The Heat Roadmap Europe methodology of combining 4 modelling tools

Deliverable 5.1: Methodology report describing the combination of the JRC-EU-TIMES and EnergyPLAN tools

Project Number:	695989
Project acronym:	HRE
Project title:	Heat Roadmap Europe (HRE): Building the knowledge, skills, and capacity required to enable new policies and encourage new investments in the heating and cooling sector
Contract type:	H2020-EE-2015-3-MarketUptake

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 695989.

Deliverable number:	**D5.1**
Deliverable title:	**Methodology report describing the combination of the JRC-EU-TIMES and EnergyPLAN tools**
Work package:	WP5
Due date of deliverable:	28 February 2017
Actual submission date:	M18 - 28/08/2017
Start date of project:	01/03/2016
Duration:	36 months
Author(s)/editor(s):	David Connolly (AAU) Susana Paardekooper (AAU) Kenneth Hansen (AAU) Jacob Zinck Thellufsen(AAU) Wouter Nijs (EC) Pablo Ruiz (EC) Neven Duić (UNIZAG FSB) Goran Krajačić (UNIZAG FSB) Nedeljko Štefanić (UNIZAG FSB) Zoran Lulić (UNIZAG FSB) Tomislav Novosel (UNIZAG FSB)
Reviewer(s):	Brian Vad Mathiesen (AAU)
Project coordinator:	Brian Vad Mathiesen (AAU)

Dissemination Level of this Deliverable:	CO
Public	*PU*
Confidential, only for members of the consortium (including the Commission Services)	***C0***

Contact: Department of Development and Planning,
Aalborg University
A.C. Meyers Vænge 15,
2450, Copenhagen
Denmark

E-mail: info@heatroadmap.eu
Heat Roadmap Europe website: www.heatroadmap.eu

Deliverable No. D5.1: Confidential Report

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 695989. The sole responsibility for the content of this document lies with the authors. It does not necessarily reflect the opinion of the funding authorities. The funding authorities are not responsible for any use that may be made of the information contained therein.

Table of Contents

1. Introduction

In Europe, there is a clear long-term objective to decarbonise the energy system, but it is currently unclear how this will be achieved in the heating and cooling sector. The Heat Roadmap Europe (HRE) project will enable new policies and prepare the ground for new investments by creating more certainty in relation to the changes that are required.

The overall objective in the HRE project is to provide new capacity and skills for lead-users in the heating and cooling sector, including policymakers, industry, and researchers at local, national, and EU level, by developing the data, tools, methodologies, and results necessary to quantify the impact of implementing more energy efficiency measures on both the demand and supply side of the sector.

This WP is aimed at developing system-wide hourly energy projections focused on heating and cooling technologies for the largest 14 MSs in Europe, by heating demand. To do this, the projections for the heating and cooling sector developed in WP4 in the FORECAST model must be combined with the JRC-EU-TIMES model to obtain projections for the whole energy system. Then, the yearly outputs from the JRC-EU-TIMES model will be transformed into suitable inputs for the EnergyPLAN tool. EnergyPLAN will then combine the hourly dynamics of energy supply and demand (provided by UNIZAG FSB) and the annual outputs from JRC-EU-TIMES, producing a detailed snapshot of the operation of the energy system within each year.

The purpose of this deliverable is to outline the methodology used to align and link these three models in a way that can produce congruent and meaningful results, and can take advantage of the different perspectives and characteristics of the models.

Energy models are very powerful tools to understand the impact of changing the energy system before the changes are carried out. The energy system can be modelled from various perspectives and over a wide variety of timeframes, so many different energy models exist which reflect this variation. For example, 37 different energy models are presented in Table 1 along with some key parameters, which illustrate their various perspectives, including:

- Geographical Area: some models focus on the global energy system, others cover the national energy system, and some are designed for individual projects, such as a combined heat & power (CHP) plant.
- Scenario Timeframe: is the time-horizon over which the energy model completes its analysis. Some energy models look at one year, while others will model the transition over multiple decades.
- Time-Step: represents the time-resolution for the calculations in the energy model. In other words, some tools model the energy system every hour, while others use a yearly time-step. Typically, an energy model with a timeframe of

one year will use a time-step of one hour or less, while an energy model with a timeframe of decades will use a time-step of one year or more.

The variation across these different tools reflects the different perspectives in the energy system and as a result, energy models can have a different perspective while investigating the same problem, which is the case in the Heat Roadmap Europe 4 (HRE4) project.

HRE4 contains four different energy models, each with a specific purpose and/or perspective. This document presents the four energy models that are used in HRE4 and afterwards, describes why and how they are connected together in the project.

Table 1: Type of analysis typically conducted by 37 Different Energy models *[1]*.

Tool	Geographical Area	Scenario Timeframe	Time-Step	Specific Focus
1. National Energy-System Tools				
1.1. Time-Step Simulation Tools				
Mesap PlaNet	National/State/Regional	No Limit	Any	-
TRNSYS16	Local/Community	Multiple Years	Seconds	-
HOMER	Local/Community	1 Year*	Minutes	-
SimREN	National/State/Regional	No Limit	Minutes	-
EnergyPLAN	National/State/Regional	1 Year*	Hourly	-
SIVAEL	National/State/Regional	1 Year*	Hourly	-
STREAM	National/State/Regional	1 Year*	Hourly	-
WILMAR Planning Tool	International	1 Year*	Hourly	-
RAMSES	International	30 Years	Hourly	-
BALMOREL	International	Max 50 Years	Hourly	-
GTMax	National/State/Regional	No Limit	Hourly	-
H2RES	Island	No Limit	Hourly	-
MARKAL/TIMES	National/State/Regional	Max 50 Years	Hourly, Daily, Monthly using user-defined time slices	-
1.2. Sample periods within a year				
PERSEUS	International	Max 50 Years	Based on Typical Days with 36 to 72 slots for one year	-
UniSyD3.0	National/State/Regional	Max 50 Years	Bi-weekly	-
RETScreen	User Defined	Max 50 Years	Monthly	-
1.3. Scenario Tools				
E4cast	National/State/Regional	Max 50 Years	Yearly	-
EMINENT	National/State/Regional	1 Year*	None / Yearly	-
IKARUS	National/State/Regional	Max 50 Years	Yearly	-
PRIMES	National/State/Regional	Max 50 Years	Years	-
INFORSE	National/State/Regional	50+ Years	Yearly	-
ENPEP-BALANCE	National/State/Regional	75 Years	Yearly	-
LEAP	National/State/Regional	No Limit	Yearly	-

MESSAGE	Global	50+ Years	5 Years	-
MiniCAM	Global and Regional	50+ Years	15 Years	-
2. Tools with a Specific Focus				
2.1. Time-Step Simulation Tools				
AEOLIUS	National/State/Regional	1 Year*	Minutes	Effects of fluctuating renewable energy on conventional generation
HYDROGEMS	Single-Project Investigation	1 Year*	Minutes	Renewable energy and hydrogen stand-alone systems
energyPRO	Single-Project Investigation	Max 40 Years	Minutes	Single power-plant analysis
BCHP Screening Tool	Single-Project Investigation	1 Year*	Hourly	Combined heat and power
ORCED	National/State/Regional	1 Year*	Hourly	Dispatch of electricity
EMCAS	National/State/Regional	No Limit	Hourly	Electricity markets
ProdRisk	National/State/Regional	Multiple Years	Hourly	Hydro power
COMPOSE	Single-Project Investigation	No Limit	Hourly	CHP with electric boilers or heat pumps
2.2. Sample periods within a year				
EMPS	International	25 Years	Weekly (With a load duration curve representing fluctuations within the week)	Hydro power
WASP	National/State/Regional	Max 50 Years	12 Load Duration Curves for a year	Power plant expansion on the electric grid
2.3. Scenario Tools				
Inv*ert*	National/State/Regional	Max 50 Years	Yearly	Heat sector
NEMS	National/State/Regional	Max 50 Years	Yearly	US Energy Markets

*Tools can only simulate one year at a time, but these can be combined to create a scenario of multiple years

2. Models

The four energy models used in HRE4 are FORECAST, Peta4, JRC-EU-TIMES, and EnergyPLAN. This chapter begins with a general description for each of these models and then describes why and how these models are combined. The interconnections and applications in HRE4 are then described in the further sections.

2.1. FORECAST

FORECAST is developed by Fraunhofer ISI, TEP Energy and IREES. Its purpose in this project is to model the buildings and industry sectors, and the effect and cost of energy efficiency measures in buildings. The outputs are detailed heating and cooling demand profiles, for the residential, industry and service sector for the year 2015. This includes a detailed breakdown by sectors and processes, end uses, temperature levels, and building classes. FORECAST aims to develop scenarios for the long-term development of energy demand by considering among others policy instruments and macro-economic framework conditions. FORECAST works as a simulation model based on consecutive and cumulative decision making, meaning it can be used to calculate a distinct pathway between now and 2050 as to when certain technologies are expected to be implemented and in what quantities.

2.2. Pan-European Thermal Atlas (Peta)

Peta, the Pan-European Thermal Atlas is developed by the Universities of Flensburg, Halmstad University and Aalborg University. Peta aims to represent the location and scale of heat demand, cooling demand, excess heat activities, and thermal renewable sources. Peta is a spatially explicit, quantitative atlas of the thermal demand and supply sector. This includes heating and cooling demands, end-use efficiency measures, technical and economic cost-supply relations of district heating and district cooling networks, and a localisation of the heat available from thermal power plants, industry, waste incineration, geothermal, and solar thermal plants. Heat synergy regions are modelled, where demand and supply can efficiently be met. Finally, quantitative information on potentials, costs and geographical constraints are forwarded to the energy systems analysis. The latest version of Peta (Peta4) is being developed specifically in HRE.

2.3. JRC-EU-TIMES

The JRC-EU-TIMES model aims to analyse the role of energy technologies and their innovation for meeting Europe's energy and climate change related policy targets. A typical question that can be addressed by JRC-EU-TIMES is what technology improvements are needed to make technologies competitive under various low carbon energy scenarios. Such technology policy analysis complements the climate and energy policy analysis that is at the core of a series of published impact assessments of the European Commission. The model's algorithm solves for the optimum investment portfolio of technologies along the whole supply chains for five sectors, while fulfilling the energy services demand. JRC-EU-TIMES supports studies that require (1) modelling at an energy system level, (2) a high technology detail and (3) intertemporal results on the evolution of the energy system.

2.4. EnergyPLAN

EnergyPLAN has been developed and expanded on a continuous basis since 1999 at Aalborg University, Denmark [2]. EnergyPLAN is a deterministic model that simulates the operation of an energy system using hourly time-steps over one year. The main purpose of the tool is to assist the design of national or regional energy planning strategies by simulating the entire energy system: thermal, renewable, storage/conversion, and transport technologies and costs (with the option of additional costs) can be modelled by EnergyPLAN. One of EnergyPLAN's core strengths is its ability to simulate the entire energy system on an hourly basis, since it enables EnergyPLAN to identify essential synergies between the various sectors of the energy system. One of the main objectives in the model is to identify synergies between the various sectors of the energy system which can improve its efficiency and increase the integration of renewable energy, which has resulted in the development of the Smart Energy System concept [7], [8].

3. Purpose of Combining the Models

In this section, the overall purpose of combining the models is described from a technical and economic perspective. This section focuses on the overarching connections between the models, where a more detailed explanation about the specific links between the models is available in sections 3.4 and 3.5.

Firstly, the primary purpose of each energy model in HRE4 is presented in Figure 1, which reveals some important distinctions. FORECST and Peta mostly focus on the heating & cooling sectors, while JRC-EU-TIMES and EnergyPLAN consider the entire energy system. FORECAST and Peta4 have a more detailed breakdown of the heating and cooling sectors due to this specific focus on the sector, so both of these tools are providing inputs to the broader energy system analysis taking place in JRC-EU-TIMES and EnergyPLAN.

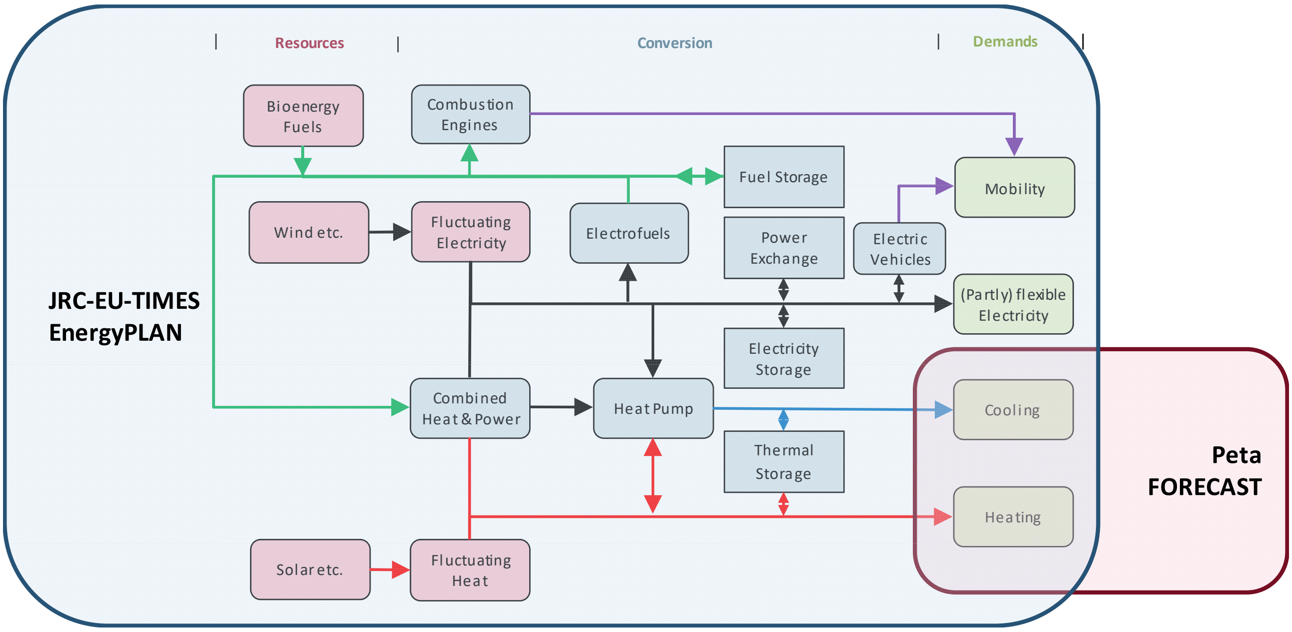


Figure 1: Primary focus of each energy model in HRE4. Peta and FORCAST contain more detail for the heating and cooling sectors while JRC-EU-TIMES and EnergyPLAN consider a broader energy system perspective.

Multiple tools are required in HRE4 to provide information based on a different perspective or using a specific approach. Some of the key distinguishing features for each of the four models are presented in Table 2, which are elaborated upon in the following sections.

Table 2: Economic perspectives, energy sectors, time horizons and resolutions for the three energy models

Model	FORECAST	Peta	JRC-EU-TIMES	EnergyPLAN
Scope: Sectors Considered*	Built Environment & Industry	Built Environment	All Sectors	All Sectors
Type of Model	Optimisation	Database & GIS	Optimisation	Simulation
Timeframe	Years/Decades	One Year	Years/Decades	One Year
Time-Step	Annual	Annual	12 time-slices and 24 periods in the power sector	Hourly
Economic Perspective	Private End-User	Societal	Mix of Societal & Private End-User	Societal

*The energy system sectors are defined here as the built environment, industry, power, transport and transformation.

3.1. FORECAST & Peta

The FORECAST model provides a detailed breakdown of the heating and cooling sector across both the built environment and industry. In HRE4, this is referred to as 'profiling' since FORECAST 'profiles' the heating and cooling sector by quantifying various features such as: the size of the demand (annually); type of demand (e.g. space heat, hot water, space cooling, temperature levels in industrial applications), energy mix, type of consumer (e.g. residential, commercial, or industrial), type of building (e.g. single-family and multi-family), and many others. Methodologies and results for this profiling can be found in D3.1, D3.3 and D3.4 of the HRE4 project.

Information like this is essential when planning and/or designing a future energy system since it defines the scale and potential for various alternatives. For example, the potential for individual solar thermal panels is often linked to the amount of hot water demand in the buildings, so to understand the potential for this technology in the future, it is important to know how much of the total heat demand is space heating or hot water. Similarly, in industry it is critical to understand the temperature levels that are required, in order to ensure that the right type of conversion technology is used.

However, one essential characteristic missing from the FORECAST tool is the location of the heating and cooling demand and supply. For this, Peta4 is used in HRE4. Location is very important in the heating and cooling sector, since the network solutions and options for decarbonising the sector are often linked to the location of the demand. For example, district heating and natural gas grids are only viable in densely populated urban areas, while biomass boilers are typically used in rural single-family homes. This location parameter is therefore essential during the development of low-carbon energy strategies, so the aggregated national values from FORECAST are connected to the location via Peta. In essence, FORECAST provides the scale and type of heating and cooling demand and supply while Peta4 identifies where this is located.

3.2. FORECAST & JRC-EU-TIMES

FORECAST is also connected to the JRC-EU-TIMES model to improve the details considered in each one. To illustrate this at a conceptual level, Figure 2 presents the supply chain to provide heat using a heat pump that is installed in a building. The FORECAST tool contains a detailed breakdown of the heating and cooling sector, so it can provide very granular information about what happens from the building-level onwards. For example, FORECAST includes data about the number of heat pumps installations, the type of buildings they are installed in, the insulation standards for those buildings, and the likely development of these buildings in future. However, FORECAST does not include a detailed model about what is occurring in the supply chain before the Final Energy Consumption, so this is provided by the JRC-EU-TIMES model.

The electricity that is consumed by the heat pump in Figure 2 could be produced using a variety of technologies, which will have an impact on the performance of the energy system. For example, if a coal-fired power station produces the electricity then the carbon dioxide emissions will be much higher than if a gas-fired power station does so. The JRC-EU-TIMES model includes detailed modelling of the transformation and transport parts of the supply change, so both models supplement the level of detail in the other. The technical connections are discussed in section 3.4.

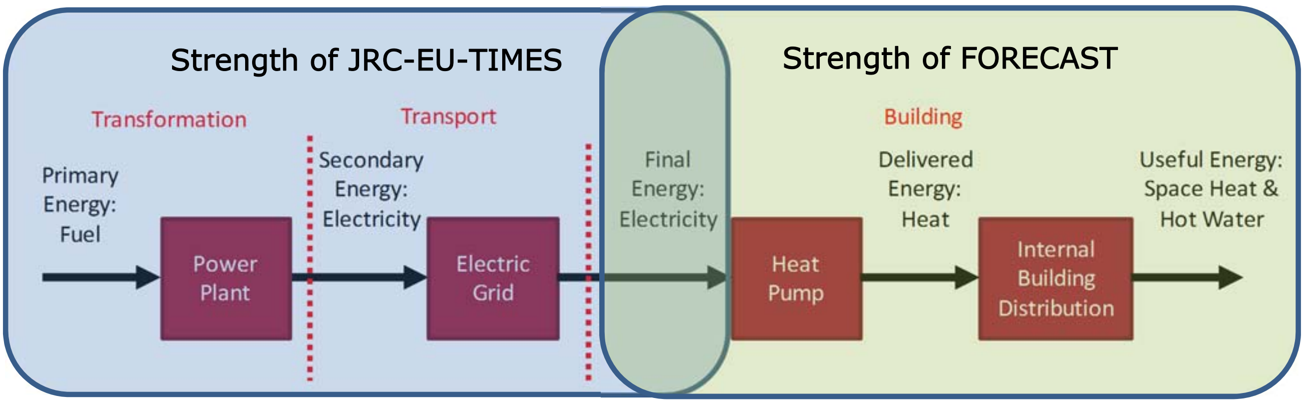


Figure 2: Energy supply chain for space heating and hot water from a building-level heat pump.

3.3. JRC-EU-TIMES & EnergyPLAN

The JRC-EU-TIMES and EnergyPLAN models are similar in terms of scope, since both are designed to analyse the entire energy system and both include an element of socio-economic approach (see Table 1). However, they are distinctly different in terms of timeframe, time-step, and approach.

EnergyPLAN is an hourly model that simulates the energy system over one year. In contrast, the JRC-EU-TIMES is primarily an annual model that optimises the energy system over decades, although it does include typical time-slices for smaller time-steps based on typical days. Due to these differences, even though the scope is very similar the focus of these two models is different.

As discussed in section 2, the core strength of EnergyPLAN is its ability to simulate how the various sectors of the energy system interact, while accounting for the variations in renewable energy production. With this focus, EnergyPLAN is able to identify synergies across the energy system that increase the efficiency and the renewable energy share of the total energy system. For example, Figure 3 shows how if there is an excess production of wind power, then EnergyPLAN can use a synergy between the electricity and heat sectors to integrate this excess production rather than it being curtailed. A heat pump or electric boiler can convert this excess renewable energy (such as wind power) into heat so it can be used in the heating sector rather than curtailed in the electricity sector. If there is no demand for the heat at that time, then the heat can be stored in a thermal storage facility until there is a demand a later stage. This synergy connects renewable energy to relatively cheap energy storage. By doing so it is possible to integrate more intermittent renewables such as wind and solar at a lower cost [5], [6]. Although the JRC-EU-TIMES model also simulates the short-term variations in the energy system, it is not as detailed as the EnergyPLAN model, so by combining the two, EnergyPLAN can supplement the JRC-EU-TIMES tool.

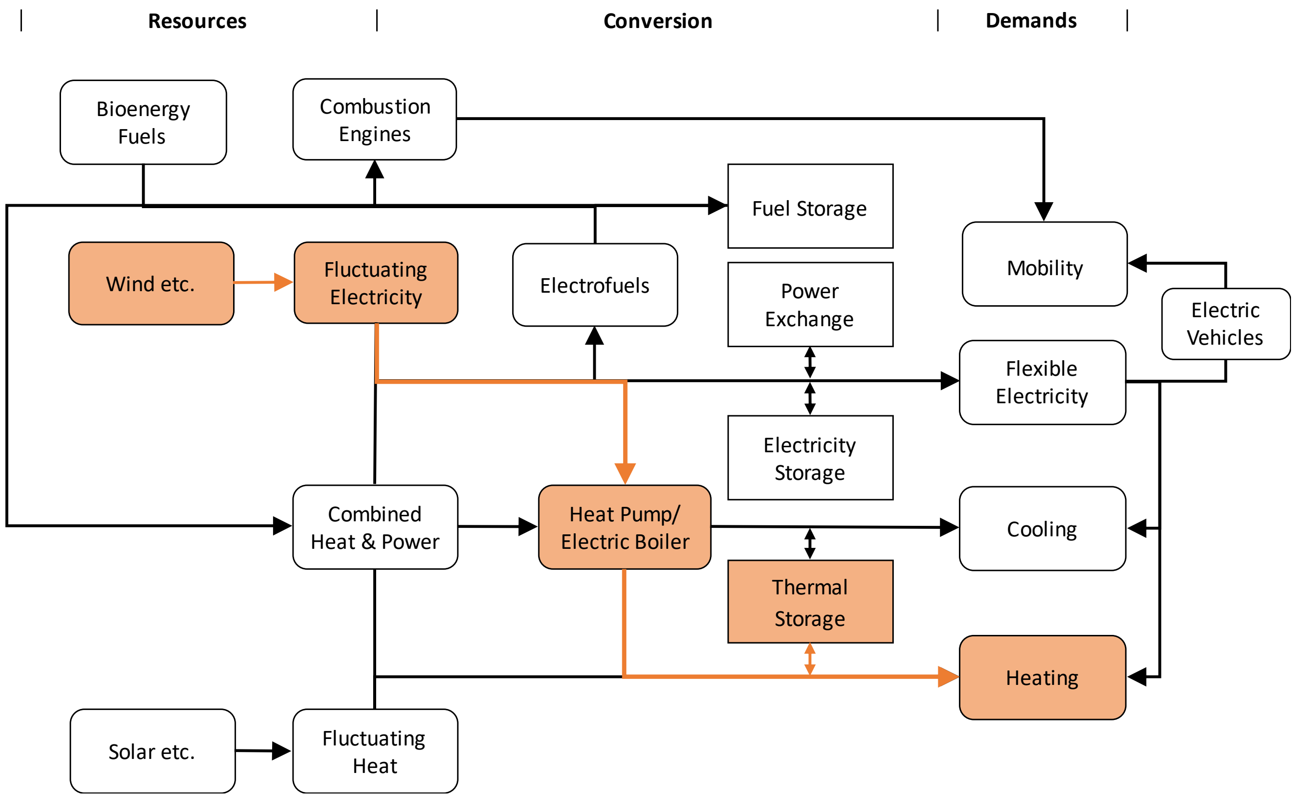


Figure 3: Energy flow in the Smart Energy System that outlines how excess renewable energy is integrated using a synergy between the electricity and heat sectors in combination with thermal storage.

Similarly, the JRC-EU-TIMES model also supplements the EnergyPLAN model. As outlined in Table 2, EnergyPLAN simulates one year at a time, so to model the transition between 2 separate years (for example from 2015 to 2050) EnergyPLAN users typically model a few sample years separately. For example, in Heat Roadmap Europe 3 [9] (also known as the STRATEGO project) the EnergyPLAN model was used to simulate the years 2010 and 2050 for five EU Member States to demonstrate how the heating and cooling sector could be decarbonised between the two years.

The JRC-EU-TIMES model uses a different approach where the transition is modelled from start to finish within the model itself, rather than as separate years by the user. For example, in a study from 2013, the JRC-EU-TIMES model was used to create various low-carbon scenarios for the European energy system by modelling a transition from 2020 to 2050 with five-year intervals in between (see Figure 4). For JRC-EU-TIMES the transition is therefore accounted for within the model itself whereas for EnergyPLAN the transition is considered by the user externally by modelling various years.

Including the transition internally within JRC-EU-TIMES means that it can account for limitations during the transition in a more systematic way than a user can manually in EnergyPLAN. For example, there may be inertia or limitations on the expansion/implementation rate for a solution that needs to be accounted during the transition. These can only be accounted for in through repeated simulations in

EnergyPLAN, so having the transition within JRC-EU-TIMES provides a layer of continuousness and visibility for this transition.

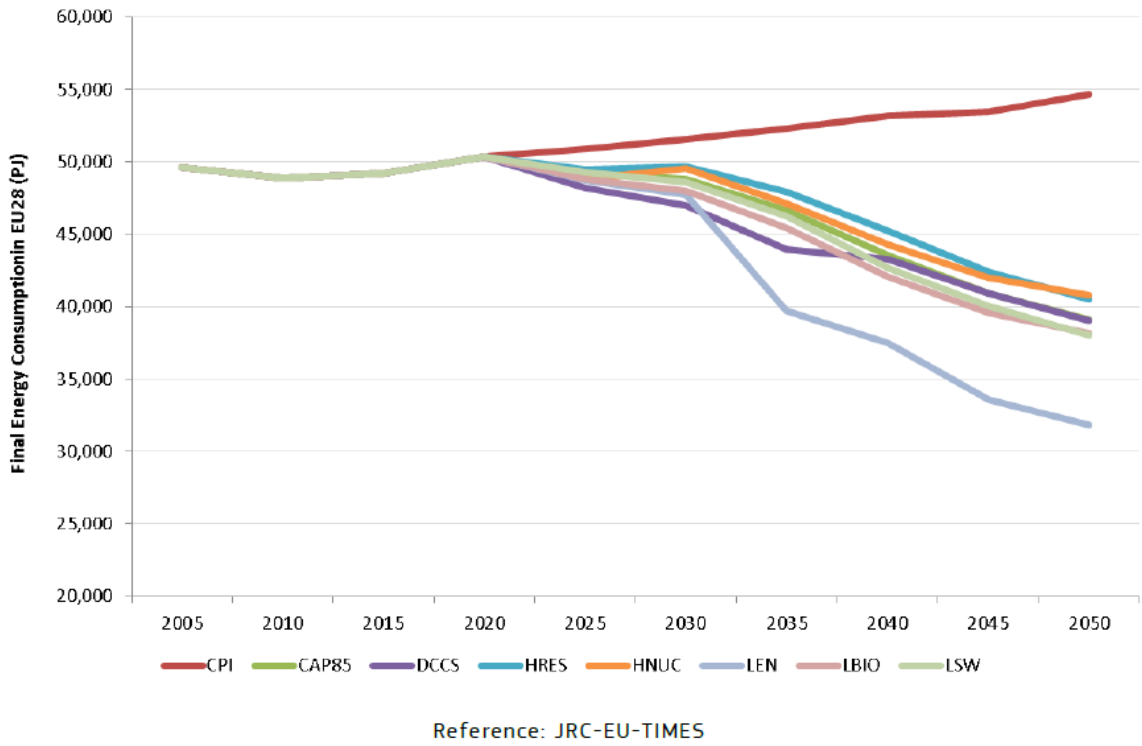


Figure 4: Final energy consumption in the EU28 from JRC-EU-TIMES outlining how the model uses 5 year intervals to model the development of various scenarios between 2020 and 2050 [10].

Overall, there are strengths and weaknesses for both EnergyPLAN and JRC-EU-TIMES, so the aim in HRE4 is combine the strengths of both tools so they function better together than they do apart. Figure 5 outlines the primary benefit of combining both tools as explained here, with JRC-EU-TIMES providing more visibility for the transition between the start and end of the transition (i.e. for the years between 2015 and 2050) and EnergyPLAN providing more visibility about how the energy system behaves on an hourly basis within the years. This enables essential synergies for efficiency and renewable energy to be identified.

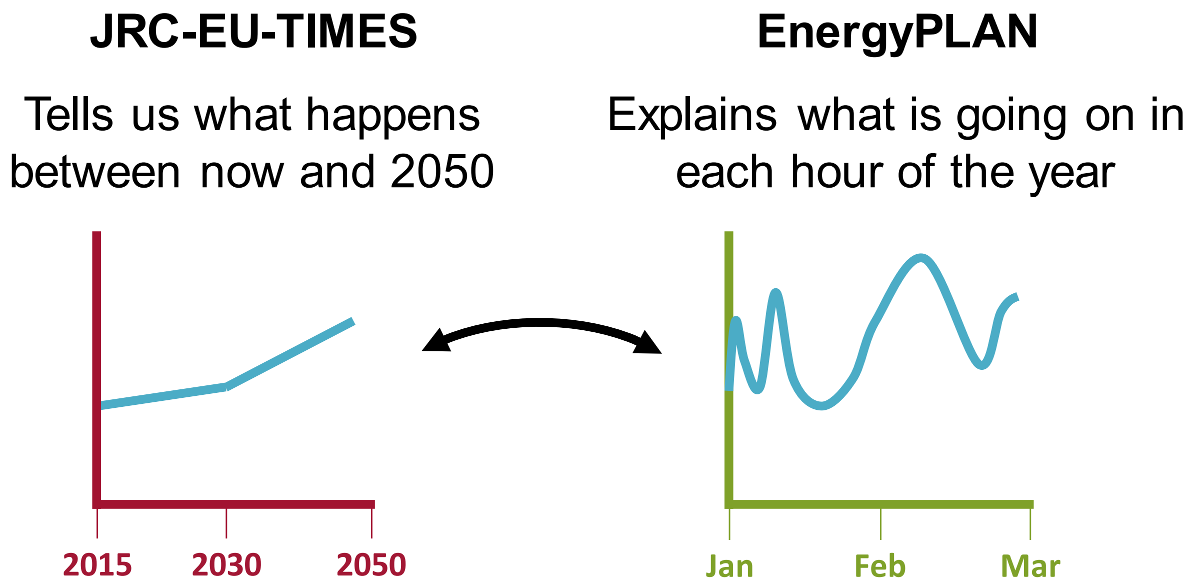


Figure 5: Connection between the JRC-EU-TIMES and EnergyPLAN models

3.4. Technical Connection Points

Figure 1 earlier outlined the scope and focus of each model in HRE4 using the Smart Energy System architecture as one way to understand the distinction. FORECAST and Peta4 focus on the heating and cooling sectors while JRC-EU-TIMES and EnergyPLAN have the broader energy system perspective. Therefore, the amount and type of data required to communicate between the various models is very different depending the specific connection in question. The three main data interfaces are presented in Figure 6 below, which function as 'anchor points' around which data is exchanged and reviewed. They include:

1. Exchange of demand data from FORECAST to Peta
2. Exchange of heating and cooling profile from FORECAST to JRC-EU-TIMES
3. Exchange of complete energy system from JRC-EU-TIMEs to EnergyPLAN

The first two exchanges are both centred on the heating and/or cooling demand. To ensure the models are speaking correctly to one another, a common definition for the heating and/or cooling demand was established. This was touched upon earlier in Figure 2, when various points along the heat supply chain were presented. After considering these various points, the delivered heat demand was chosen as the most appropriate point to connect FORECAST with both Peta and JRC-EU-TIMES. The delivered heat demand is the amount of heat that is generated by the heating units within the buildings, so it effectively signifies the amount of heat that needs to be produced for a building. Some of this heat may be lost on its way to the consumer by for example the internal heat distribution pipes, so it is likely higher than the final heat demand required by the user. This leads to the following definitions in relation to the heat demand within the consortium:

A. **Final Energy:** Energy input to the heating/cooling unit (such as a fuel to a boiler or heat/cold to a substation)
B. **Delivered Energy/Secondary Energy:** Heat/cold produced by the heating/cooling unit
C. **Useful Energy:** Useful heat delivered to the user (such as space heat and hot water after some losses due to the internal heat distribution system and the building).

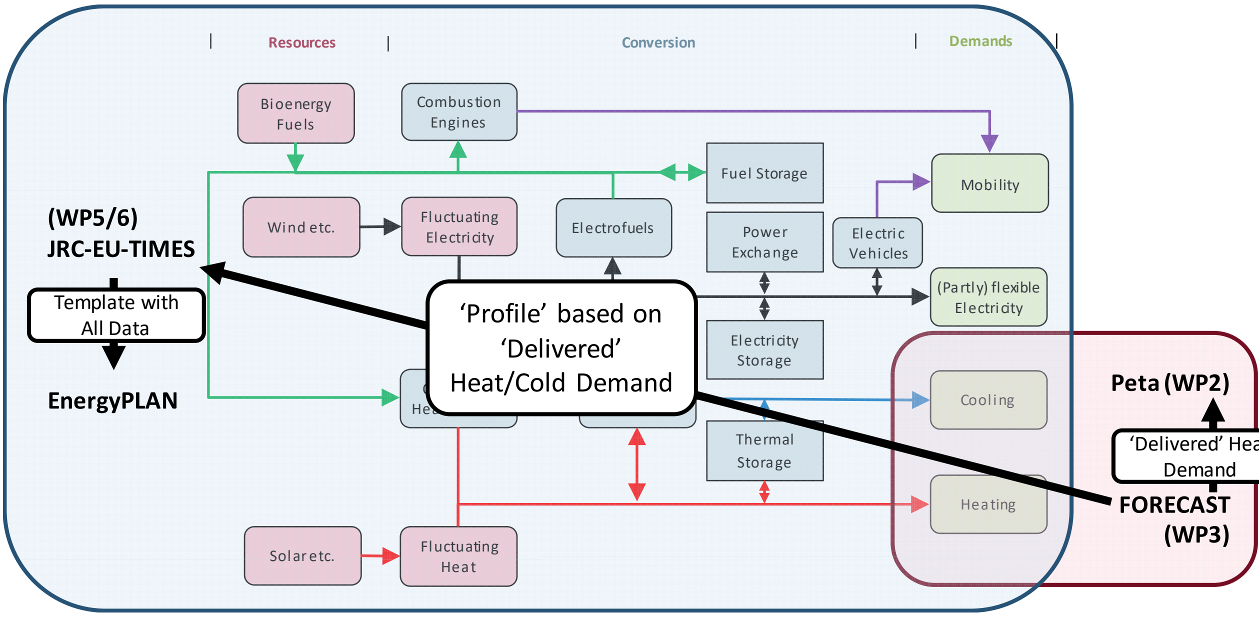


Figure 6: Connection points between the various energy models in HRE4. Delivered heat demand is outlined in more detail in Figure 2.

By using the 'delivered heat', or 'delivered cold' for the cooling sector, the Peta tool will display the amount of heat that needs to be produced by a heating unit which is what is important when comparing various heat supply alternatives. Similarly, the delivered heat/cold demand gives the JRC-EU-TIMES model the inputs required to consider various supply options for the heating and cooling sectors. It also provides FORECAST with the anchor point necessary to consider various heat savings options within the building or process itself. Finally, JRC-EU-TIMES and EnergyPLAN will need to align all assumptions across the energy system so a complete 'data exchange template' is used to transfer all of this information rather than just a single exchange point. For example, many demands, capacities, and efficiencies for all sectors of the energy system are exchanged between the energy system models so the range of data is more extensive than for the other connection points. In the case of the Baseline scenarios (see section 4) this is illustrated in Figure 7.

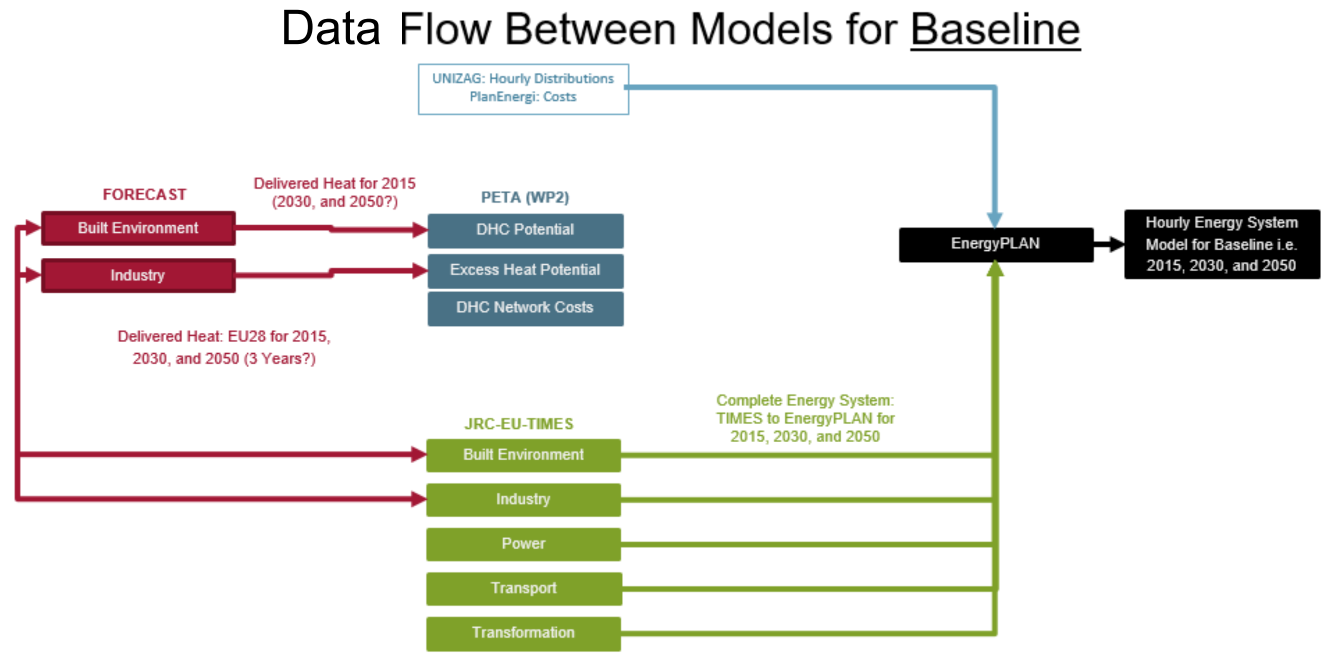


Figure 7: Flow of data between the energy models in HRE4 for the Baseline scenario.

3.5. Economic Connections

The energy models are linked by their economic assumptions as well as their technical inputs, so here the various economic approaches are presented in more detail. Peta only includes the (total) investment costs for network solutions, in alignment with the inputs required for EnergyPLAN, so is excluded from this section.

FORECAST is intended to forecast the future and express what kinds of developments will take place in the baseline approach, under certain policy conditions. FORECAST works as a market optimisation model based on consecutive and cumulative decision making, meaning it has to factor in the (shorter term) available interest rates to the different private entities who are responsible for the investment choices. In addition, FORECAST can be used to make intertemporal decisions, and create a distinct pathway between now and 2050 as to when certain technologies are expected to be implemented and in what quantities.

This forecasting approach means that private time value of money is used, since the model aims to replicate and forecast the choices of private entities. This also means the risks, liquidity and access to capital are privately bourn, and need to be representative of the access and judgement of the private parties' whose behaviour is modelled as expected. Similarly, different types of policy barriers, intangible costs, and information barriers are also included, since these are factors which will affect the decision making in a forecasted scenario. The economic perspective is based on a private, technologically specific discount rate, which reflects policy initiatives, barriers, and intangible costs. This is appropriate because it is used to model and simulate peoples' decision making.

This discount rate is applied to find specific costs over a lifetime, and in intertemporal decisions.

The JRC-EU-TIMES model combines a more social approach towards the time value of money and a more private approach towards risk and the cost of financing based on the individual technologies. The JRC-EU-TIMES model uses a social rate to express the time value of money, to continue relating the pathways to public sector sustainability ambitions and policy assessments. However, the cost of capital is technology specific, and based on the access to capital and risks to private investors. Using these rates allows for an approach that will consider sustainability, but also mimics the decisions and actions made in the energy market in an intertemporal way.

The JRC-EU-TIMES model uses a mix of private and social discount rates, since for the evaluation of investment decisions private discount rates are used, but for the timing of investment a social discount rate is applied. The first determines whether an investment pays off with the assumed private discount rate. The higher the (perceived) risk the higher the discount rate. Technologically specific discount rates are used to balance planning approaches and include risks for specific technologies. The second determines when is the best timing to do investments reflecting the time preference for consuming as well as a decreasing marginal utility of future consumption. This discount rate is applied primarily to make intertemporal decisions based on NPV.

The aim of EnergyPLAN is to be able to simulate and model energy system scenarios to understand their impact, including the equivalent annual costs, from a social perspective. The model is designed to look towards 100% renewable energy systems and be able to incorporate radical technological changes. This means that EnergyPLAN is purposely unrestricted by current policy boundaries, assumes very high levels of reallocation, and assumes a high level of risk-sharing. This allows for the development and optimisation of a future scenario without sub-optimal decision making, an assessment and evaluation of what the system would look like for society at large, and a direction for where public funding and policy should be steering towards.

Given the EnergyPLAN model is primarily aimed at understanding how sustainable energy systems can be designed and planned, there is an inherent implication that the future is afforded importance and the time value of money is low, to reflect the sustainable ambitions assumed in the scenario design. Similarly, the social and central planning approach means that risk premia are kept low since there is an assumption that risks can be spread over both society at large and all the different technologies in the system. The treatment of access to capital in EnergyPLAN similarly assumes a high level of reallocation, the removal of explicit barrier to access capital, and the removal of other barriers to decision-making. The EnergyPLAN model is based on a social discount rate, which reflects the central planning and sustainability approaches. Only one year is modelled, so discount rates are used to annualise costs, which are used as an input for decision making.

In summary and as presented in Table 3, FORECAST has a private end-user perspective, JRC-EU-TIMES has a mix of socio-economy (time value of money) and private economy (risk, capital), and EnergyPLAN uses a purely socio-economic perspective. Most of the differences between the models are appropriate since they match other underlying differences between the models, and are congruent with the different purposes that the models have in the HRE4 project.

Table 3: Overview of different economic approaches between the models. The red areas outline differences between the JRC-EU-TIMES and EnergyPLAN models that will need to be investigated during the analysis to understand their impact on the final results.

Model	Time value of money	Risk premiums	Access to capital	Liquidity	Reflecting barriers
FORECAST	High – private users	High – private users	Less access – private users	Lower – private users	Yes – in order to forecast behaviour accurately
JRC-EU-TIMES	Low – societal perspective	High- private users	Less access – private users	Lower – private users	No – societal perspective
EnergyPLAN	Low / societal perspective	Low / societal perspective	Easy access / societal perspective	Higher / societal perspective	No / based on policy change

One major point of interest is between the two entire energy systems models: since the JRC-EU-TIMES and EnergyPLAN will both model the entire energy system, but the JRC-EU-TIMES model takes a private-user perspective for some decision-making whereas EnergyPLAN applies a socio-economic approach throughout, the differences between the different economic approaches should become explicit as the differences are analysed. However, since there are other differences between the two models (notably their time perspectives, and the way the models generate peak capacity requirements), that the differences between the results cannot be only explained by the differences in the economic approaches. It is currently unclear how much this will affect the results from both tools, so it is highlighted during this connection process as something to be investigated in more detail when combining the tools with one another.

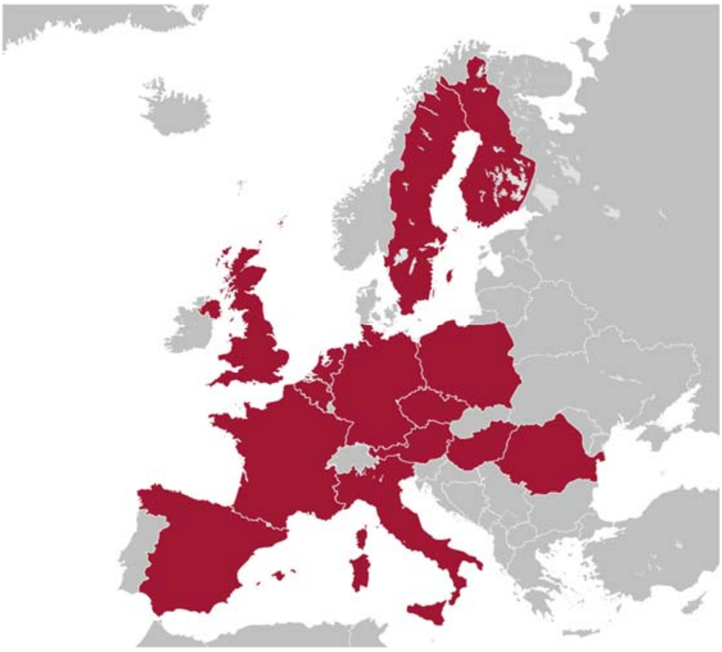
4. Scenarios

The previous section described the primary role and connection points between the models whereas this section presents how the models are used. Throughout the HRE4 project, the energy models will be used to create two main scenarios for each country:

- The Baseline scenario: this outlines the development of the energy system if existing policies are implemented. More background can be found in D3.3, D3.4, and D5.2 of the Heat Roadmap Europe project. It assumes that the EU meets its 2030 target of a 40% CO_2 reduction, with minor reductions after that point.
- Heat Roadmap: this scenario includes additional changes to the Baseline scenario for the electricity, heating, and cooling sectors based on the new information created in the project. For example, in previous Heat Roadmap Europe studies, this scenario included more heat savings, district heating, and heat pumps than the Baseline scenario [11]–[14].

The Baseline and Heat Roadmap scenarios will be developed for two different years and 14 different countries. There is a further ambition to extend the methodology and data exchange to three years (including 2030) and the full EU28, although the priority is on the 14 largest countries, which cover about 90% of the EU heat demand currently. The years are 2015 and 2050, while the 14 countries are:

- Germany
- France
- United Kingdom
- Italy
- Poland
- Spain
- Netherlands
- Sweden
- Belgium
- Czech Republic
- Romania
- Austria
- Finland
- Hungary



These three separate components make up the name assigned to a scenario in the HRE4 project, so for example, the Baseline scenario for Germany in the year 2030 is referred to as "Baseline Germany 2030" or the 2050 Heat Roadmap scenario for Austria is referred to as "Heat Roadmap Austria 2050". The following chapter describes how the various energy models contribute to the Baseline and Heat Roadmap scenarios along with the specific data exchanges required in both scenarios, since it is different between the two.

4.1. Baseline Scenario

The Baseline scenario presents how the energy system is expected to develop if existing policies are implemented. More background and explicit discussion of the assumptions in different sectors can be found in D3.3, D3.4, and D5.2 of the Heat Roadmap Europe project. The Baseline provides a reference point for other scenarios to be compared with, in this case the Heat Roadmap scenarios. It is not a forecast of the future, but a scenario under certain assumptions and conditions, with some of the main ones including:

- The macro-economic drivers are taken from the REF2016 scenario developed by the European Commission such as international fuel prices, discount rates, population, energy services demands and materials [15].
- It is assumed that current climate and energy policy goals for the year 2030 will be met, with relatively modest developments beyond that point. These are summarised in Table 4.

Table 4: Changes in renewable energy penetration, primary energy supply, and carbon emissions in the Baseline scenario.

	2030	2050	Ref year
Renewable Energy	27%	31%	-
Primary Energy	-23% (-30%)	-20%	2005 (2030)
CO_2 total	-40%	-48%	1990
CO_2 total	-36%	-44%	2005
Emissions Trading Scheme (ETS)	-43%	-62%	2005
Non-ETS	-30%	-28%	2005

The development of the heating and cooling demand in the Baseline scenario will be modelled in FORECAST, while the remainder of the energy system will be created in JRC-EU-TIMES. The final outcome will be hourly energy models for each of the 14 countries for some specific years such as 2015, (2030), and 2050.

4.2. Heat Roadmap Scenario

Much of the work to develop Heat Roadmap Scenarios will take place in WP6 of the HRE4 project. The Heat Roadmap scenario will use the Baseline scenario as a starting point, but it will include a number of new measures that will decarbonise the energy system further than the Baseline.

In previous Heat Roadmap Europe studies, the main changes have been [11]–[14]:

- More heat savings in the buildings
- Replacing natural gas with district heating in urban areas
- Replacing coal and oil with heat pumps in the rural areas, with smaller shares of biomass boilers and solar thermal panels where appropriate and available
- Adding more intermittent renewable energy to the electricity sector such as wind and solar power, due to the additional demand and flexibility that now exists in linking the heating and electricity sector.

These changes formed the new 'Heat Roadmap' scenario and once they are simulated, this new scenario can be compared to the Baseline to quantify their impact. For example, Figure 8 presents some results from the HRE3 project which compares the 'Baseline Czech Republic 2050' and 'Heat Roadmap Czech Republic 2050' scenarios in terms of:

- Energy: based on the primary energy supply
- CO_2: based on the annual carbon dioxide emissions
- Costs: based on the total annual socio-economic cost

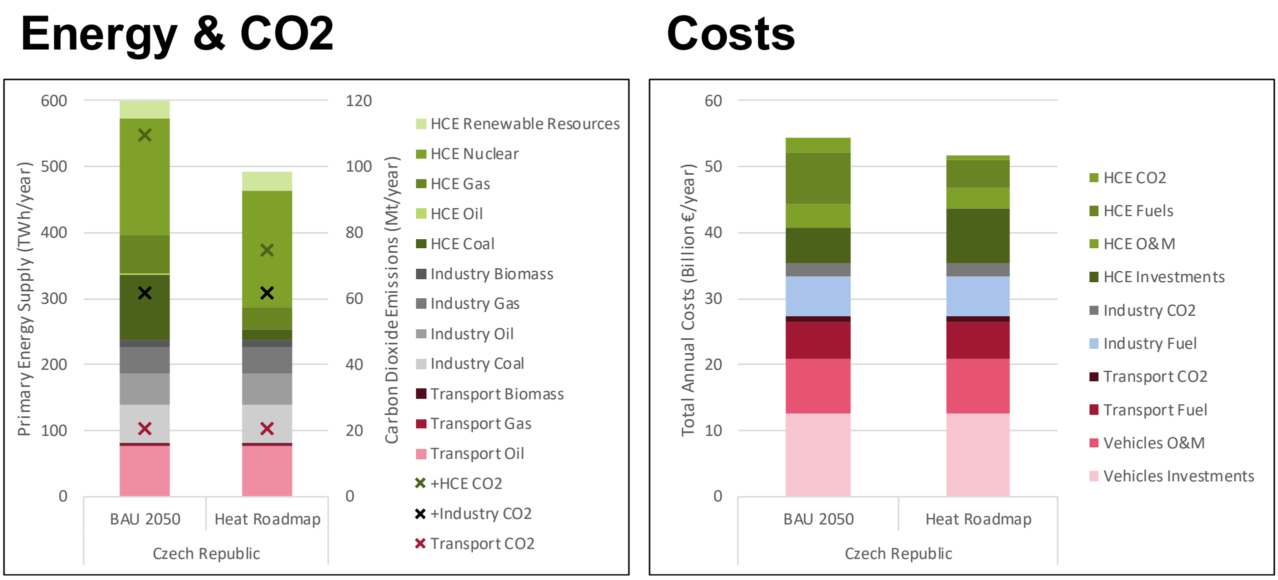


Figure 8: Results from HRE3 outlining how the Baselines is used as a benchmark for the Heat Roadmap scenarios.

The results indicate that the Heat Roadmap Czech Republic 2050 scenario is more efficient, produces less CO_2, and costs less than the Baseline scenario, thus suggesting that these alternative measures are very beneficial for the Czech Republic energy system. A similar methodology will be applied in HRE4 as in the HRE3 project.

To carry out this analysis, a new data flow will be required between the HRE4 energy models compared to the connections required in the Baseline scenario that were presented in section 4.1. The flow of data between the energy models for the Heat Roadmap scenarios beings when the Baseline scenario is complete, since this is the point of departure of the analysis. Data is exchanged in a different way as presented in

Figure 9, where the solid lines outline the data exchange that is necessary while the dotted lines outline some additional data flows that will be carried out for validation and comparison purposes.

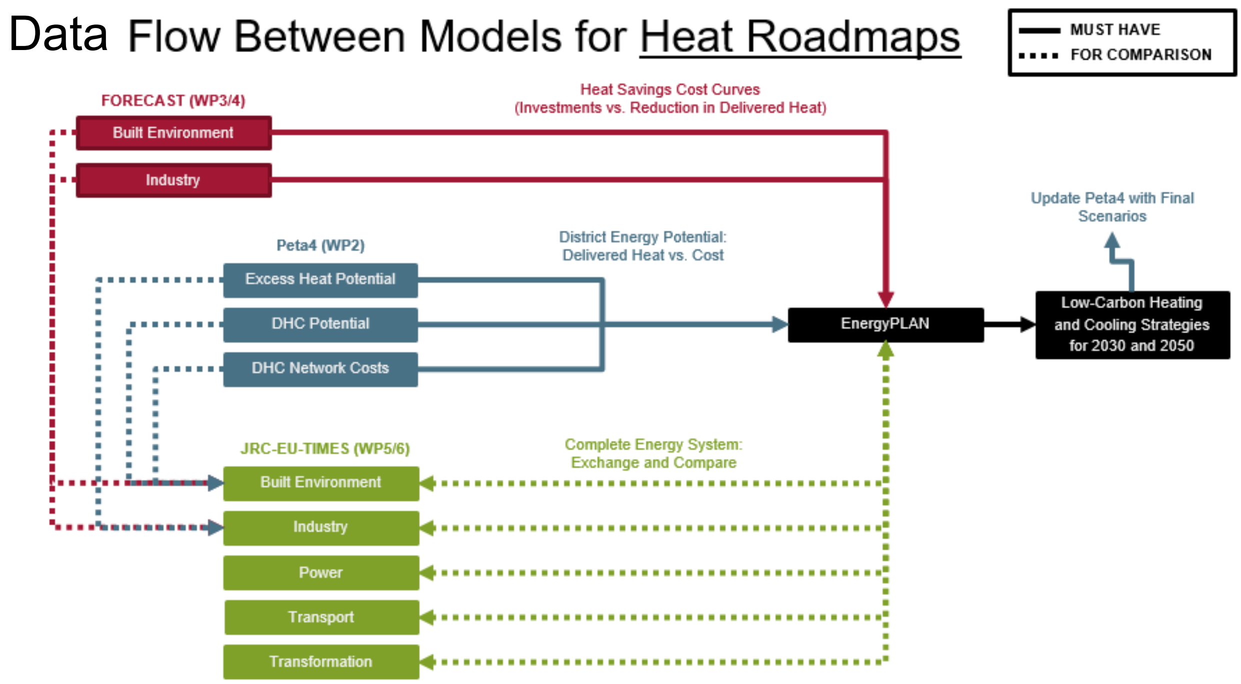


Figure 9: Flow of data between the energy models in HRE4 for the Heat Roadmap scenario.

All data will be collected in the EnergyPLAN model to make the Heat Roadmap scenarios. Peta4 will identify the potential for district heating and cooling based on the location of the demand and the resources nearby that could offer a low-carbon heating or cooling supply. Peta will inform EnergyPLAN about the potential for district heating and cooling, the cost of developing the networks in the cities (see Figure 10), and the potential for low-carbon heat/cold supply such as excess heat and renewable heat. In previous HRE studies, excess heat included subcategories for power plants, industry, and waste incineration while renewable heat included geothermal, solar thermal, and bioenergy, so these will likely be the applied again in HRE4 [16]–[18].

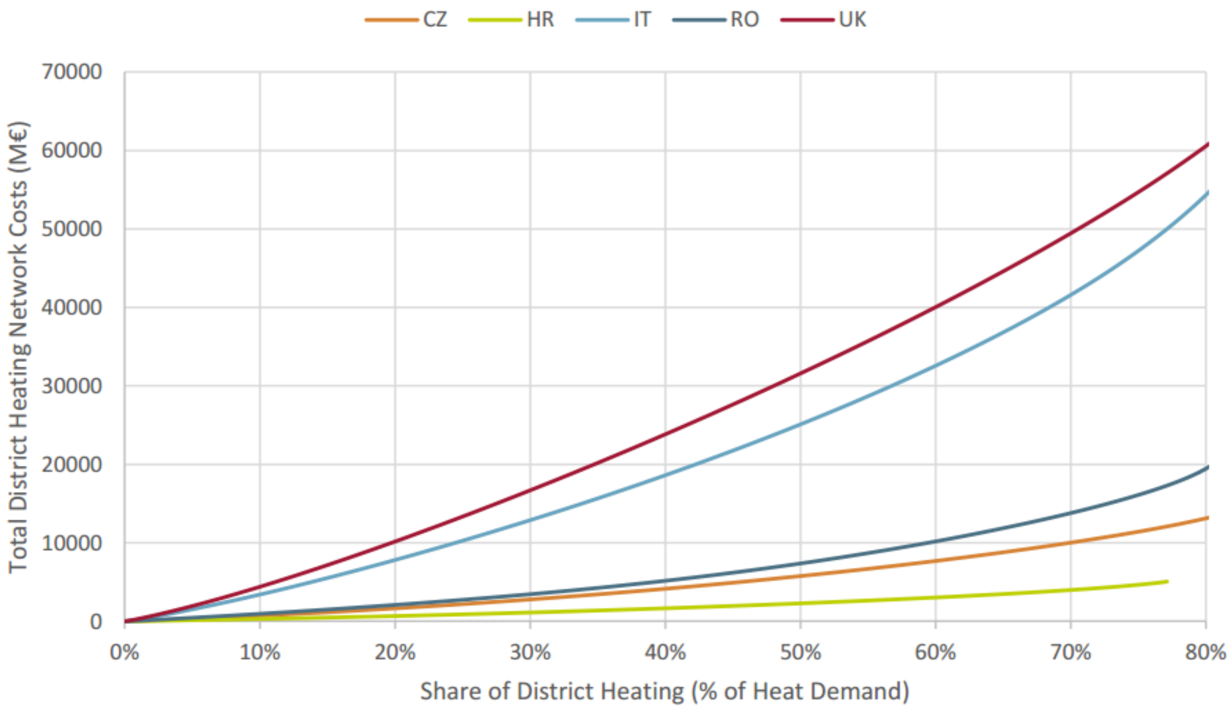


Figure 10: Investment costs in district heating pipes for various levels of district heating supply in five EU countries from the HRE3 study [13].

The FORECAST model will provide information about the cost and potential for heat savings in the Built Environment and Industry of each HRE4 country, which will be used in the EnergyPLAN analysis to define the level of heat savings that should be implemented. This work is being carried out as part of WP4 and it will use the detailed profile of the heating and cooling sector from WP3 as the starting point for the analysis.

Using these inputs from FORECAST and Peta, EnergyPLAN will be used to compare various levels of heating savings and district energy in each HRE4 country for the years 2030 and 2050, while also applying a range of other changes to the energy system. For example, EnergyPLAN can consider various heating and cooling supply options such as boilers, heat pumps, solar panels, and CHPs, as well as exploring some new synergies that could existing in the energy system, such as the link between wind power and thermal storage that was presented earlier. EnergyPLAN will identify the optimum level of each measure to implement so that each HRE4 country can decarbonise its heating and cooling sector in a least-cost manner.

After identifying the optimum mix of each solution, EnergyPLAN will then inform the Peta model about the final levels of district energy, excess heat, and renewable heating, so the Peta tool can be updated with the final Heat Roadmap scenarios.

Furthermore, there is an ambition that EnergyPLAN will also feed the Heat Roadmap scenarios back to JRC-EU-TIMES so the Heat Roadmap Scenarios can be examined using a second energy model. This is not explicitly within the scope of the HRE project, but a mutual ambition on the side of AAU and the JRC. It is likely that this will create an iterative process that will improve the robustness of the final Heat Roadmap scenarios since the JRC-EU-TIMES model will have a different perspective to EnergyPLAN. As described in section 3, EnergyPLAN looks at the energy system on an hourly basis over one year while JRC-EU-TIMES typically models the energy system on an annual basis over decades, so applying both perspectives for the final Heat Roadmaps will likely reveal some issues that each model would miss on its own.

5. Conclusion

HRE4 contains a variety of energy models, each with its one specific purpose and perspective of the energy system, that are called Peta, FORECAST, JRC-EU-TIMES and EnergyPLAN. Combining these with one another improves the scope, detail, and robustness of the final scenarios developed in the project. The two main scenarios developed in the project are the 'Baseline' scenario and the 'Heat Roadmap' scenario, with each one being created for the 14 countries considered in the project. The Baseline scenario represents what will occur by 2050 if existing policies are implemented, including the 2030 energy targets. The Heat Roadmap scenarios will include additional measures based on the findings of the HRE4 project in relation to heat savings, district energy, and heat/cold supply.

FORECAST includes a detailed profile of the heating and cooling sectors for the Built Environment and Industry such as the energy mix, type of heat/cold unit, number of units, type of building, and type of demand. It is used in the project to develop a detail picture of heating and cooling sectors in the Baseline scenario from the year 2015 to 2050 using five-year intervals.

Peta builds on the information from FORECAST by identifying the location of the heating and cooling demand. Location is essential in heating and cooling planning since it often defines the viability of various low-carbon solutions in the future. For example, district energy is only suitable in areas with a high population density so Peta is used here to quantify that scale of this potential.

JRC-EU-TIMES is an energy system model, so it goes beyond the Built Environment and Industry sectors by including Power, Transport, and Transformation also. Therefore, JRC-EU-TIMES takes the heating and cooling profile from FORECAST as an input and builds the additional sectors around it in the Baseline scenario, also from 2015 to 2050 using five-year intervals in between.

EnergyPLAN takes the complete energy system dataset from JRC-EU-TIMES for specific years and simulates one year at time on an hourly basis. Therefore, EnergyPLAN has less detail than JRC-EU-TIMES in terms of the transition (i.e. EnergyPLAN simulates one year rather than decades), but it increases the granularity within each year (i.e. EnergyPLAN models every hour within the year whereas JRC-EU-TIMES usually has some typical days). The final output is an hourly model of the entire energy system for each HRE4 country for the years 2015, 2030, and 2050, which can be used as a starting point to develop the Heat Roadmap scenarios.

The same models are used to create the Heat Roadmap scenarios, but their role is slightly different. EnergyPLAN is the anchor point for the scenarios since all information is fed into EnergyPLAN in order to assess and compare scenarios. Peta outlines the potential to expand district energy and FORECAST quantifies the potential for heat savings in the built environment and industry. Using these inputs, EnergyPLAN identifies the optimum combination of various solutions to decarbonise the heating and cooling sector in the future, which results in the final Heat Roadmaps for each country. These final Heat Roadmaps will use the Baseline scenario as a starting point and as a benchmark since the Heat Roadmaps will ideally have lower energy demands, carbon footprint, and costs than the Baseline scenario. The final outputs from the project will outline how to implement a low-carbon heating and cooling sector in each HRE4 country, while also presenting the consequences of doing so.

6. References

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

[2] H. Lund, "EnergyPLAN Advanced Energy System Analysis Model," Aalborg University, www.energyPLAN.eu, <U>www.energyPLAN.eu</U>, 2007.

[3] H. Lund, "EnergyPLAN, Advanced Energy Planning Systems Analysis Computer Model - Documentation Version 11.0," Department of Development and Planning, Aalborg University, Denmark, Mar. 2013.

[4] H. Lund, P. A. Østergaard, D. Connolly, I. Ridjan, B. V. Mathiesen, F. Hvelplund, J. Z. Thellufsen, and P. Sorknæs, "Energy Storage and Smart Energy Systems," *Int. J. Sustain. Energy Plan. Manag.*, vol. 11, pp. 3–14, 2016.

[5] D. Connolly, H. Lund, and B. V. Mathiesen, "Smart Energy Europe: The technical and economic impact of one potential 100% renewable energy scenario for the European Union," *Renew. Sustain. Energy Rev.*, vol. 60, pp. 1634–1653, Jul. 2016.

[6] D. Connolly and B. V. Mathiesen, "A technical and economic analysis of one potential pathway to a 100% renewable energy system," *Int. J. Sustain. Energy Plan. Manag.*, vol. 1, pp. 7–28, 2014.

[7] B. V. Mathiesen, H. Lund, D. Connolly, H. Wenzel, P. A. Østergaard, B. Möller, S. Nielsen, I. Ridjan, P. Karnøe, K. Sperling, and F. K. Hvelplund, "Smart Energy Systems for coherent 100% renewable energy and transport solutions," *Appl. Energy*, vol. 145, pp. 139–154, May 2015.

[8] H. Lund, A. N. Andersen, P. A. Østergaard, B. V. Mathiesen, and D. Connolly, "From electricity smart grids to smart energy systems - A market operation based approach and understanding," *Energy*, vol. 42, no. 1, pp. 96–102, 2012.

[9] D. Connolly, K. Hansen, D. Drysdale, H. Lund, B. V. Mathiesen, S. Werner, U. Persson, B. Möller, O. G. Wilke, K. Bettgenhäuser, W. Pouwels, T. Boermans, T. Novosel, G. Krajačić, N. Duić, D. Trier, D. Møller, A. M. Odgaard, and L. L. Jensen, "Enhanced Heating and Cooling Plans to Quantify the Impact of Increased Energy Efficiency in EU Member States (Heat Roadmap Europe 3)," 2015.

[10] S. Simoes, W. Nijs, P. Ruiz, A. Sgobbi, D. Radu, P. Bolat, C. Thiel, and S. Peteves, "The JRC-EU-TIMES model - Assessing the long-term role of the SET Plan energy technologies," Publications Office of the European Union, Luxembourg, Belgium, 2013.

[11] D. Connolly, B. V Mathiesen, P. A. Østergaard, B. Möller, S. Nielsen, H. Lund, D. Trier, U. Persson, D. Nilsson, and S. Werner, "Heat Roadmap Europe: First pre-study for EU27." Aalborg University, Halmstad University, and Euroheat & Power, 2012.

[12] D. Connolly, B. V Mathiesen, P. A. Østergaard, B. Möller, S. Nielsen, H. Lund, U.

Persson, S. Werner, J. Grözinger, T. Boermans, M. Bosquet, and D. Trier, "Heat Roadmap Europe: Second pre-study." Aalborg University, Halmstad University, Ecofys Germany GmbH, PlanEnergi, and Euroheat & Power, 2013.

[13] D. Connolly, K. Hansen, D. Drysdale, H. Lund, B. V. Mathiesen, S. Werner, U. Persson, B. Möller, O. G. Wilke, K. Bettgenhäuser, W. Pouwels, T. Boermans, T. Novosel, G. Krajačić, N. Duić, D. Trier, D. Møller, A. M. Odgaard, and L. L. Jensen, "Enhanced Heating and Cooling Plans to Quantify the Impact of Increased Energy Efficiency in EU Member States - Main Report," 2015.

[14] D. Connolly, H. Lund, B. V. Mathiesen, S. Werner, B. Möller, U. Persson, T. Boermans, D. Trier, P. A. Østergaard, and S. Nielsen, "Heat Roadmap Europe: Combining district heating with heat savings to decarbonise the EU energy system," *Energy Policy*, vol. 65, no. 0, pp. 475–489, 2014.

[15] European Commission, "EU Reference Scenario 2016: Energy, transport and GHG emissions Trends to 2050," 2016.

[16] U. Persson, B. Möller, and S. Werner, "Heat Roadmap Europe: Identifying strategic heat synergy regions," *Energy Policy*, 2014.

[17] U. Persson, "STRATEGO WP2 Background Report 7: Quantifying the Excess Heat Available for District Heating in Europe," 2015.

[18] B. Möller, "STRATEGO WP2 Background Report 9: Mapping the Renewable Heat Resources in Europe," 2015.

7. Appendix

7.1. Minutes from Petten: 8-10th August 2016

7.2. Minutes from Utrecht: 25-26th October 2017

7.3. Interest Rate Comparison

7.4. Hourly Distributions Report

2050

Heat Roadmap Europe

A low-carbon heating and cooling strategy

WP5 and WP6

Working meeting

JRC, Petten, the Netherlands

8-10 August, 2016

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 695989.

Attendance/Travel itineraries

Arrivals (flight times)

August 6th, Saturday

- Jakob: 13.05 (train to Alkmaar)
- Susana: 13.15 (train to Alkmaar on Sunday)

August 7th, Sunday

- Tomislav: 18.30
- Kenneth: 18.50
- David: 20.35

August 8th, Monday

- Morten: 20.35

Departures (be at airport 2h advance)

August 9th, Tuesday

- Jakob: 15.15 Schiphol (taxi to airport; ask Zuzana how/when)
- Kenneth: 16.30 at Schiphol (train in Alkmaar at 15.15)

August 10th, Wednesday

- David: 15.00 Schiphol (train to airport in Alkmaar at 14.00)
- Susana: 15.00 Schiphol (train to airport in Alkmaar at 14.00)
- Morten: 15.00 Schiphol (train to airport in Alkmaar at 14.00)
- Tomislav: 16.20 Schiphol (train to airport in Alkmaar at 14.00)

Day 1, Monday August 8th

1 Hour (with minor clarification questions only)

- Brief overview of modelling in HRE to Date (David)
- Tasks in WP5 and WP6 of HRE4 - (years, steps, other agreements we have made so far.) (David)
    - Who is modelling what?

1 Hour (with minor clarification questions only)

- Overview of the EnergyPLAN Model (AAU)
    - Main purpose
    - Inputting data
    - Running the model
    - Type of outputs
    - Future developments
    - Present some exemplary results in order to show the capabilities of the model

1 Hour (with minor clarification questions only)

- Overview of the TIMES model (JRC)
    - Same breakdown as for EnergyPLAN

½ Hour (with minor clarification questions only)

- Zagreb:
    - Fuel prices today and in the future (especially bioenergy), including variations between countries (Tomislav)
    - Bioenergy resources in the future in each country (Tomislav)

Remainder of the Day (open discussion)

- Exchange of data between TIMES and EnergyPLAN (Discussion):
    - Type of data:
        - Demands
        - Capacities
        - Efficiencies
        - Costs: a lot to discuss here in terms of assumptions associated with costs and emissions, discount rate, etc. (Susana)
    - Alignment with Template for WP3

- Concept of "2050 BAU" baseline - clarify any question regarding the alignment of the models with the new Energy Reference Scenario 2016, which will be input- rather than output-based

Day 2: Tuesday August 9th

½ Hour (with minor clarification questions only)

- PlanEnergi
    - Technology costs between Member States (Morten)

All Day (Jakob and Ken leave at 13:00)

- How we exchange data:
    - TIMES create a scenario, we replicate it in EnergyPLAN via templates for example?
    - Review the template
    - Carry out a demo while we are together
- What developments do we need in TIMES or EnergyPLAN to facilitate the data exchange in the future?
- Feedback between models – how do we ensure that both models can run the system with similar data inputs?
- Deep dive into the model: connect a country

Day 3: Wednesday August 10th

- Costs to be exchanged:
    - Type
    - Cost calculations in the model
- Business-as-Usual Scenario:
    - What assumptions should it include

Minutes of Meeting

Susana Paardekooper, August 2016.

Attendees

- Susana Paardekooper susana@plan.aau.dk, AAU
- Jakob Zinck Thellufsen jakobzt@plan.aau.dk, AAU
- David Connolly david@plan.aau.dk, AAU
- Kenneth Hansen khans@plan.aau.dk, AAU
- Ignacio Hidalgo-Gonzalez Ignacio.HIDALGO-GONZALEZ@ec.europa.eu, JRC
- Wouter Nijs Wouter.NIJS@ec.europa.eu, JRC
- Pablo Ruiz-Castello Pablo.RUIZ-CASTELLO@ec.europa.eu, JRC
- Morten Hofmeister mh@planenergi.dk, PE
- Tomislav Novosel tomislav.novosel@fsb.hr, UNIZAG

Action List

The meeting followed the agenda outlined previously. Modelling approaches in the EnergyPLAN and JRC-EU-TIMES models were presented by AAU and the JRC. After discussing the type of data required in each tool, the 'Data Exchange Template' was reviewed to see how the two models could work together. Italy was used as a case study and the 'Data Exchange Template' was populated by both the EnergyPLAN and JRC-EU-TIMES models based on the year 2010, to ensure that the two models were connecting the correct data.

This coordinated a large variety of discussions, since it revealed a number of new considerations during the connection between the models. For example, EnergyPLAN referred to 'Total Domestic Electricity Production' which will need to be converted to 'Total Electricity Demand' to align with energy statistics and the JRC-EU-TIMES model and similarly, both modelling teams agreed on a common definition for Primary Energy Supply and Gross Inland Consumption (Primary Energy Supply plus fuels consumed for Non-Energy Use).

The following action list was created after populating the exchange template with both models.

AAU / EnergyPLAN:

- Will arrange a follow-up workshop between AAU, JRC, and Fraunhofer to align the EnergyPLAN, JRC-EU-TIMES, and FORECAST models. Provisional date for this is the 24-25th of October 2016. The purpose of this meeting is to align the models as much as possible, especially for the Baseline scenario to 2050.
- Will send an overview of the current costs and the costs required for the EnergyPLAN model, so the JRC can share their cost assumptions which are currently based on ETRI cost data (https://ec.europa.eu/jrc/en/news/etri). Learning rates may also need to be exchanged with the FORECAST modelling.
- At present, the JRC-EU-TIMES model uses a different discount rate for different technologies while EnergyPLAN uses the same one for all technologies. Therefore, AAU will investigate the possibility of applying technology-specific interest rates to align with the JRC-EU-TIMES model,.
- Will change "Total electricity demand" to "Total domestic electricity production" in the model
- Will change "CO2 price" in EnergyPLAN to reflect its meaning more accurately such as "CO2 Damage". There is some research by Dr. O.J. Kuik on the "CO2 Damage" price, which is typically €70-200/ton.

JRC / JRC-EU-TIMES:

- Will review the 'Data Exchange Template' and send to AAU, which will include a suggestion for the breakdown of industry (i.e. could be based on Eurostat industrial categories or it could be based on potential alternatives in the future such as bioenergy and electrification)
- Will check the PP/CHP capacities at the start of the simulation, since a lot of existing capacity is retired very quickly since they are not required by the model.
- Will divide pumped-hydro electric energy storage between 'pure' and 'hybrid'. It is all 'hybrid' right now. Results from a recent journal article could be used for the distinction:
    - F. Geth, T. Brijs, J. Kathan, J. Driesen, and R. Belmans, "An overview of large-scale stationary electricity storage plants in Europe: Current status and new developments," Renew. Sustain. Energy Rev., vol. 52, pp. 1212–1227, 2015.
- Will provide electrical interconnection capacities by country
    - Historical and current interconnection capacities are available from ENTSO-E at https://transparency.entsoe.eu/dashboard/show and https://www.entsoe.eu/publications/statistics/Pages/default.aspx.
    - ENTSO-E also publishes the assumptions of the Ten-Year Network Development Plans: http://tyndp.entsoe.eu/.
- Will share their cost data for estimating the price of expanding the electric grid, which is based on Eurostat estimates.

- Will check if costs are available to implement 'load-following capabilities' into Nuclear power plants.
- Heating is currently divided into three steps:
    A. Fuel input to the heating unit (such as a boiler)
    B. Heat produced by the heating unit
    C. Useful heat delivered to the user (such as space heat and hot water after some losses due to the internal heat distribution system and the building).
- Data will be provided for all three steps since EnergyPLAN considers part A and B, while FORECAST considers part C. JRC will discuss this with their building-unit colleagues in JRC-IDEES to try and find references for the low system efficiency.
- Will report gas for cooking separate to heating demands in the residential and commercial sectors.
- Will review inputs for diesel in the new model so it aligns with Eurostat
- Based on Eurostat data, JRC will clarify a possible flaw in the categorisation of CHP. In some countries, a big share of the "Main activity CHP plants"(non-autoproducers) also provide heat to industries and are not to be considered as district heating CHPs. These plants typically have higher operating hours.

UNIZAG:

- Hourly Distributions:
    - Will use an updated methodology developed in STRATEGO to develop the hourly space heating and cooling demands
    - Will develop and validate the PV and wind production distributions according to meteorological data gathered from METEONORM and databases containing capacity and production information
    - Will utilize Entso-e to create the hourly electricity demand and hydro production distribution
    - Will use a standard daily distribution for hot water demand
    - Will review existing research to develop the hourly transport demand
    - Will contact partners for potential data that might be useful in the validation phase for distributions such as DH, DC, wind and PV production
- Fuel Prices:
    - Will review report from the JRC to establish how bioenergy prices vary around Europe: "The JRC-EU-TIMES model. Bioenergy Potentials for EU and neighbouring countries"
    - JRC will connect with the "Biomass Future" project
    - Will discuss fuel price variations with JRC-EU-TIMES modelling team, since they assume that coal and gas vary between MSs.

- The JRC-EU-TIMES would also like to improve their assumptions for fuel handling as well as the cost of mining indigenous gas and coal, so this could be a focus area in this work? Something to discuss with the JRC after reviewing existing work.
- Will connect with Bioenergy mapping in WP2

PlanEnergi:

- Presented their work currently underway for developing Individual Heating and Cooling Unit Costs for four regions in Europe, which is expected to be finalised in September/October 2016. Four countries; Portugal, Hungary, Germany and Denmark (regarding costs), representing Southern Europe, Eastern Europe, Central Europe and Northern Europe. House installations and small-scale district heating networks are included. Energy savings are also included, cf. the mapping activities in HRE. The mapping activities in HRE could use the new data on individual technologies.
- Could use breakdown between 'equipment' and 'installation' as a guide for the cost variations between different EU countries. Variations across different EU countries regarding the "installation" costs can be estimated based on EuroStat and/or based on the typical labour costs for each EU country provided on page 130 (Annex 7) of the JRC Report "The JRC-EU-TIMES model. Bioenergy Potentials for EU and neighbouring countries" that Pablo wrote.
- Need to identify the most important costs to consider such as wind turbines, power plants, and heating units, so these can be the main focus of their work when assessing cost variations across Member States. At present, EnergyPLAN and the JRC-EU-TIMES models assume the same costs for all countries, but the models can be used to identify the technologies that account for most costs, so PlanEnergi can focus on these. A new tender from JRC is expected autumn 2016) regarding large plants. Data from this study, when it is finalized, can be applied.
- AAU will send data from HRE2 about the cost variations for heating units in different EU countries. To be compared with the EnergyPLAN cost database (under www.energyplan.dk, "Useful resources" zip-file. If not in the context of this new project, PlanEnergi can investigate costs with the purpose of HRE4 WP6, based on data sources in the current study.
- EnergyPLAN Costs, Investments, fixed OM, Additional:
    - District heating pipes (see report; heatroadmap.eu, "Background report 6 – mapping potential for DHC20160202 – version 2, released Feb 2016.PDF", page 9; graph "investments costs as function of heat density", same graph applied to all countries, "STRATEGO WP2 - main report 20160202 – version 2.PDF", figure 30,

        - Only transmission, distribution and branch pipes. (Not including substations in the houses – which is 2000 EUR/house. System without heat exchangers.
        - Example – Helsingborg-Lund (55 km), one DH network.
        - Costs calibrated with typical Danish and Swedish project costs. See "HRE – creating flexibility using district heating, HotCool 2016.docx", 8 pages
    - Heat infrastructure (not integrated in EnergyPLAN, but in "Additional" (calculated in HRE3), although this may be updated during HRE4.

General:

- The 'Business-As-Usual' scenario will be referred to as the 'Baseline' scenario. It will assume that the EU meets is 2030 target of a 40% CO2 reduction, with minor reductions after that point.
- Results from a 80% low carbon scenario from JRC-EU-TIMES can be shared to improve the understanding of a carbon constraint on the remaining heat demand as well as available heat from for example the power and industry sector. Using these results is optional.
- For cooling, the JRC-EU-TIMES model has 1) an electricity demand and 2) a typical COP. It does not include a breakdown of the number, size, and type of units. EnergyPLAN will align with this.
- Gross Inland Consumption refers to Primary Energy Supply plus fuels consumed for Non-Energy Use
- The total electricity produced by the power plants excludes "own use of electricity" in the JRC-EU-TIMES model. Instead, this is included in the efficiency of the power plants. EnergyPLAN will align with this.

2050

Heat Roadmap Europe

A low-carbon heating and cooling strategy

WP3, WP4, WP5, and WP6

Working Meeting – Final Minutes

Utrecht, the Netherlands

25-26th October, 2016

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 695989.

Table of Contents

1 Participants and travel itineraries

Utrecht

1. Robert Harmsen
2. Cathelijne Rutten

JRC

1. Wouter Nijs
2. Pablo Ruiz Castello

ISI Fraunhofer

3. Rainer Elsland (Monday to Wednesday)
4. Tobias Fleiter (arriving for 26th) (Tuesday to Wednesday)

TEP Energy

5. Ulrich Reiter
6. Giacomo Catenazzi

AAU

7. David Connolly
8. Susana Paardekooper
9. Kenneth Hansen

2 Agenda Day 1, Tuesday October 25th

2.1.1 FORECAST (ISI)

- Overview of the FORECAST Model
  - Main purpose
  - Inputting data types
  - Running the model
  - Type of outputs
  - Future developments
  - Present some exemplary results in order to show the capabilities of the model
  - (if time: present a very simple model to show working)

2.1.2 Overview of meeting in Petten

- Introduction to TIMES (JRC)
- Introduction to EnergyPLAN (AAU)
- General agreements and alignments

2.1.3 Upcoming deliverables and status (AAU)

- Overview and synergies between the modeling in HRE4
- Tasks in WP3, 4, 5, and 6.
  - D3.1 Profile of heating and cooling demands in the base year (ISI)
  - D3.2 Cooling technology datasheets (AS)
  - D3.3 Baseline/2050 for heating and cooling in buildings (November: ISI)
  - D3.4 Baseline/2050 for heating and cooling in industry (November: UU)
  - D3.5 Report for lead-users on FORECAST (February: ISI)
  - D5.1 Methodology report on JRC-EU-TIMES and EnergyPLAN (February: AAU)
  - D4.1 Methodology document "cost-potential curves" (May 2017: UU)
  - D5.2 Model outputs for BAU/Baseline/2050 scenario from JRC-EU-TIMES (May 2017: JRC)

3 Agenda Day 2, Wednesday October 26th

3.1.1 Issues that need alignment

- What should we align and to what extent?
    - Energy consumption/demand
    - Capacities
    - Costs
        - JRC report that PlanEnergi are doing
        - AS cooling datasheets
        - WP3 heat savings costs (Robert)
        - Interest rate approaches
        - Fuel costs
    - Building types (inc. commercial)
    - Industrial categorisation (Wednesday)
    - Degree heating days
    - Vehicle number, types
- Baseline scenarios/2050
    - Baseline scenario 2050: this will assume that the EU meets is 2030 target of a 40% CO_2 reduction, with minor reductions after that point.
    - How much of FORECAST and TIMES must we connect for those?

3.1.2 Finalise decisions

- Agreements on extent of alignment
- Sources for common inputs
- Confirm action table
    - D3.3 and D3.4: is the end of November still a credible date?
    - Technology catalogue coming from PlanEnergi: no distinct date yet.

Responsible	Due date	Action
ISI	19 October 2016	Upload WP3 Exchange Template with 2015 industry, tertiary and residential sectors
JRC	21 October 2016	Provide the TIMES model for Italy 2010 to AAU
ISI	4 November 2016	Draft D3.1 Profiles for Base year (2015)
AS	4 November 2016	Draft D3.2 Cooling technology datasheets
ISI		*Draft D3.3 Baseline/2050 for heating and cooling in buildings*
UU		*Draft D3.4 Baseline/2050 for heating and cooling in industry*
AS	28 November	Final D3.2 Cooling technology datasheets
ISI	*30 November 2016*	*Final D3.3 Baseline/2050 for heating and cooling in buildings*
UU	*30 November 2016*	*Final D3.4 Baseline/2050 for heating and cooling in industry*
AAU	30 November 2016	Provide replication of Italy 2010 in EnergyPLAN to compare

3.1.3 Reference files:

- Sync/Shared HRE4 files/WP6 – Scenarios/Meeting Utrecht October 2016
- Sync/Shared HRE4 files/WP6 – Scenarios/Meeting JRC August 2016
    - Agenda and Minutes
    - Modeling Exchange To Do List (most current version)
- Grant Agreement

4 Minutes of the Meeting

4.1 Attendees

- Susana Paardekooper susana@plan.aau.dk, AAU
- David Connolly david@plan.aau.dk, AAU
- Kenneth Hansen khans@plan.aau.dk, AAU
- Wouter Nijs Wouter.NIJS@ec.europa.eu, JRC
- Pablo Ruiz-Castello Pablo.RUIZ-CASTELLO@ec.europa.eu, JRC
- Cathelijne Rutten c.c.s.rutten@uu.nl, UU
- Rainer Elsland, Rainer.Elsland@isi.fraunhofer.de, ISI
- Robert Harmsen, R.Harmsen@uu.nl, UU
- Tobias Fleiter, Tobias.Fleiter@isi.fraunhofer.de, TEP
- Ulrich Reiter, ulrich.reiter@tep-energy.ch, TEP
- Giacomo Catenazzi, giacomo.catenazzi@tep-energy.ch, TEP

4.2 Minutes

Minutes: Susana Paardekooper, Octover/November 2016.

The meeting began with a round table introduction and afterwards, followed the items outlined in the agenda. However, some key topics became the focus for discussion during the meeting, which are outlined in more detail below.

4.2.1 Interest Rate

The approach towards discount rates throughout the energy models is two-fold:

- We will aim to explain the differences, and analyse what the impact of the different approaches towards the interest rates are.
- Depending on the ease with which the models can be connected, we will run separate analyses where we try to make the discount rates similar, to understand to what extent the results are a function of differing interest rates and other methodological differences.

A separate document will be created by AAU and circulated which expands on this. This will also form a basis for discussing those issues in the methodology reports.

In summary, the interest rate is used to represent different things in each of the models:

- FORECAST: private, technologically specific discount rate, which reflects policy initiatives, barriers, and intangible costs. This is appropriate because it is used to model and simulate peoples' decision making. This discount rate is applied to find specific costs over a lifetime, and in intertemporal decisions.
- JRC-EU-TIMES: a mix, since for the evaluation of investment decisions private discount rates are used, but for investment timing a social discount rate is applied. The first determines whether an investment pays off with the assumed private discount rate. The higher the (perceived) risk the higher the discount rate. Technologically specific discount rates are used to balance planning approaches and include risks for specific technologies. The second determines when is the best timing to do investments reflecting the time preference for consuming as well as a decreasing marginal utility of future consumption.This discount rate is applied primarily to make intertemporal decisions based on NPV.
- EnergyPLAN: social discount rate, which reflects the central planning and sustainability approaches. Only one year is modelled, so discount rates are used to annualise cost, which are used as an input for decision making.

Model	Time value of money	Risk premiums	Access to capital	Liquidity	Reflecting barriers
FORECAST	High – private users	High – private users	Less access – private users	Lower – private users	Yes – in order to forecast behaviour accurately
JRC-EU-TIMES	Low – societal perspective	High- private users	Less access – private users	Lower – private users	No – societal perspective
EnergyPLAN	Low / societal perspective	Low / societal perspective	Easy access / societal perspective	Higher / societal perspective	No / based on policy change

4.2.2 Definition of Heating

It is important to make sure that it is clear what the data means when it is transferred between models. Therefore, we defined the following terms for three distinct steps:

A. **Final Energy:** Energy input to the heating unit (such as a fuel to a boiler or heat/cold to a substation)
B. **Delivered Energy/Secondary Energy:** Heat/cold produced by the heating/cooling unit
C. **Useful Energy:** Useful heat delivered to the user (such as space heat and hot water after some losses due to the internal heat distribution system and the building).

Using this framework, we created an energy flow for three types of heating units (see picture from the whiteboard at the meeting):

- Boilers
- Heat Pumps
- District Heating

Fraunhofer (Rainer) will create a more detailed version of this for dissemination. Wouter presented an example from some previous work, which may be useful when defining losses: (P16: https://www.belspo.be/belspo/organisation/Publ/pub_ostc/CPen/rCP22_en.pdf)

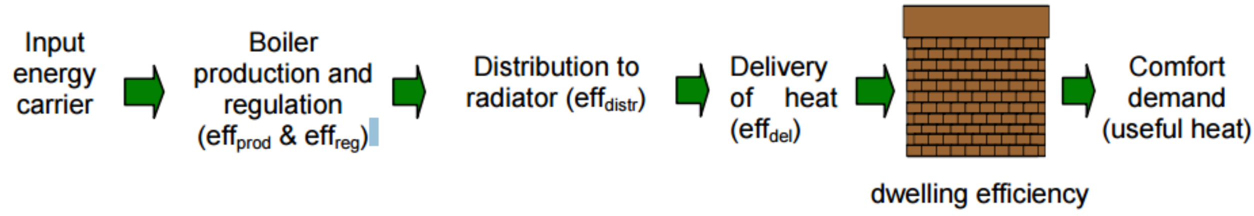
When data is transferred between models, it is important to define:

- What the data relates to i.e. Final Energy, Delivered Energy, or Useful Energy
- What an efficiency represents i.e. transfer from Final Energy to Useful Energy OR from Final Energy to Delivered Energy

CONCLUSION:

- For the cost curves, delivered energy will be provided to EnergyPLAN.
- For the buildings and industry, Final energy and Delivered Energy will be provided to EnergyPLAN.
- If the outputs of FORECAST are going to be used as an input for JRC-EU-TIMES, *for Industry* final energy would be provided (sectoral level) and *for Buildings*, final energy, useful energy and insulation would be provided.

Figure 2: Efficiency of a dwelling



Total heat efficiency of a heating system (eff_{inst}) can thus be divided into four components: production (the boiler), regulation (the system is not 100% flexible to the demand), distribution (from boiler to heating units) and heat delivery (e.g. convectors deliver heat less efficient than radiators).

$$eff_{inst} = eff_{prod} * eff_{reg} * eff_{distr} * eff_{del}$$

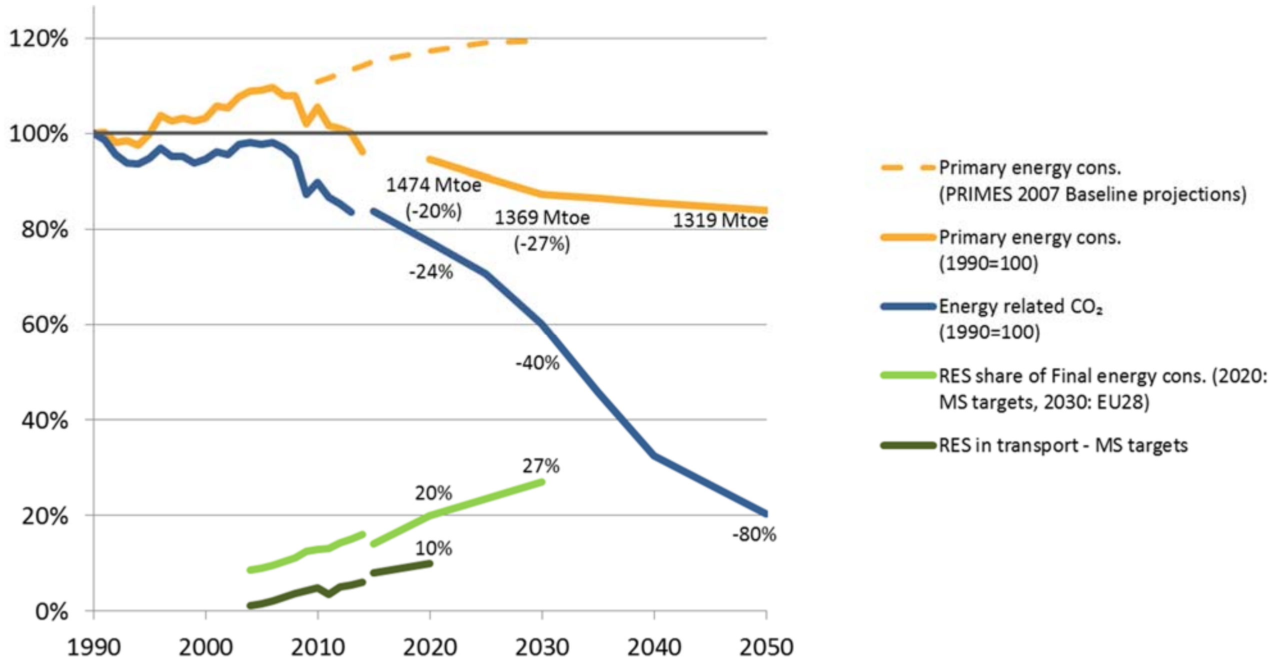
where:
eff_{prod} : efficiency of the boiler
eff_{reg} : efficiency of the regulation
eff_{distr} : efficiency in the heat distribution
eff_{del} : efficiency of heat delivery

4.2.3 Defining the Baseline

The Baseline we create in HRE4 will need to be linked to the development of the energy system resulting from the baseline assumptions. Some proposals defining this at the meeting included:

- Replicating the latest Reference scenario results from PRIMES: achieve a 35% CO2 reduction in 2030 and a 48% reduction in 2050.
- Meeting the EU targets (see examples below): 40% CO2 reduction in 2030. The 80-90% CO2 reduction target for 2050 is not considered a 'Baseline' scenario at present, so in 2050 the Baseline would likely represent a minor improvement from 2030, similar to the PRIMES approach. There is also an official renewable energy target of 27% in 2030.
- FORECAST has simulated a 'Baseline' already for 2030 based on the impact of existing policies and came to a CO2 reduction of ~30% and renewable energy share of ~25%.

The JRC will consider these different approaches to define the Baseline and will write the aim of this Baseline. Fraunhofer will proceed with their existing Baseline for now, since it represents what existing policies can achieve.



4.2.4 Purpose of the different models:

- FORECAST will provide a Baseline from the 'end-users' perspective using existing policies between the years 2015 and 2050. The modelling in FORECAST includes 'end-user' prices so they include taxes and subsidies, within the framework of existing policies. Therefore, the Baseline in FORECAST will indicate what will happen if the market responds to the measures currently in place. Fraunhofer have already made a Baseline for 2030, but this will be extended to 2050. FORECAST is a demand-side model, so it does not include generation: for example, the electricity market is represented as a price rather than modelling the supply/generation portfolio.
- The JRC-EU-TIMES model also presents the transition from 2015 to 2050, but from an energy system perspective, so it models both generation/supply and demand. It has a mix of societal perspective and end-user cost of financing, rather than a complete end-user perspective like FORECAST.
- EnergyPLAN is an energy system model and it has a societal perspective, but it only models one year whereas JRC-EU-TIMES models many years during the transition from today until the future.

Model	FORECAST	JRC-EU-TIMES	EnergyPLAN
Economic Perspective	Private End-User	Mix of Societal & Private End-User	Societal
Energy System	Built Environment & Industry	All Sectors	All Sectors
Time Horizon	Years/Decades	Years/Decades	One Year
Resolution	Annual	12 time-slices and 24 periods in the power sector	Hourly

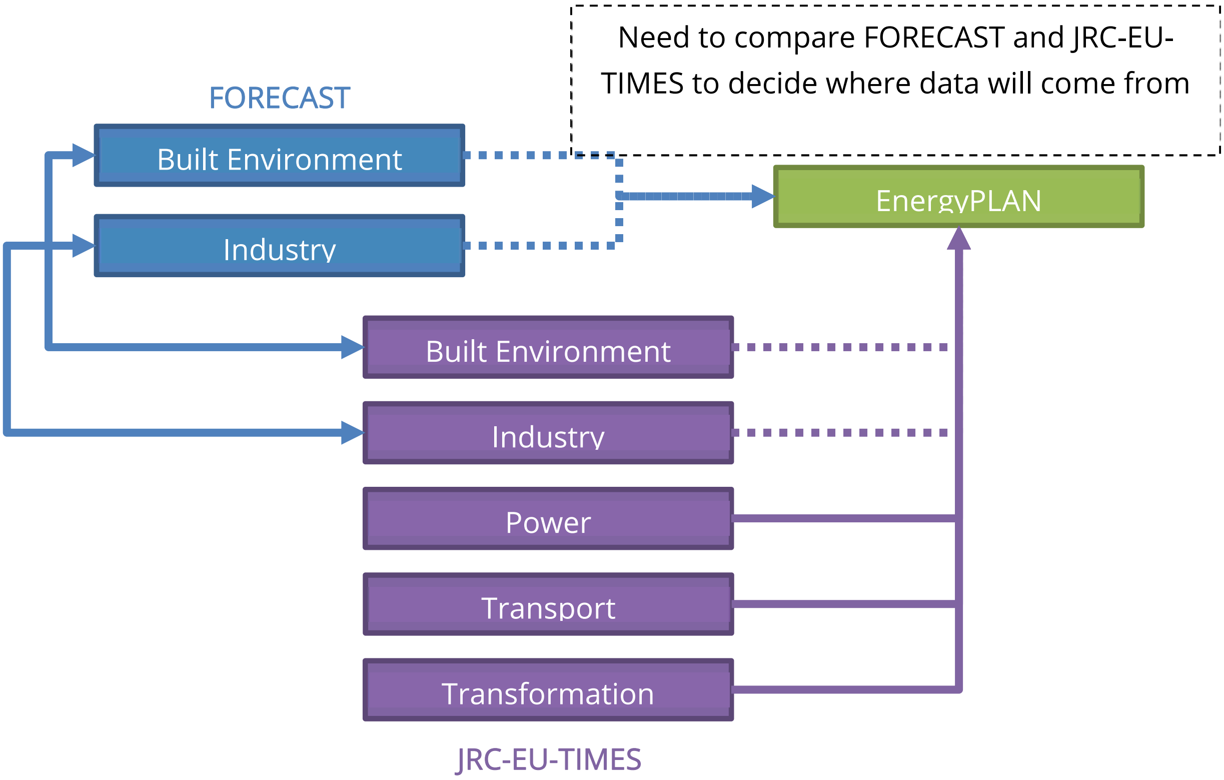
4.2.5 Flow of data between the models:

- FORECAST and JRC-EU-TIMES will both model the transition from 2015-2050. The basic assumptions for the Baseline will be taken from the latest EU Reference scenario from PRIMES, such as
  - fuel costs
  - CO2 costs or total energy related CO2 emissions
  - Population
  - GDP
  - wholesale electricity prices, but not in JRC-EU-TIMES because this is an output and not an input.
- Other data will need to be aligned internally such as:
  - Investment costs
  - O&M costs
  - Lifetimes
  - Learning rates (maybe in PRIMES report)

  AAU will collect and compare this data which needs to be aligned internally. The JRC would like to distinguish between 'overnight capital costs' and the 'costs of financing' in the final investment cost results from the modelling.

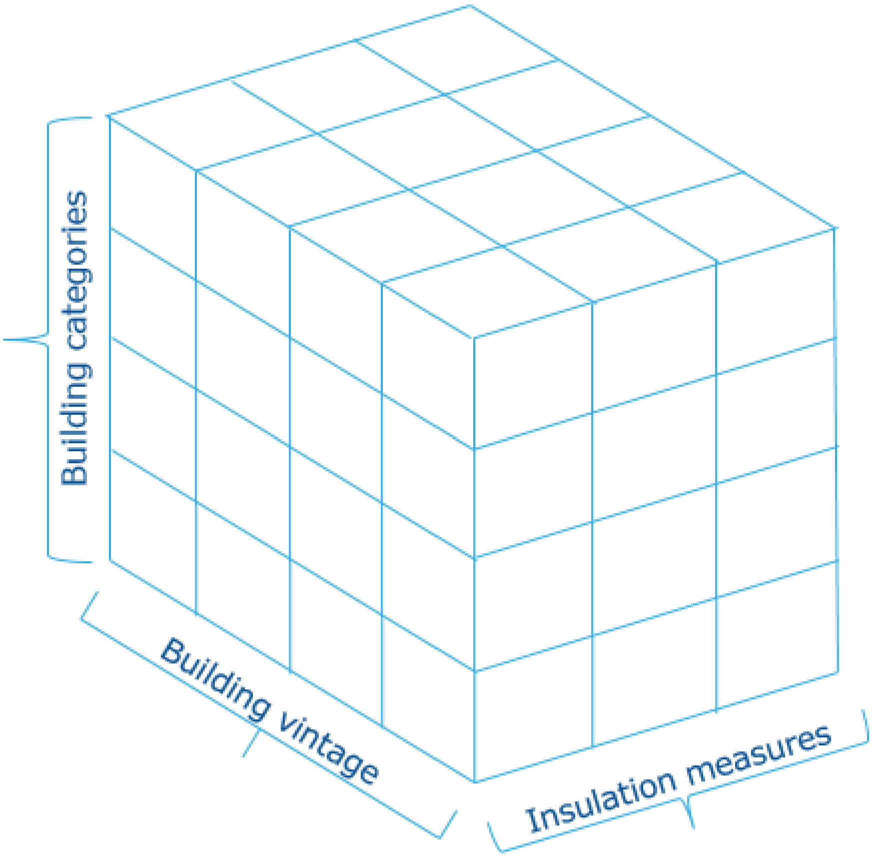
- FORECAST and JRC-EU-TIMES both include a detailed breakdown of the Built Environment and Industry, so these will need to be aligned with one another. It is not clear at present how easy it will be to connect these, so for now, the Baseline will be constructed in both models and compared with one another: this will occur at the next meeting via video, which will take place on the 12th December:

- It seems possible for the built environment. The coupling could be by fixing the final energy (Forecast to JRC-EU-TIMES), by aligning (bidirectional) all key inputs (prices, technology characteristics etc…) or by doing 1 or 2 iterations. JRC can run JRC-EU-TIMES with and without such constraints and then try to explain/understand the differences. JRC presented their background data for the built environment. See slide called "Main Input Parameters" in the JRC presentation.
- For industry the comparison may be difficult since some subsectors of the industry are modelled explicitly in JRC-EU-TIMES such as the iron and steel industry. Will see if they can align industry categories.



Building Characteristics in JRC-EU-TIMES:

- Categories i.e. Single-Family, Multi-Family, detached, semi-detached
- Vintage: year of construction
- Insulation measures: how much, etc

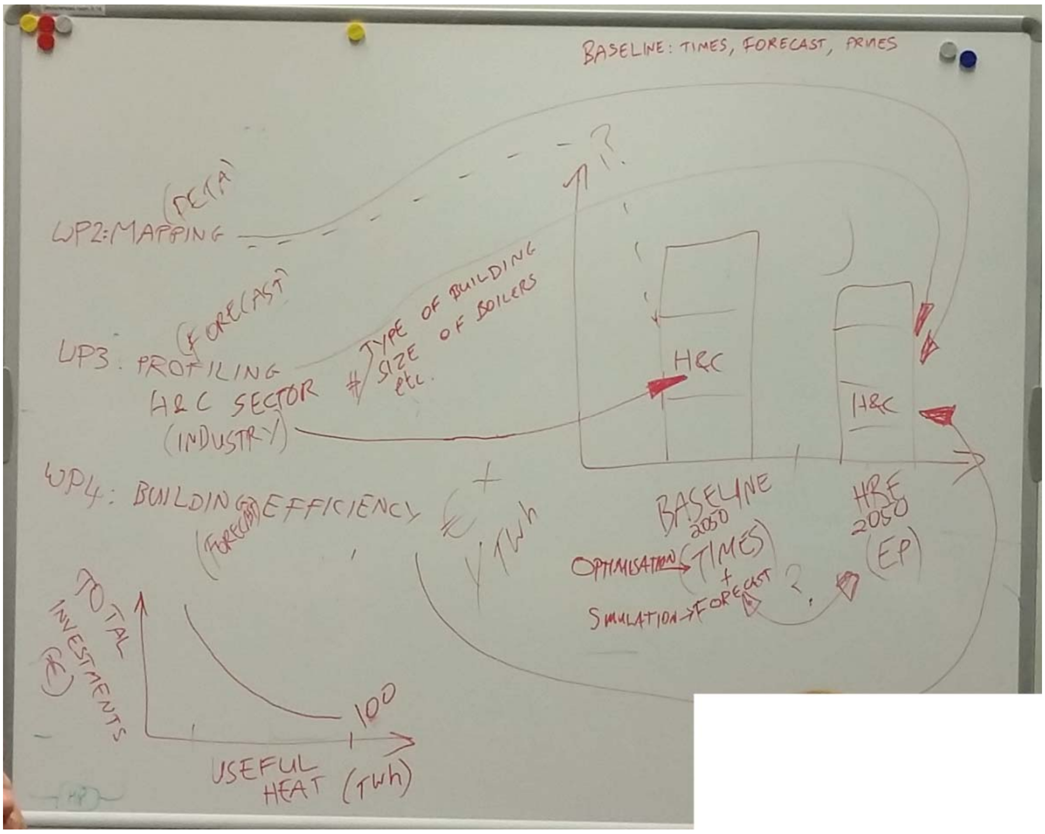


4.2.6 Scenarios and the Models Used for in each one during HRE4

There are four models in total in HRE4, each with a very specific strength in the project:

- Peta: Geographical representation of heat/cold demands and potential supplies
- FORECAST: Detailed breakdown of the heating and cooling sectors. Can model the transition of the heating and cooling sectors over decades.
- JRC-EU-TIMES: Can model the energy system over decades.
- EnergyPLAN: Models the energy system on an hourly basis over one year.

The ultimate aim of combining these models is to use each of their strengths to produce a robust 'Heat Roadmap' for each of the 14 countries in HRE4. The group discussed how each model and WP will feed into the final scenarios which are presented graphically in the picture below.



4.2.7 Data Available from Peta in WP2

All three energy models (FORECAST, TIMES, and EnergyPLAN) will benefit from the results from Peta in WP2. The two important results from Peta for the energy modelling will be:

1. District heating network costs, which are described in detail in the HRE3 Background Report 6 [1]. Note that Peta will only provide the cost of the piping network for district heating, so the 'heat supply' price must be calculated separately or potential obtained from EnergyPLAN. Similarly, the cost of installing a substation in the home for the district heating network will also need to be added.
2. Excess heat potentials, which are described in the paper Persson *et al.* [2]

AAU presented how these results can be applied in an energy systems analysis tool. For example, the district heating network costs will be provided in a similar format as in HRE3, quantifying the cost to construct district heating networks for increasing shares of district heating penetrations (see below). The excess heat volumes will be provided for power plants, industry, and waste incineration as documented in Persson *et al.* [2], as well as in the video available here.

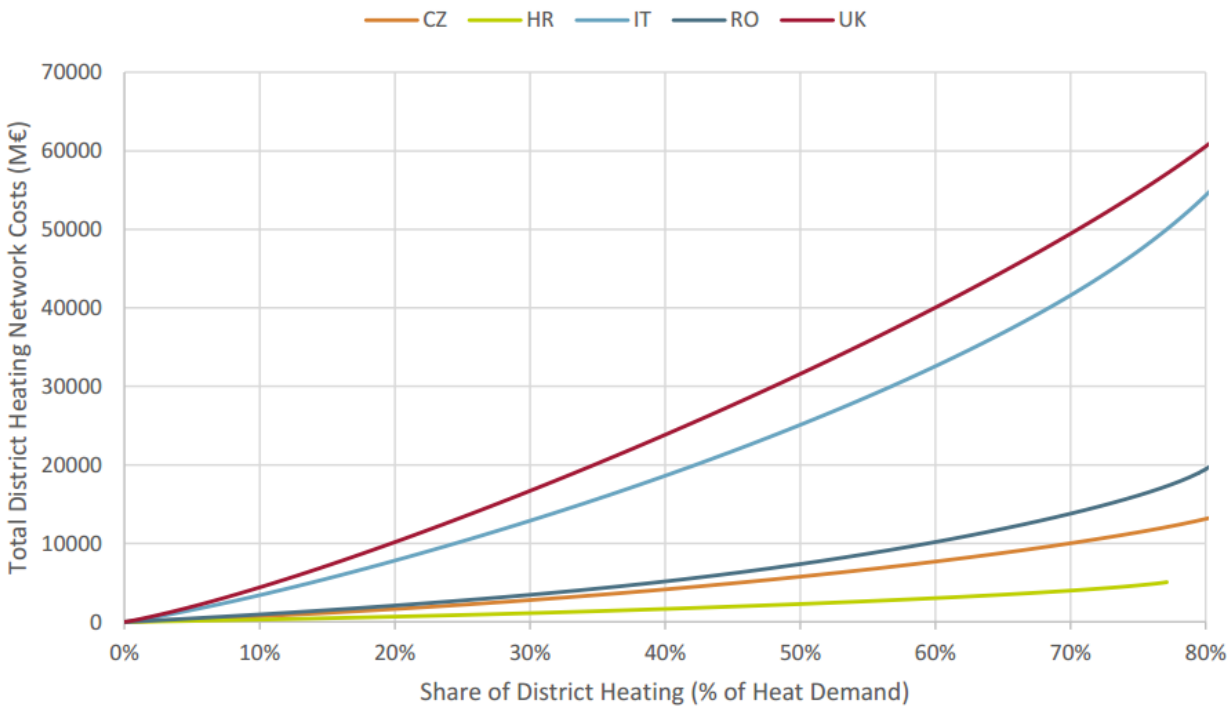


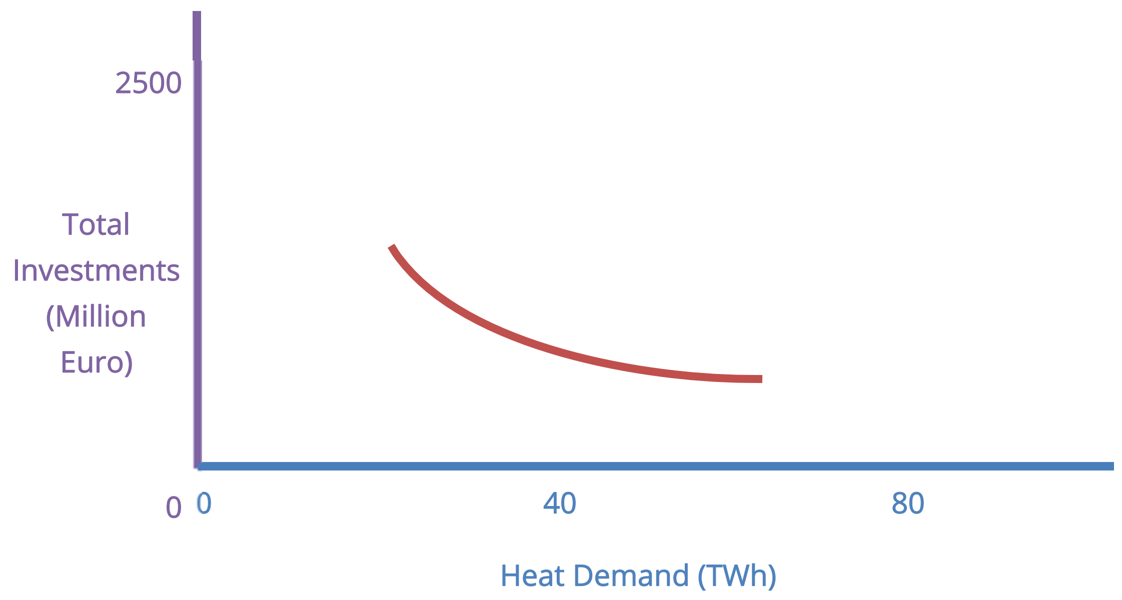
Figure 10: Investment costs in district heating pipes for various levels of district heating supply in the five STRATEGO countries. These costs were updated in Version 2 (January 2016) based on the new costs in Background Report 6, but the changes did not affect the overall results.

From Page 25 of the STRATGEGO Main Report:
http://www.heatroadmap.eu/resources/STRATEGO/STRATEGO%20WP2%20-%20Executive%20Summary%20%26%20Main%20Report.pdf

4.2.8 Cost Curves

WP4 has started with a general inventory of the demands of EnergyPLAN and the available outputs of FORECAST. Initial discussions showed that work needs to be done to obtain a common understanding what cost curves are about and how they should be constructed. UU has started the development of the cost curve method. This document is supposed to be a living document involving the relevant project partners in its development. A first draft will be circulated for comments in December 2016.

The cost curve for EnergyPLAN will need to represent 'Total Investments in Building Measures i.e. Insulation, Doors, Windows' compared to the 'Total Useful Heat/Cold Demand', see below.



4.3 Action List

4.3.1 All

- Put slides on Sync
- See Table Below with Key Deliverables in the coming months

Responsible	Due date	Action
ISI	19 October 2016	Upload WP3 Exchange Template with 2015 industry, tertiary and residential sectors
JRC	ASAP	Define the framework for the 2030/2050 Baseline
JRC	ASAP	Provide the TIMES model for Italy 2010 to AAU
JRC	7 December 2016	Baseline for 2015, 2030 and 2050 – all 14 countries to AAU
ISI	4 November 2016	D3.1 Profiles for Base year (2015)
AS	4 November 2016	Draft D3.2 Cooling technology datasheets
AS	28 November	Final D3.2 Cooling technology datasheets
ISI	*30 November 2016*	*D3.3 Baseline/2050 for heating and cooling in buildings*
UU	*30 November 2016*	*D3.4 Baseline/2050 for heating and cooling in industry*

AAU	30 November 2016	Compare the costs from ISI, AAU, and JRC
AAU	30 November 2016	Make an overview of the role and application of the interest rate in FORECAST, EnergyPLAN, and TIMES: PRIMES have a 7 page overview in their report and p34 of the JRC report describes the interest rate in TIMES.
All	12 December 2016	Online meeting to compare Baselines in FORECAST and JRC-EU-TIMES. We start with comparing the numbers for Germany.
AAU	Will specify date once JRC provide inputs	Provide replication of Italy 2010 in EnergyPLAN to compare

4.3.2 Fraunhofer

- Rainer: Make an illustration of the definitions for heat i.e. Final Energy, Heat/Cold Delivered, and Useful Heat/Cold for:
    - Boilers
    - Heat Pumps
    - District Heating
- Send cost assumptions to AAU
- Fraunhofer will include the typical size of a boiler in the profile data
- Finalise a date from the next consortium meeting in conjunction with the WP7 partners, which will be in Brussels
- Fraunhofer will exchange industrial categories with JRC-EU-TIMES to see if they can align with each other.
-

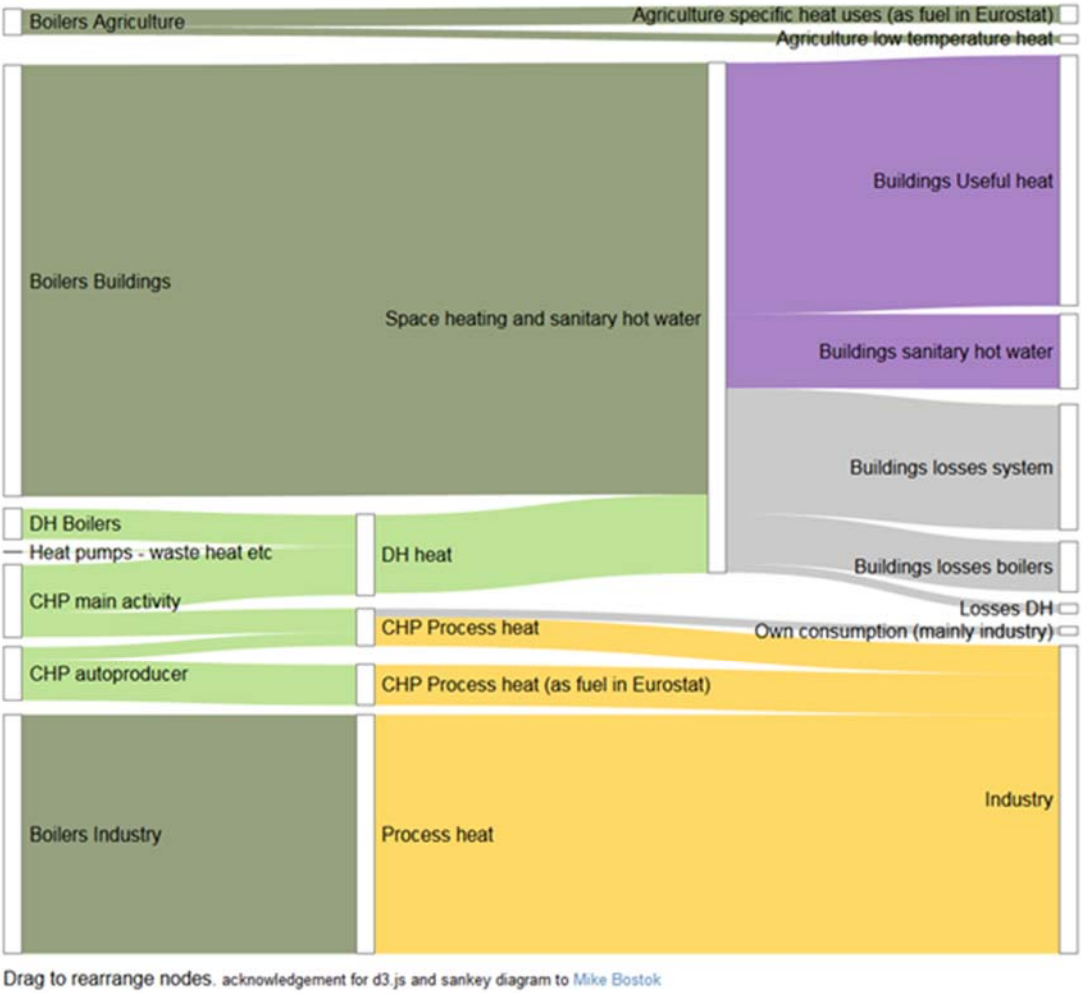
4.3.3 AAU

- Compare costs from FORECAST, EnergyPLAN, and TIMES
- Create overview of interest rate: what it is and how it is used in each model. Can also include a comparison of how PRIMES consider the interest rate: they provide a 7 page overview in their report (Annex 4,4). The JRC would like to distinguish between 'price' and the 'cost of financing' in the final cost results from the modelling. Robert also described how the specific costs are the same regardless of the approach i.e. private or social.

- Send paper with IPCC degree day predictions for the future to JRC
- Send 'Print Results' from EnergyPLAN to JRC for the Italy 2010 and 2050 models from HRE3
- Send material comparing EnergyPLAN and PRIMES from HRE2 and HRE3 to JRC (Pablo)

4.3.4 JRC

- Send cost assumptions to AAU
- Define Baseline i.e. what will it represent
- Send the 2010, 2015, and 2050 model of Italy to AAU so it can be replicated. Need to resolve:
    - Capacity vs. Production issue for CHP
    - Heat pumps are expanding too fast at present
    - Degree days in 2010 were very high so future years need to consider this
- Align Baseline with Fraunhofer/FORECAST
- Heating sector breakdown will look something like below:



4.3.5 UU

- Describe how the specific costs (euro/ton or euro/GJ) of a technology are the same (assuming no learning and constant fuel and O&M costs) regardless whether the investment is made today or in twenty years from now (the NPV of both investments will differ).
- Develop the methodology for the 'cost curves'

Discount rates

N.B. This working document was finalised in January 2017 and further developments have taken place in D5.1: Methodology for linking energy models.

Because HRE4 uses four different models, it is imperative to have a coherent understanding of how interest rates are used to discount costs and benefits, and for what purpose. This does not mean we will necessarily align interest rates, but it will allow us to understand some of the drivers for different results.

In short, EnergyPLAN uses a social approach to time-discounting, FORECAST is a private decision making model so uses private decision making discount rates, and the JRC-EU-TIMES model uses a social approach towards time-value of money, but uses technology-specific discount rates to express risk and uncertainty as applicable to different technologies. These three different types of modelling are consistent with the different purposes of the model in HRE4.

1.1. Overview of time-discounting and the discount rate

The discount rate is used to account for time passing before or while a decision or investment is being made. Since HRE4 concerns both investments which are to be made in the future as well as many technologies whose lifespans hugely excess a single year, discounting will allow for an accurate comparison between technologies, investments, and scenarios.

Specifically, there are two main uses for the discount rate in HRE4.

- Choices between technologies or scenarios with different lifetimes, by finding 'specific costs' or equivalent annual costs.
- Choices about at what point in time to make decisions concerning technologies and scenario development (intertemporal decision making).

Discounting is done with a discount rate, which is used to express the time preference observed in decision-making and investment. The discount rate can be conceptualised as consisting of several components:

- Time-value of money: to what extent is the future as important as the present?
- Risk premium: what is the risk of this investment?
- Opportunity costs: what is the cost of using this now?
    - Liquidity and access to capital: is borrowing money an option?
    - Reflecting barriers: intangible costs, non-market barriers that dissuade financing into these options

1.2. Discount rates in HRE4 models.

The discount rate is used in function of what the model contributes to the HRE4 project. Broadly speaking, FORECAST and the JRC-EU-TIMES models are used to create a baseline, based on current policy projections and expected behaviour and the EnergyPLAN model is used to develop a more socially optimal Heat Roadmap Europe scenario for 2050.

Model	Time value of money	Risk premiums	Access to capital	Liquidity	Reflecting barriers
FORECAST	High – private users	High – private users	Less access – private users	Lower – private users	Yes – in order to forecast behaviour accurately
JRC-EU-TIMES	Low – societal perspective	High- private users	Less access – private users	Lower – private users	No – social perspective
EnergyPLAN	Low – social perspective	Low – social perspective	Easy access - social perspective	Higher – social perspective	No - based on policy change

1.2.1. FORECAST

FORECAST is intended to forecast the future and express what kinds of developments will take place in the baseline approach, under certain policy conditions. FORECAST works as a market optimisation model based on consecutive and cumulative decision making, meaning it has to factor in the (shorter term) available interest rates to the different private entities who are responsible for the investment choices. In addition, FORECAST can be used to make intertemporal decisions, and create a distinct pathway between now and 2050 as to when certain technologies are expected to be implemented and in what quantities.

This forecasting approach means that private time value of money is used, since the model aims to replicate and forecast the choices of private entities. This also means the risks, liquidity and access to capital are privately bourn, and need to be representative of the access and judgement of the private partiers' whose behaviour is modelled as expected. Similarly, different types of policy barriers, intangible costs, and information barriers are also included, since these are factors which will affect the decision making in a forecasted scenario.

The role of FORECAST in HRE4 is to provide a valuable insight to the developments and expectation of the buildings sector in Europe specifically over the next 35 years, but also to create a baseline scenario. The aim of the baseline developed by FORECAST is to incorporate the ways in which policy and technology developments are expected to influence the market for buildings and energy efficiency initiatives in the future under the main drivers on which decisions are made within the current market framework. This baseline can then be used to compare with alternative scenarios in order to develop the best 'Heat Roadmap Europe' scenario possible and be able to inform policy decisions.

1.2.2. JRC-EU-TIMES

The JRC-EU-TIMES model aims to analyse the role of energy technologies and their innovation. As an optimisation model, JRC-EU-TIMES aims to show the impact and possible pathways based on policy initiatives and technology developments. In order to accommodate the current market starting point and reflect the long-term planning and increasingly sustainable ambitions for the energy system, JRC-EU-TIMES uses a combination of time value of money and cost of capital rates for different technologies.

Specifically, the JRC combines a more social approach towards the time value of money and a more private approach towards the cost of financing based on the individual technologies. The JRC-EU-TIMES model uses a social rate to express the time value of money, to continue relating the pathways to public sector sustainability ambitions and policy assessments. However, the cost of capital is technology specific, and based on the access to capital and risks to private investors. Using these rates allows for an approach that will consider sustainability, but also mimics the decisions and actions made in the energy market in an intertemporal way.

The role of JRC-EU-TIMES in HRE4 is to contribute to the energy efficiency initiatives in the baseline scenario (using inputs from FORECAST), and to develop the baseline for the entire energy system. The inclusion of differentiated interest rates means that the model is expected to accurately show the potential and role of different energy technologies within the current framework.

1.2.3. EnergyPLAN

The aim of EnergyPLAN is to be able to simulate and model energy system scenarios to understand their impact, including the equivalent annual costs, from a social perspective. The model is designed to look towards 100% renewable energy systems and be able to incorporate radical technology changes. This means that EnergyPLAN is purposely unrestricted by current policy boundaries, assumes very high levels of reallocation, and assumes a high level of risk-sharing. This allows for the development and optimisation of a future scenario without sub-optimal decision making, and 'cost-benefit' of what the system would look like for society at large, and a direction for where public funding and policy should be steering towards.

Given the EnergyPLAN model is primarily aimed at understanding how sustainable energy systems can be designed and planned, there is an inherent implication that the future is afforded importance and the time value of money is low, to reflect the sustainable ambitions assumed in the scenario design. Similarly, the social and central planning approach means that risk premia are kept low since there is an assumption that risks can be spread over both society at large and all the different technologies in the system. The treatment of access to capital in EnergyPLAN similarly assumes a high level of reallocation, the removal of explicit barrier to access capital, and the removal of other barriers to decision-making.

The role of EnergyPLAN in HRE4 is not to mimic a current pathway, but to design an improved energy system, based on different types of energy efficiency initiatives in both the supply and the demand sector, in order to show the impacts, feasibility and necessity of a socially more optimal system. The use of a much more social discount rate in EnergyPLAN reflects this aim and the central planning approach from a social perspective, and allows for modelling that can inform the funding and policy strategies of public bodies at different levels of government.

1.3. Further steps

To be continued in methodology document; this will be heavily dependent on how well the models can turn each other's' respective results into new inputs to produce reiterations.

Overall impressions from the meetings:

- Every model will use their own approach initially, because it best suits the function that we need the models to have at the moment.
- It will be important to know at the end of the different modelling comparisons what the impact of the interest rate was on the results.
- If JRC-EU-TIMES would like to start optimising towards the EnergyPLAN HRE scenario, or starts iterating with EnergyPLAN, a way to correct for the differentiated discount rates will be required, since otherwise we cannot compare if the difference is in the workings of the model, or due to the discount rates returning a different optimum.

1. Hourly distributions

Key inputs for any scenario developed within EnergyPLAN are hourly demand and supply distribution profiles. Depending on the analysed case these profiles include the following:

- Demand profiles
  - Electricity demand;
  - District heating demand;
  - Individual heating demand;
  - Cooling demand;
  - Transport demand;
  - Industry demand.
- Supply profiles
  - PV electricity supply;
  - Solar thermal heating supply;
  - Wind onshore electricity supply;
  - Wind offshore electricity supply;
  - Nuclear electricity supply;
  - Accumulation hydro electricity supply;
  - Run of river electricity supply;
  - Tidal electricity supply;
  - Wave electricity supply;
- Electricity cross border trade.

The above mentioned distributions have initially been gathered and prepared for the 14 largest EU member states, as defined in the Grant Agreement, and later on expanded to the remaining 14 brining the end result to the scale of EU28. The methods used for their creation as well as some examples can be found below.

1.1. Hourly demand profiles

The hourly demand profiles needed by EnergyPLAN include electricity, individual and district heating, cooling, transport and industry demands.

1.1.1. Electricity demand

The hourly electricity demand profiles can be easily obtained for most EU member states from the ENTSO-E database [1]. Excel and visual basic have been used to prepare the gathered data in the needed form. Figure 1 shows an example of the created distribution. It shows the normalized hourly distribution of Germany's electricity demand for the first week of 2015. As can be seen, the data does not show the actual demand in kWh but a distribution of 0-100% of the peak load. The data has been gathered in a similar fashion for all EU28 countries, whenever possible for the year 2015. If the 2015 data was not available, the closest available year has been selected. Since 2015 was not a leap year and EnergyPLAN requires 8784 data points (366 days), one day has been repeated in the final distribution in order to comply with that requirement.

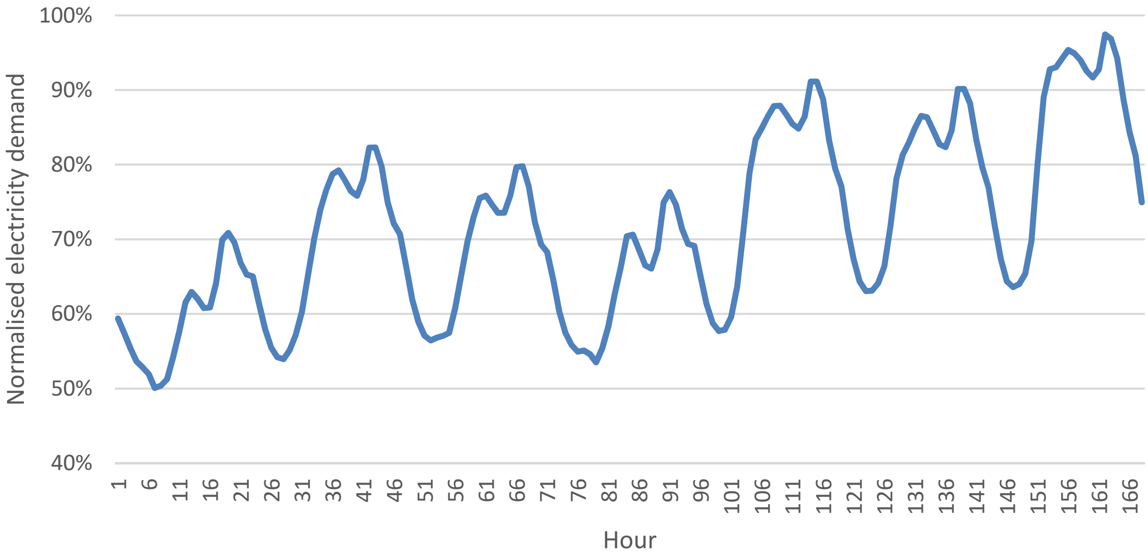


Figure 1 Example of the hourly electricity demand distribution

1.1.2. Heating demand

The hourly heating demand distributions have been created as a combination of the space and domestic hot water (DHW) heating demands, both for individual and district systems. The method is based on a degree day analysis for space and EU statistics for DHW heating. Additionally, the implementation of operational rules has been added to the created model in order to enable the simulation of end user behaviour in individual and operational guidelines in district heating systems. Figure 2 shows an example of the space and DHW demands used to create the final heating demand distributions. On the left, the space heating demand of the first week of a year for Germany can be seen while the right shows a generic hourly demand for DHW gathered from literature [2].

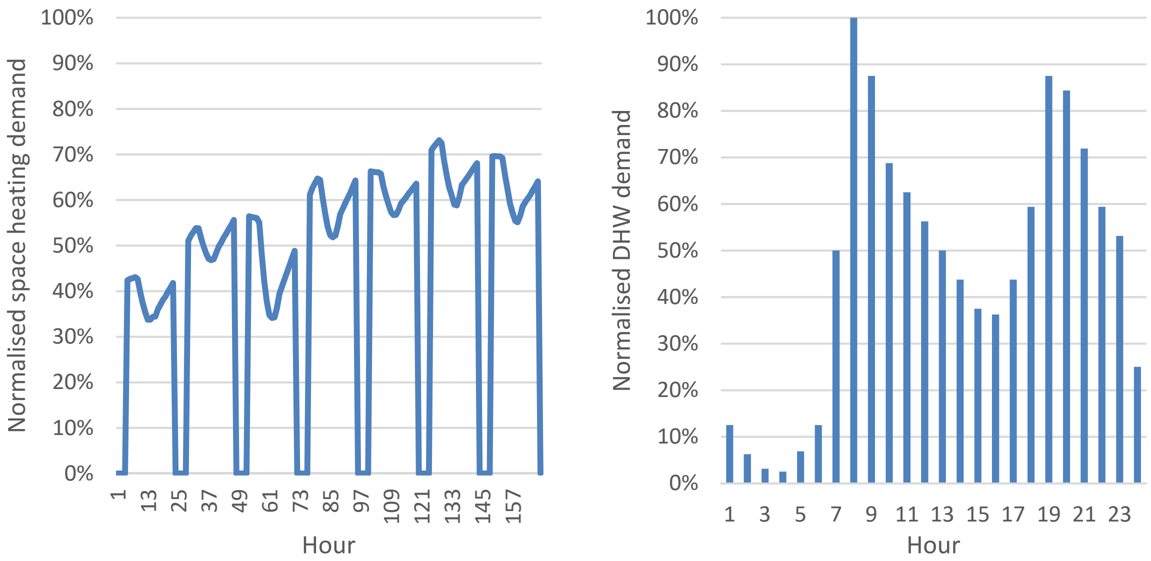


Figure 2 Examples of space and DHW heating demands

Meteonorm [3] has been used to gather the hourly outside temperatures of several cities within the observed country, 3 to 7 cities depending on its size. These hourly temperatures have then been used to create a degree hour analysis that has been supplemented with the above mentioned operational rules to create the final distribution. The rules can be modified in the validation process to achieve more realistic results. The share of DHW in the total heating demand has been gathered from the Odyssey database [4]. The process is the same for both individual and district systems but the distributions can be modified using the rules. In the case of the district heating distributions an assumed level of heat losses has been added. The total loses were assumed to be 9% of the total district heating demand (space and DHW). This has been distributed as a flat baseload. The share of loses can easily be modified from country to country if more accurate data can be gathered.

1.1.3. Cooling demand

The hourly cooling demand distributions have been developed in a similar fashion to heating. It should be noted that these data relate to district and not individual cooling which is represented in the electricity demand. The basis again consists of a degree day analysis utilizing the hourly outside temperature from Meteonorm [3] and operational rules. Where the rules described real life operations of district heating plants for the heating distributions, they have been used here to better described the non-weather dependent heating by adding a share of base load. Figure 3 shows an example of the created distribution for Germany. As it can be seen, a constant baseload is present. It represents the above mentioned non-weather dependent cooling such as process cooling, kitchens, data centres and server rooms. The ratios were taken from relevant literature and experience of the HRE advisory board [5].

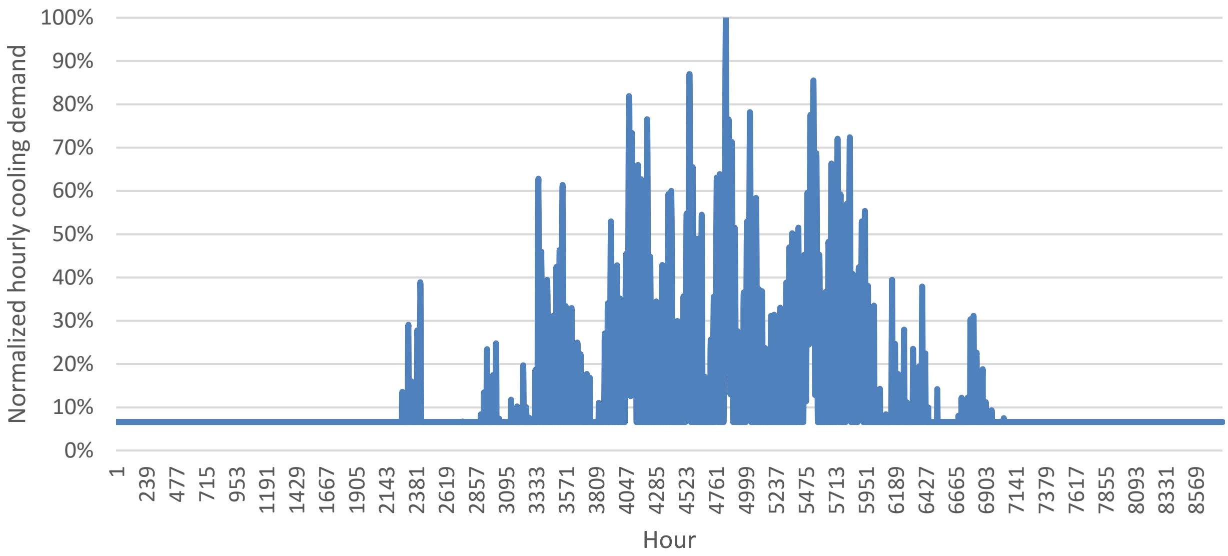


Figure 3 Example of the hourly cooling demand

1.1.4. Transport demand

The transport demand needed by EnergyPLAN basically represents the hourly energy demand of the road vehicles themselves. This can be quite accurately represented by the number of vehicles in traffic. Data such as this is not widely available. For this reason, modelled data has been used to create the normalized distribution. A detailed description of the methodology is provided in a paper created by the researchers at UNIZAG FSB [6]. Figure 4 shows the example for one week.

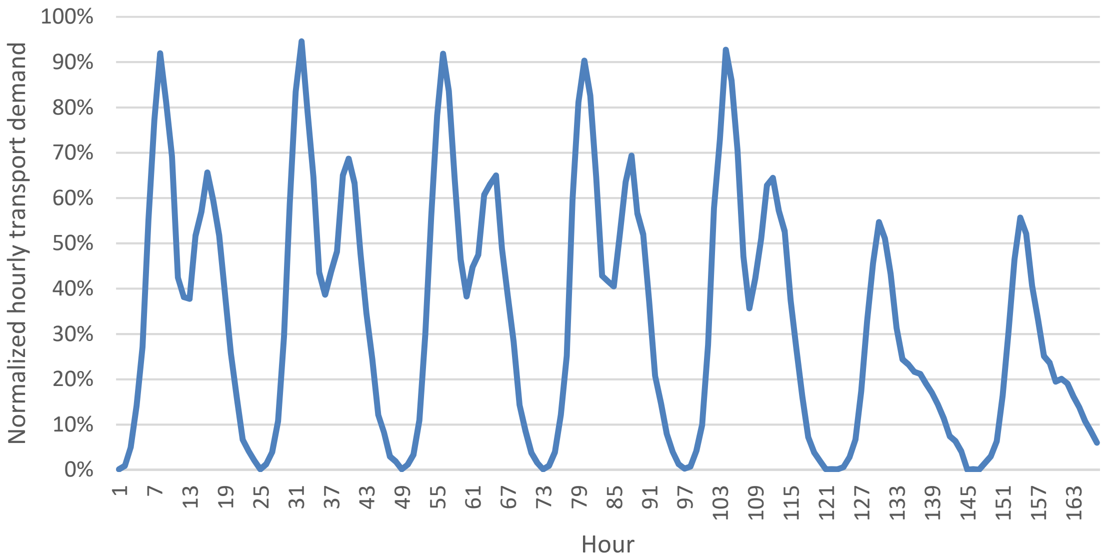


Figure 4 Example of the hourly transport demand

1.1.5. Industry demand

Since the hourly energy consumption of the industry sector greatly depends on its composition, something that varies greatly from country to country and from year to year it becomes quite difficult to model and predict. Additionally, it will also usually be very difficult to control and influence since industry is profit oriented. Because of this, industry usually provides a flat energy demand unless specific demand response techniques are not modelled. Due to all of this, the hourly industry demand distribution was assumed to be constant.

1.2. Hourly supply profiles

The hourly supply profiles needed by EnergyPLAN consist of renewable electricity and heat generations and nuclear power production.

1.2.1. PV electricity supply

The creation of the hourly PV supply distributions has been tackled via two approaches utilizing the EMHIRES dataset [7] and Meteonorm [3]. The EMHIRES dataset includes the historical normalized hourly distributions of PV generation for the EU-28 region. Whenever available, the 2015 data has been used, when it wasn't the closest year has been selected. Alongside this, the hourly distributions have also been collected from Meteonorm. For this purpose, a set of 3 to 7 cities have been collected for each observed country, depending on its size, and averaged to create the distribution. Both hourly datasets have been provided for each country.

1.2.2. Solar thermal supply

The hourly solar thermal supply distributions have been created by utilizing Meteonorm [3] data. Air temperature (T_a) and global solar radiation (G) on a flat plane and at the optimal solar angle have been collected for 3 to 7 cities for every observed country, depending on its size. Two sets of specific solar thermal supply curves have been created: with the optimal solar plane inclination and for the 0° tilted plane.

Besides the acquired meteorological data, additional technical specifications of the solar thermal collectors have been collected: optical efficiency of the solar thermal collector (η_0), mean collector fluid temperature (T_m), 1st order heat loss coefficient (a_1) and 2nd order heat loss coefficient (a_2). These characteristics strongly depend on a solar collector type: flat plate collector (FPC) and evacuated tube collector (ETC) [8]. In order to calculate the solar thermal supply distribution, a generic medium performing FPC collector has been chosen [9]. Its technical characteristics are shown in Table 1.

Table 1 Medium range FPC technical characteristics

Optical efficiency, η_0 [-]	1st order heat loss coefficient a_1 [W/Km2]	2nd order heat loss coefficient 2 [W/K2m2]	Mean collector fluid temperature T_m [°C]
0,75	3,4	0,0062	80

The overall efficiency of the solar thermal collector (η_C) has been calculated using the following equation [9], [10].

$$\eta_C = \eta_0 - a_1 \frac{(T_m - T_a)}{G} - a_2 \frac{(T_m - T_a)^2}{G}$$

T_a, G are hourly values, i.e. the solar collector's efficiency isn't constant. Mean fluid temperature, T_m, has been taken as a constant parameter, which isn't true. In reality, it is a dynamic variable which depends on the overall fluid flow, thermal demand, ambient temperature, etc. This was a simplification of the model. By knowing the overall efficiency of the solar thermal collector, the specific thermal power output can be calculated as follows:

$$P_C = \eta_C \cdot G$$

1.2.3. Wind supply

The hourly on-shore and off-shore wind supply distributions have been created in a similar fashion to PV. Again, both the EMHIRES dataset [11] and Meteonorm [3] have been used. Whenever possible, the normalised hourly distribution profiles for both on-shore and off-shore wind production from EMHIRES have been utilized. The year 2015 has been selected where available, where not the closest year. If EMHIRES data was not available, primarily for off-shore wind in countries that do not have any but do have potential such as Romania, the distributions have been modelled. Hourly wind speeds from Meteonorm and power curves for actual wind turbines have been used here. The data has been modelled using Excel. Figure 5 shows an example of the data for Germany. On the left, the on-shore wind supply and on the right off-shore wind supply is shown. The figure demonstrates the much higher average load factor of the off-shore wind which is expected.

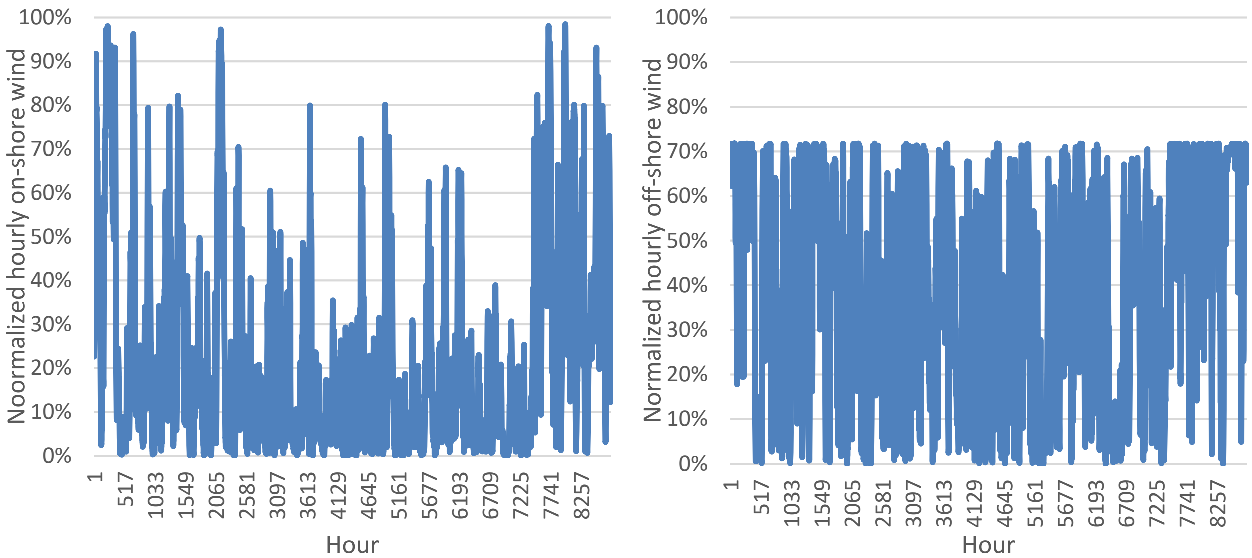


Figure 5 Example of the on and off-shore wind data

1.2.4. Nuclear supply

The nuclear distributions have been created by using the ENTSO-E countries' packages [1]. The provided datasets include aggregated monthly nuclear productions. In order to create the hourly distributions needed for EnergyPLAN, monthly values were divided by the total number of hours in the specific month. This way, 12 sets of hourly values were created and merged.

1.2.5. Hydro supply

The hydro supply distributions have been created by using the ENTSO-E countries' packages [1] and precipitation data from Meteonorm [3]. ENTSO-E hydro production consists of two datasets: renewable hydro (run of river) and other hydro (accumulation). Both are given as aggregated monthly values. In order to create the hourly distributions needed for EnergyPLAN, monthly values were divided by the total number of hours in the specific month. This way, 12 sets of hourly values were created and merged.

To develop more realistic hydro power supply distributions, additional white noise has been added to the created hourly values. As a scaling parameter, hourly precipitation has been chosen and collected for 3 or 7 cities, depending on the countries size, and then averaged. The hydro supply distributions were created using the following equation:

$$P_{hydro}(t) = \begin{cases} P_{hydro,monthly}(t) + P_{hydro,monthly}(t) \cdot \left[r(t) - r_{avg}\right] \cdot c_f, if\ r(t) > r_{avg} \\ P_{hydro,monthly}(t) - P_{hydro,monthly}(t) \cdot \left[r(t) - r_{avg}\right] \cdot c_f, if\ r(t) < r_{avg} \end{cases}$$

Where:

$P_{hydro}(t)$ – hourly distribution of a hydro power supply, including white noise

$P_{hydro,monthly}(t)$ - hourly distribution of a hydro power supply, without white noise

$r(t)$ – precipitation in a specific hour

r_{avg} – yearly average precipitation

c_f – correction factor

An obvious boundary condition was that the yearly sum of $P_{hydro}(t)$ has to be equal to the yearly sum of $P_{hydro,monthly}(t)$. In order to do so, the correction factor c_f was introduced. It is selected so that the yearly sum difference is lower than 1%. Since every country has different precipitation and ENTSO-E data, this factor is also country-dependent.

1.2.6. Tidal and wave supply

Due to the lack of data and low impact tidal and wave energy have on the developed scenarios, data created for the STRATEGO project [12] has been averaged and used here.

1.3. Electricity trade

Electricity trade represents the electricity import and export of the observed country and as in the previous distributions, EnergyPLAN requires hourly data here. For the purpose of this project the ENTSO-E Transparency platform [13] has been used. It contains hourly data for both the import and export of electricity for the entire EU-28 region. It should be noted that a lack of data does occur in certain time periods. No trade was assumed in those cases.

2. References

[1] "European Network of Transmission System Operators for Electricity." [Online]. Available: https://www.entsoe.eu/Pages/default.aspx. [Accessed: 21-Jun-2017].

[2] "Measurement of Domestic Hot Water Consumption in Dwellings."

[3] "Meteonorm: Irradiation data for every place on Earth." [Online]. Available: http://www.meteonorm.com/. [Accessed: 21-Jun-2017].

[4] "Energy Efficiency Trends & Policies | ODYSSEE-MURE." [Online]. Available: http://www.odyssee-mure.eu/. [Accessed: 21-Jun-2017].

[5] S. Frederiksen and S. Werner, *District heating and cooling*. Studentlitteratur, 2013.

[6] T. Novosel *et al.*, “Agent based modelling and energy planning – Utilization of MATSim for transport energy demand modelling,” *Energy*, vol. 92, pp. 466–475, Dec. 2015.

[7] GONZALEZ APARICIO Iratxe, HULD Thomas, CARERI Francesco, MONFORTI-FERRARIO Fabio, and ZUCKER Andreas, “EMHIRES dataset: Part II: Solar Power Generation: European Meteorological derived HIgh resolution RES generation time series for present and futures scenarios: Part II: PV generation uding the PVGIS model - European Commission,” 2017. [Online]. Available: https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/emhires-dataset-part-ii-solar-power-generation-european-meteorological-derived-high.

[8] “SPF Online Collector Catalogue.” [Online]. Available: http://www.spf.ch/index.php?id=111&L=6. [Accessed: 30-Aug-2017].

[9] SPF Online Collector Catalogue, “Collection of fact sheets WP3 – D3.1 & D3.2,” 2012.

[10] Peter Kovacs, “Quality Assurance in solar thermal heating and cooling technology – keeping track with recent and upcoming developments,” 2012.

[11] GONZALEZ APARICIO Iratxe, ZUCKER Andreas, CARERI Francesco, MONFORTI-FERRARIO Fabio, HULD Thomas, and BADGER Jake, “EMHIRES dataset Part I: Wind power generation. European Meteorological derived HIgh resolution RES generation time series for present and future scenarios - European Commission,” 2016. [Online]. Available: https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/emhires-dataset-part-i-wind-power-generation-european-meteorological-derived-high-resolution. [Accessed: 30-Aug-2017].

[12] “Stratego.” [Online]. Available: http://stratego-project.eu/. [Accessed: 30-Aug-2017].

[13] “ENTSO-E Transparency Platform.” [Online]. Available: https://transparency.entsoe.eu/. [Accessed: 30-Aug-2017].