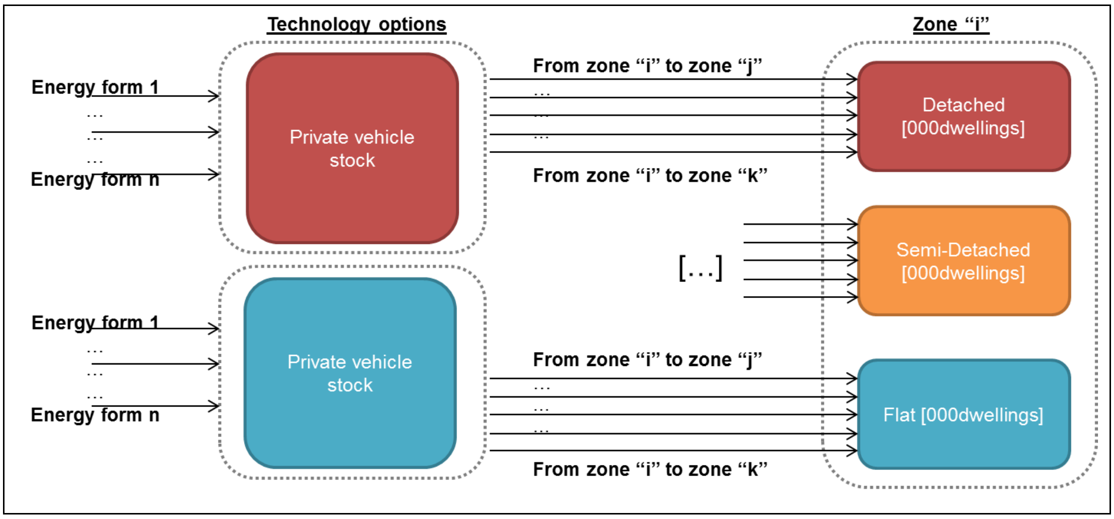


Fig. 4. Private mobility from zone “i” as demands of the households in zone “i”

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.

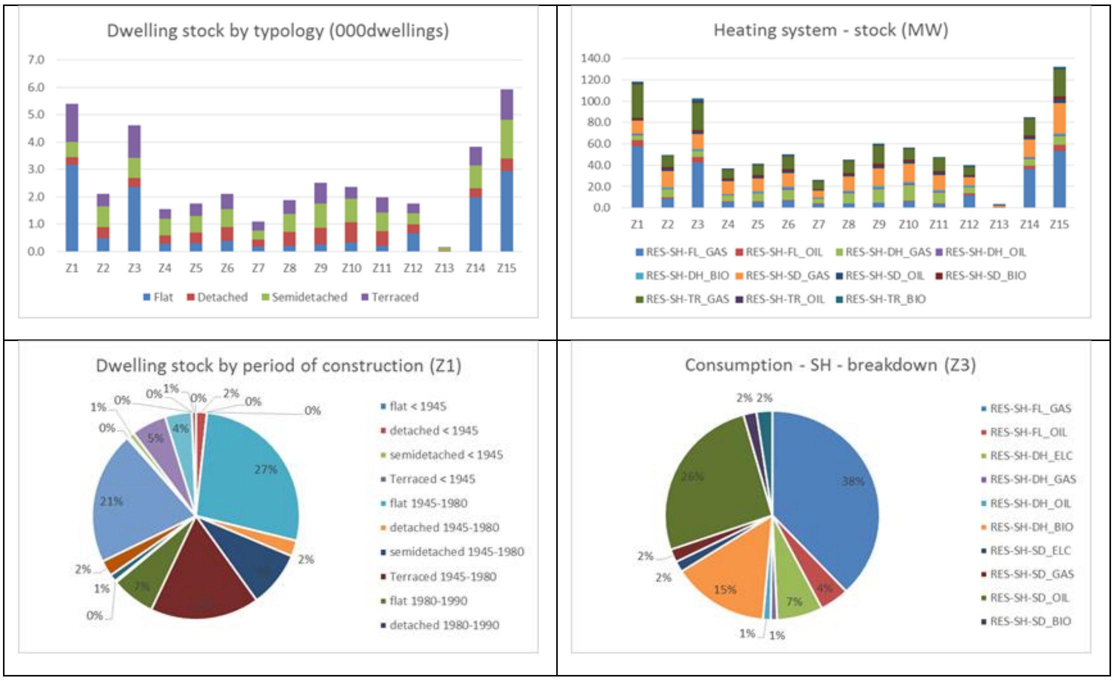
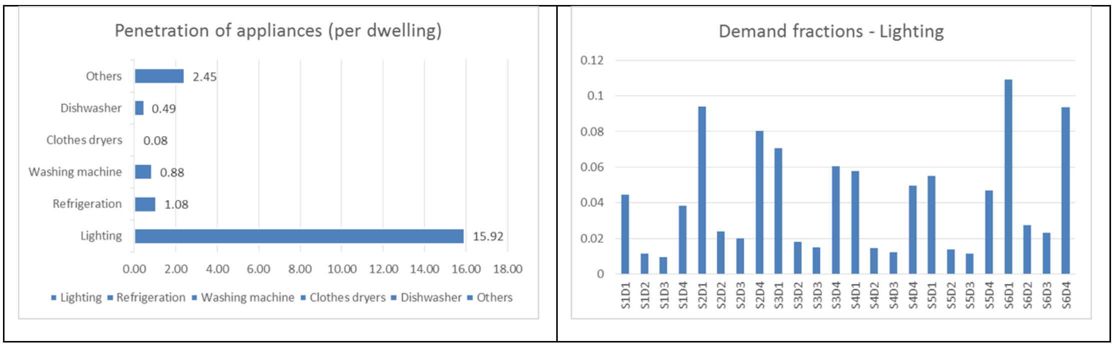


Fig. 6. Dwelling stock by typology and zone (top). Dwelling stock by period of construction (Z1) and share of heating system by fuel of Cesena (Z3)

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).



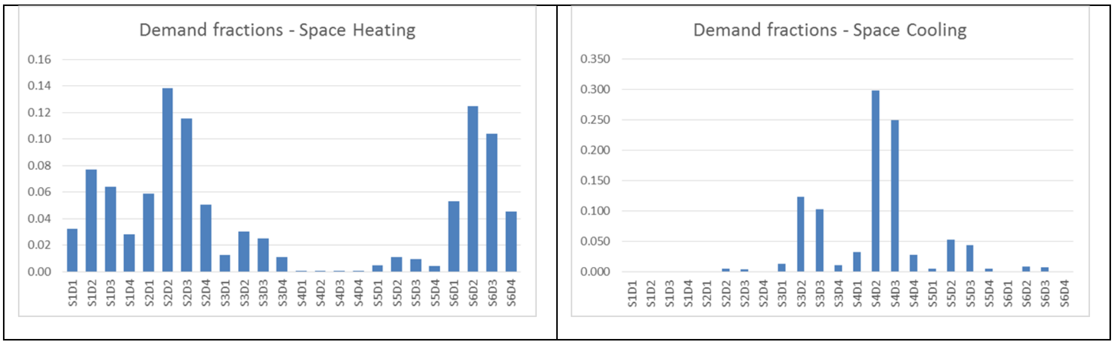


Fig. 7. Pure electrical services of the households: penetration and shapes

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.

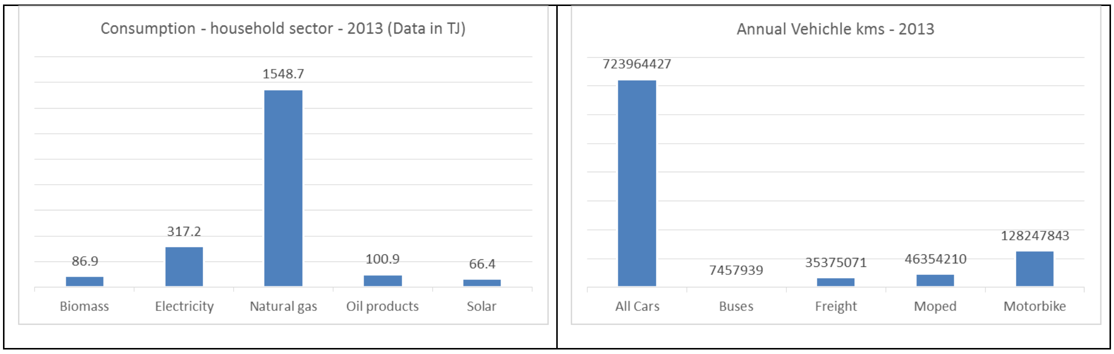


Fig. 8. Base year consumption in residential sector and transport demand by vehicle

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

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[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).

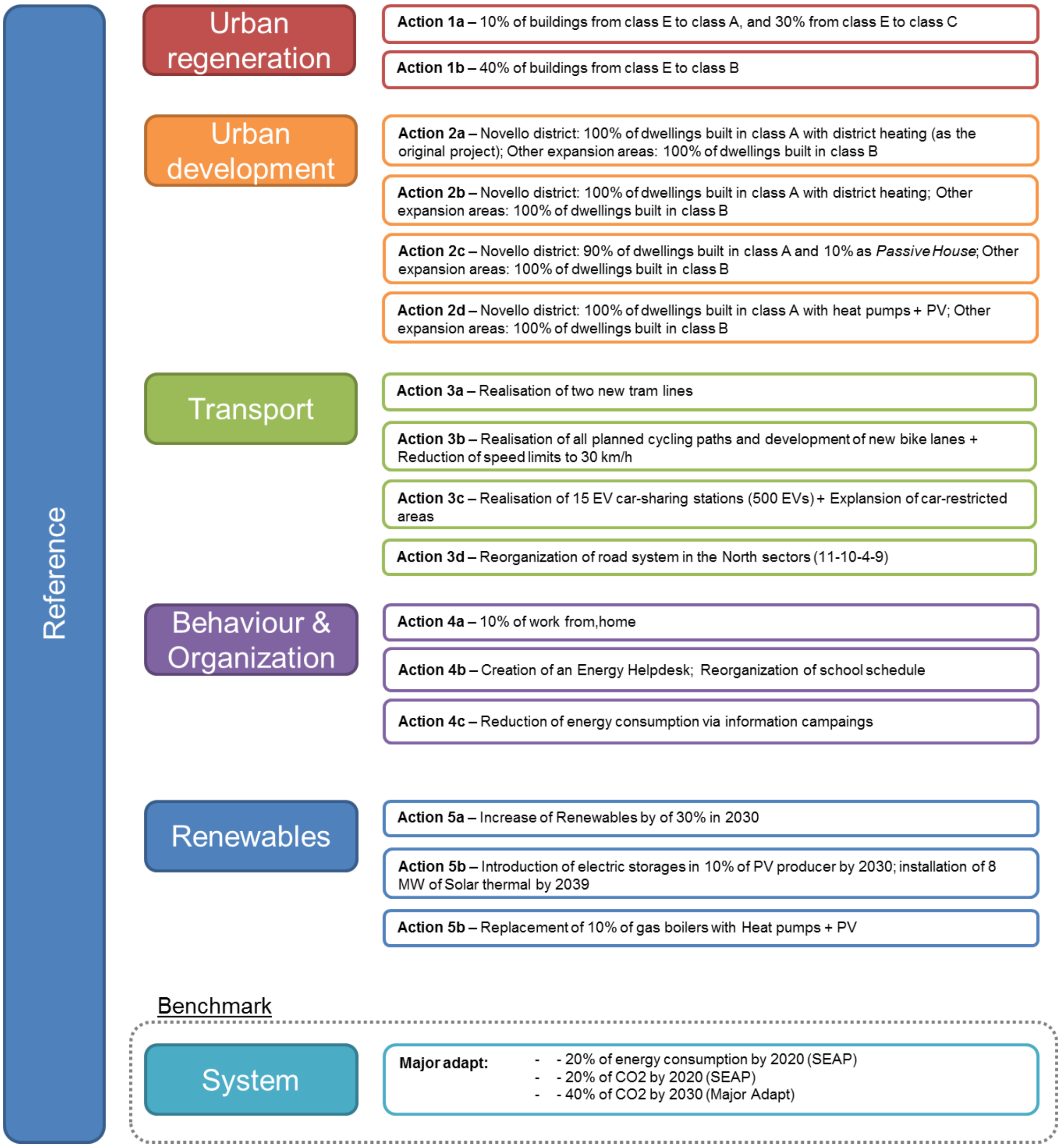

Fig. 13. Actions and measures by area

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.

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[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.

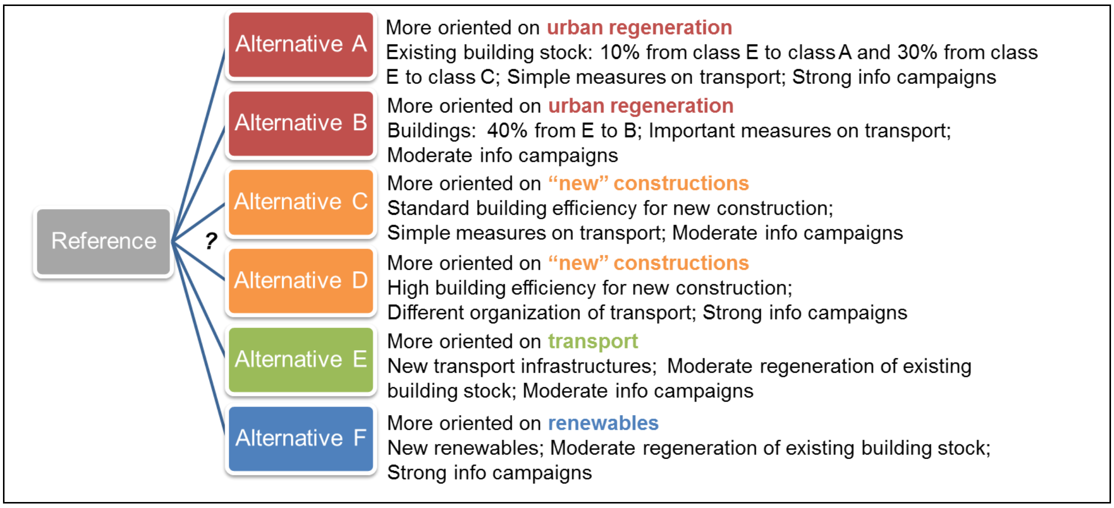

Fig. 14. Composition of the alternatives

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.

[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).

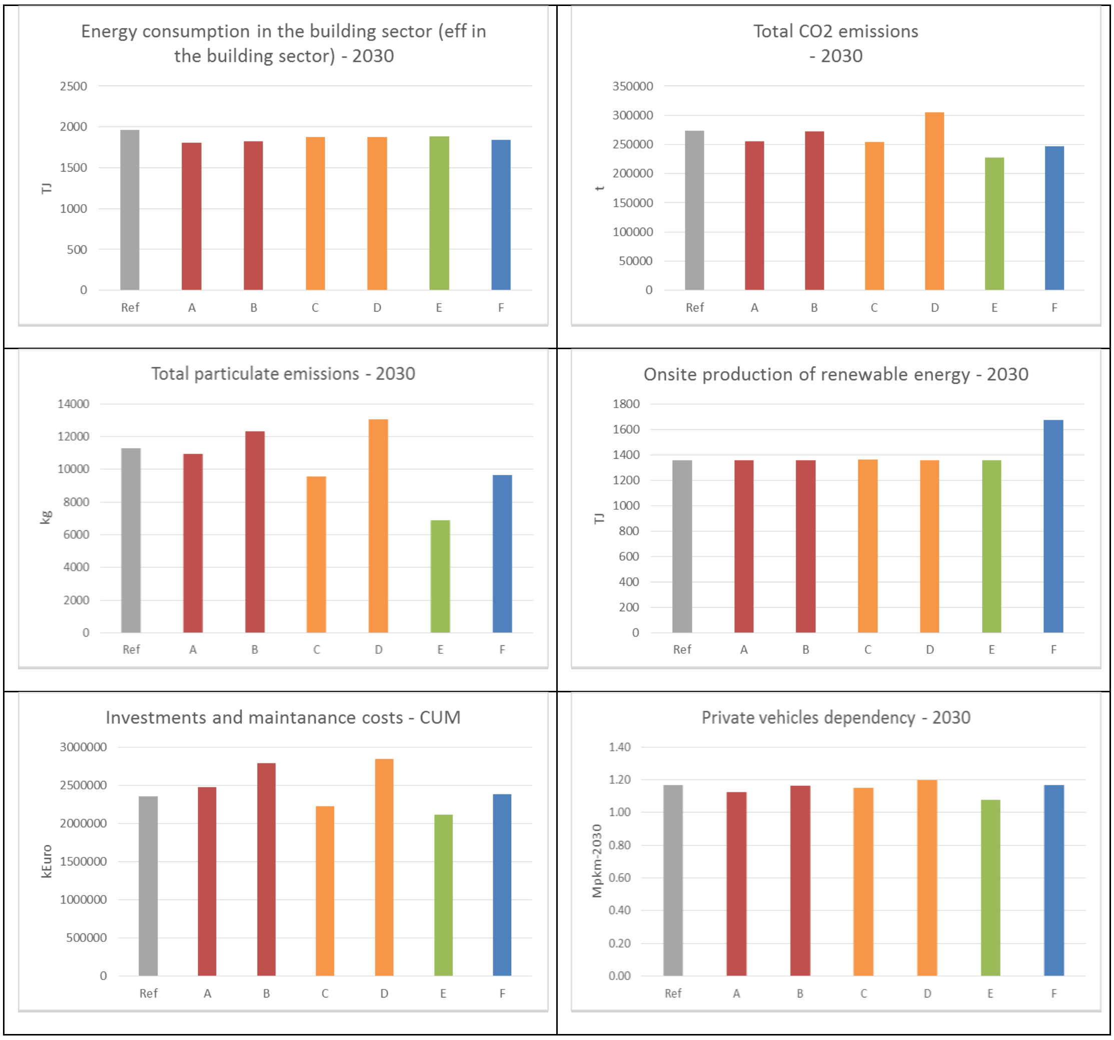

Fig. 15. Results: static indicators from MCDA

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.

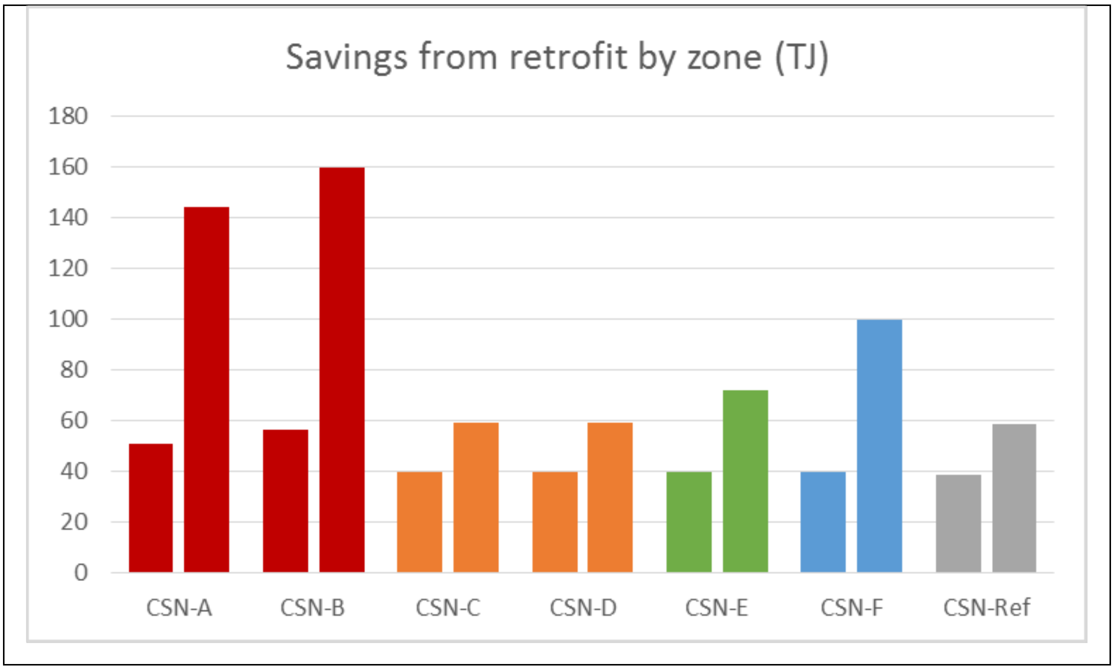

Fig. 17. Results: savings from retrofits in 2020/2030

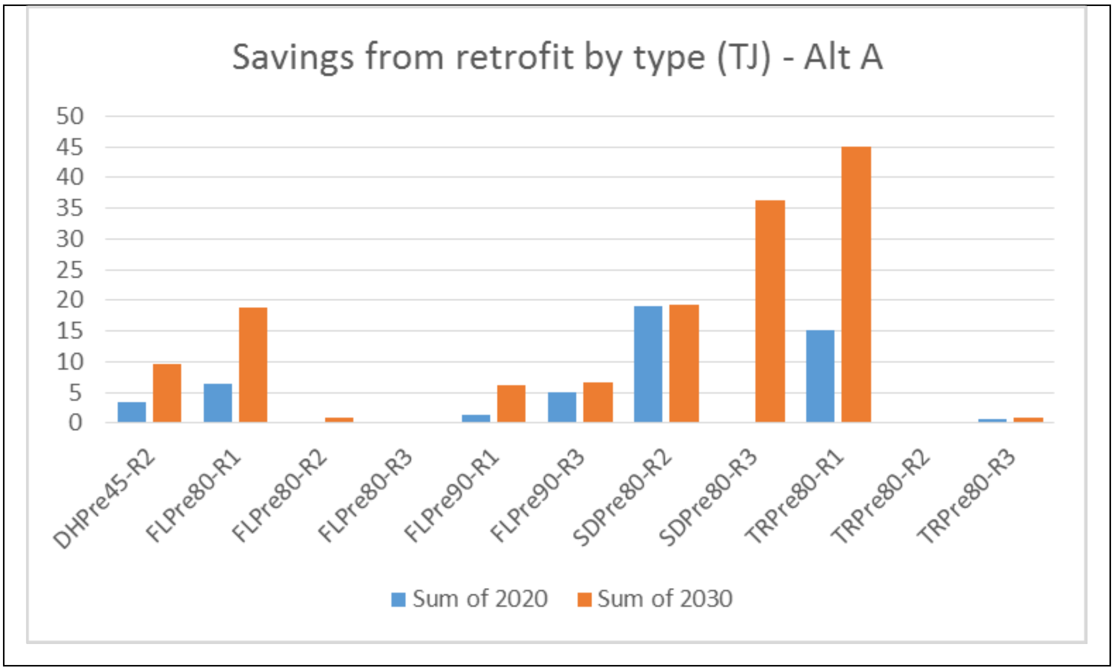

Fig. 18. Results: savings by retrofit type in 2020/2030 - Alternative A

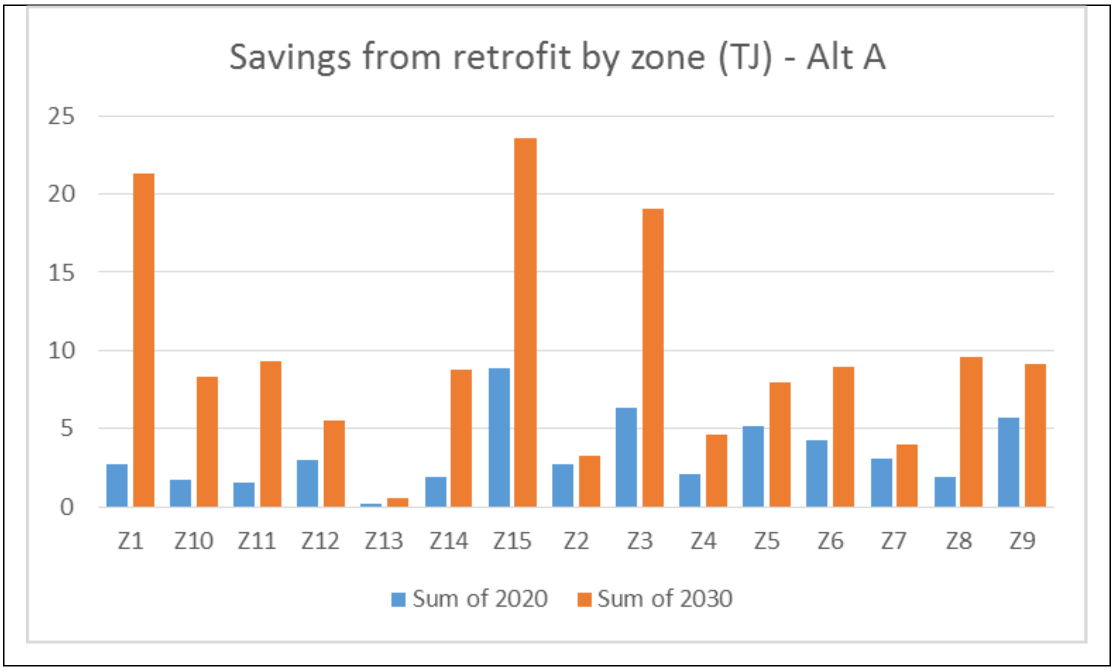

Fig. 19. Results: savings from retrofit by zone in 2020/2030 - Alternative A

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

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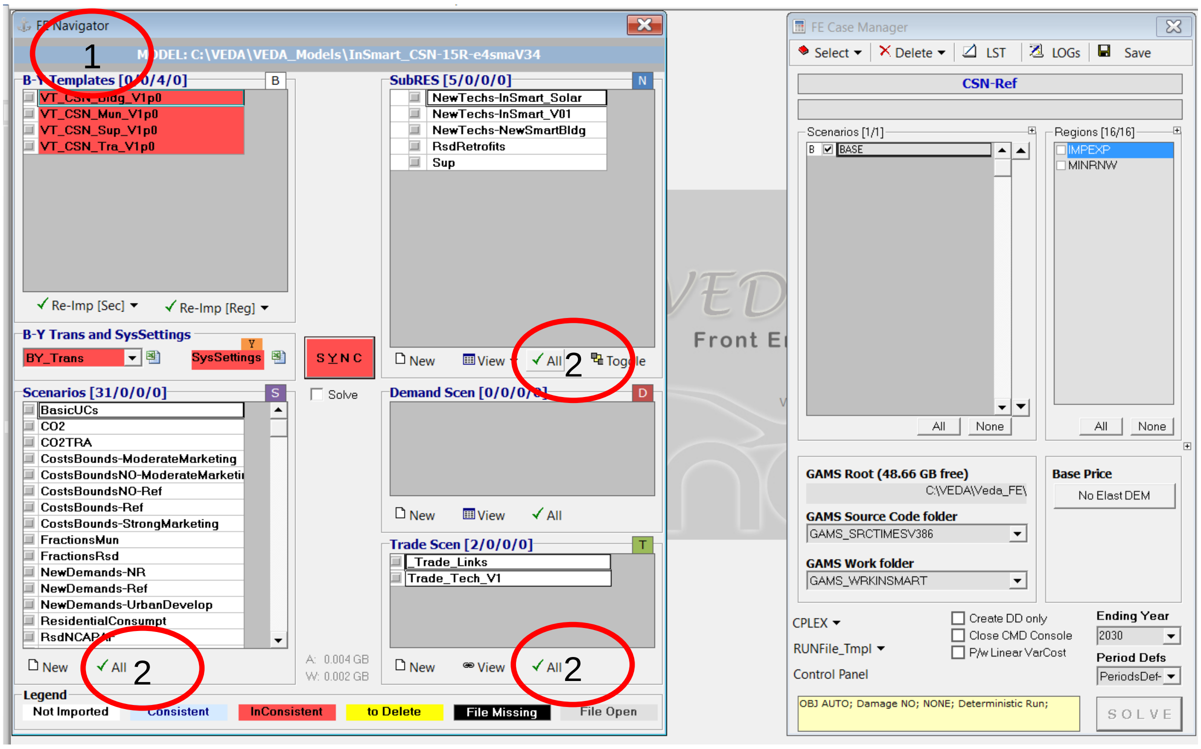
Acknowledgements

For brevity the authors list of this manuscript contains only the people involved directly in the development of this manuscript. However the authors acknowledge the Municipalities of Cesena and, in specific, all the people directly and indirectly involved in the project, as they all contributed to the development of this work.

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.

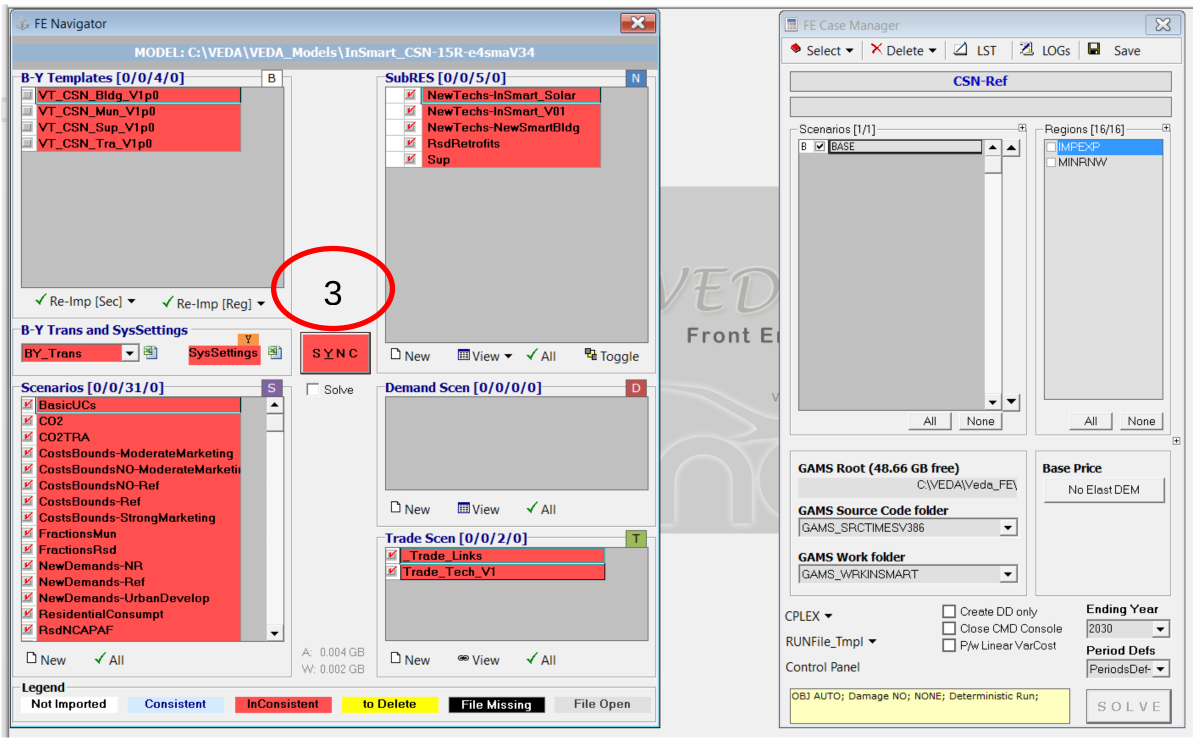


- *B-Y Templates (upper-left corner of the FE Navigator)* comprise the base year calibration templates with the data depicting the energy balance and current system composition.
    - organized by sector;
    - may contain some default time-dependent constraints (e.g. demolition rates for buildings).
- *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.).

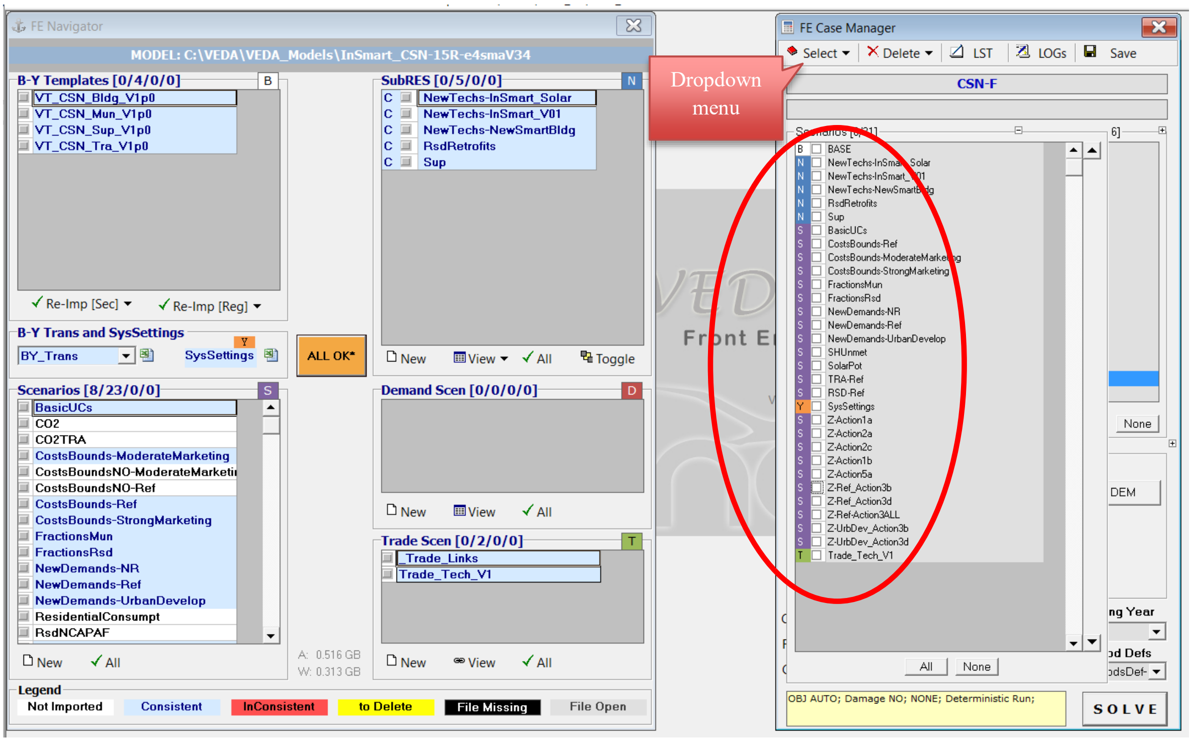
[10] http://www.iea-etsap.org/web/docs/Files_Times_Tutorial.zip

- *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.

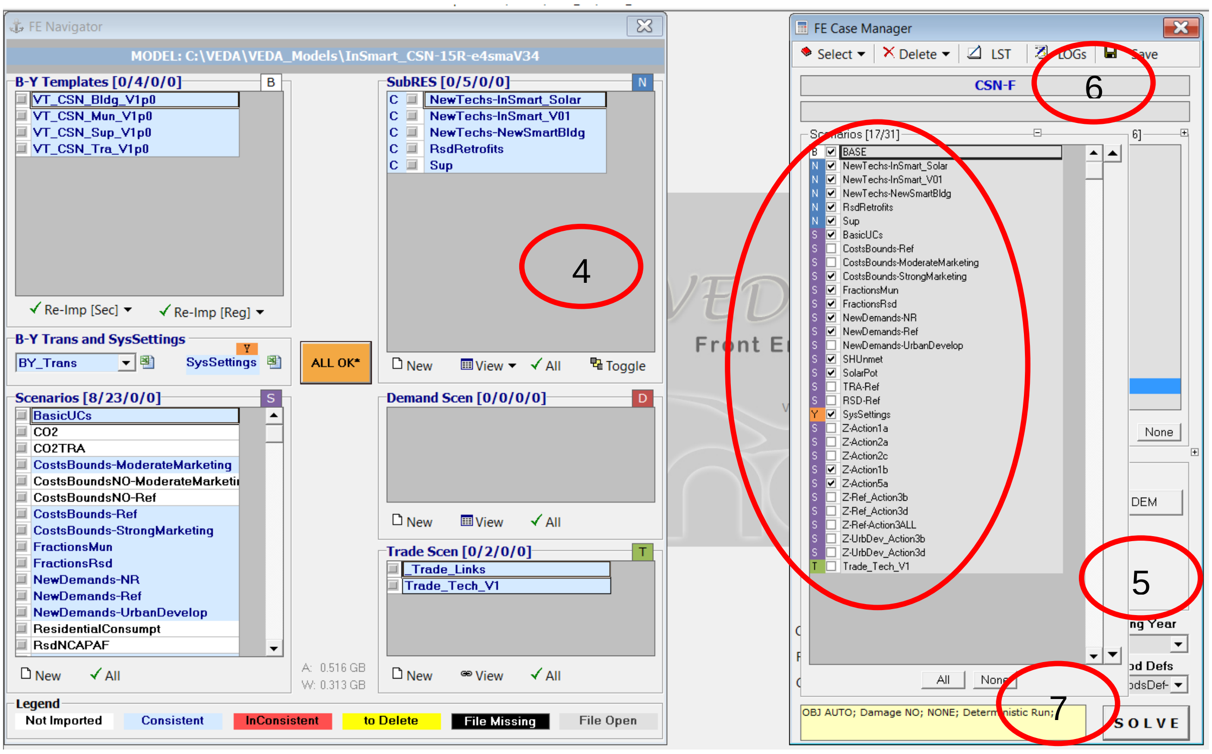
2) Select all (click on "All") the other files, or at least the subset of files required for the run. Once the selected files are viewed as "inconsistent" (as in the figure below), then synchronize the files.



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).



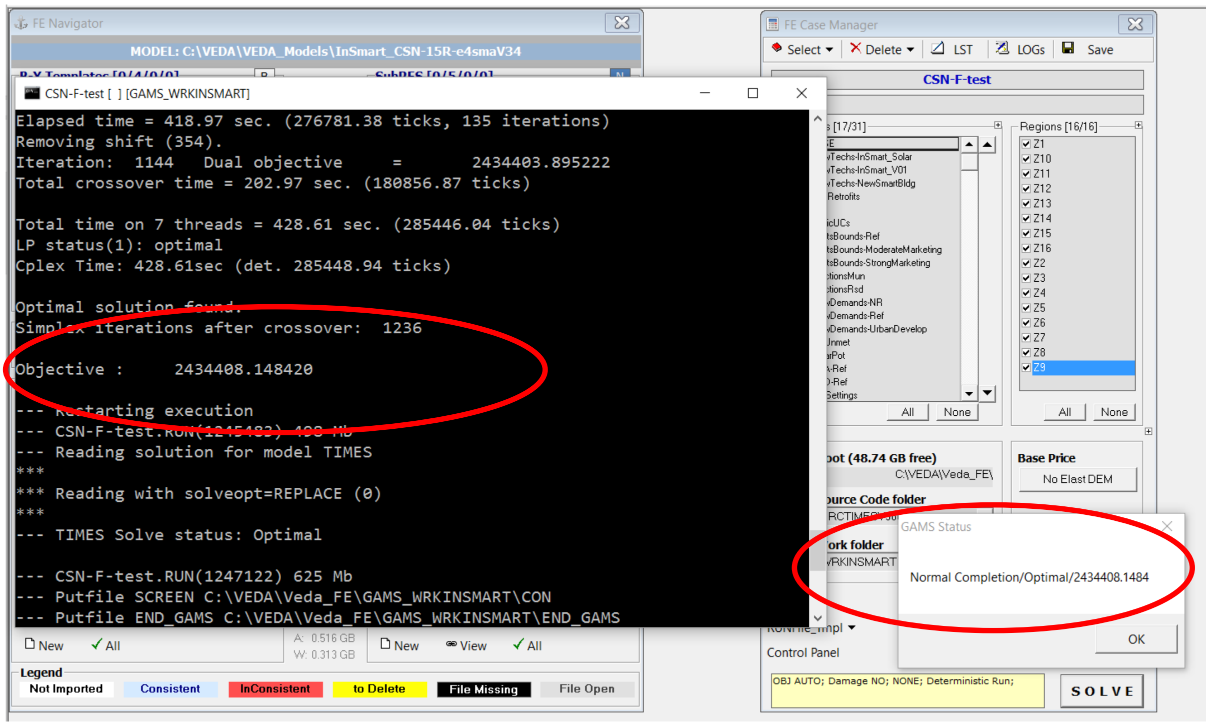
4) Make sure to select a consistent set of files, and to sort them in the appropriate order, before running the model (see the dropdown menu of the case manager to select predefined combinations of scenarios).



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).