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Heat Roadmap Europe
A low-carbon heating and cooling strategy

JRC-EU-TIMES and EnergyPLAN comparison

Deliverable 6.3: Methodology report for comparing the JRC-EU-TIMES and EnergyPLAN scenarios

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Deliverable No. D6.3: Methodology report for comparing the scenarios between JRC-EU-TIMES and EnergyPLAN

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1. Introduction

The EU has an ambitious and clear long-term objective to decarbonise the energy system, but it is currently unclear to a large extent how this will be achieved in the heating and cooling sector. Heat Roadmap Europe 4 (HRE4) is a three years research project, co-funded by the European Union (Horizon 2020), with a consortium of 23 academic, industrial, governmental and civil society partners. The overall aim in HRE4 is to develop low-carbon heating and cooling strategies, which are called Heat Roadmaps, and subsequently to quantify the impact of implementing them at a national level for 14 EU Member States. HRE4 provides new capacity and skills for lead-users in the heating and cooling sector, including policymakers, industry, and researchers at local, national, and EU level. These new capacities and skills are based on a quantification of the effects of increased efficiencies on both the demand and supply side of the heating and cooling sector, in terms of energy consumption, environmental impacts and costs. Thus, HRE4 enables new policies and prepares the ground for new investments by creating more certainty in relation to the changes that are required.

The Joint Research Centre of the European Commission contributes to HRE4 in work packages 5 and 6. In work package 5, a baseline annual evolution of the EU energy system was created up to 2050[1] and the two energy system models used in HRE4, JRC-EU-TIMES and EnergyPLAN, were connected. This report focuses on work package 6, which identifies cost-effective solutions by assessing different heating and cooling scenarios developed with JRC-EU-TIMES and EnergyPLAN, which form the basis of in-depth policy recommendations and roadmaps resulting from the HRE4 project.

The aim of this report is to improve the understanding of how both models deal with different aspects of the energy system. More specifically, this report compares the methodologies (Chapter 3), describes how the models are linked (Chapter 4) and compares insights provided by JRC-EU-TIMES and EnergyPLAN with a focus on the Netherlands (Chapter 5). As a summary, key messages are given about the soft-linking, the extent to which results align and the merits of having both models in one project.

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[1] See also HRE Deliverable 5.2 (http://www.heatroadmap.eu/resources/HRE4_D5.2.pdf) and its summary for lead-users D5.4 (http://www.heatroadmap.eu/resources/HRE4_D5.4.pdf)

2. Key messages from soft-linking JRC-EU-TIMES and EnergyPLAN

1 It is the first time that two large energy system models with a different time resolution have been soft-coupled for all EU Member States, with a focus on heating and cooling.

- 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 sub-annual time-slices.

2 When coupling models with a different temporal resolution, also the model with a focus on the long term should incorporate feedback from a model with high temporal resolution. Within HRE4, hourly data and intermediate modelling results make up a large part of the input data of both JRC-EU-TIMES and EnergyPLAN.

- The analysis of the ever-increasing renewable energy sources (RES), flexibility issues in the power sector and sectoral integration require high time resolution data. By design, EnergyPLAN can model a full year in hourly resolution using 8784 time slices (leap year).
- For electricity, JRC-EU-TIMES uses a parametrisation that is based on results of an hourly model that includes hundreds of possible combinations of wind, solar and storage capacities for each country and that is based on EMHIRES data [1, 2].

3 There is no need for having a full alignment of input data because the focus of JRC-EU-TIMES is the long term and the focus of EnergyPLAN is the short term.

- The soft-linking includes fixing some EnergyPLAN inputs to JRC-EU-TIMES outputs. The soft-linking also includes aligning input data to the extent needed so that both models complement each other. Full alignment on all dimensions (time, technological coverage, constraints,…) is impossible without making both models virtually identical. That would produce a model extremely complex (able to estimate long-term capacity expansion and with hourly resolution in all sectors) and nearly impossible to run without massive amounts of data and computing capacity.

- Except of course for the parts where the models are linked, differences in results occur. We conclude that when differences are explained by a difference in methodology, these bring in fact added value. The merit of having both models is that one model comes to improved conclusions, unless adjustments are made in the other model.

4

The main merit of JRC-EU-TIMES is that it provides EnergyPLAN with cost optimal capacity expansions and energy uses over time, up to 2050. The main merit of EnergyPLAN is that it allows a very fast analysis of possible combinations of assets in an integrated energy system at hourly resolution within a given year.

- JRC-EU-TIMES provides capacity expansions over time and the energy supply and demand of all sectors for all MS covered in HRE4 up to 2050. EnergyPLAN is flexible enough to use the capacities and energy flows computed by JRC-EU-TIMES and analyse the hourly operation of the system in a given year.
- From the hourly approach and the dynamic interaction between production, storage and possible transformation between energy sectors, EnergyPLAN gives an immediate answer about the impact of adding, substituting or removing capacity of a certain technology.
- Based on a specific analysis of the Heat Roadmap scenario for the Netherlands with EnergyPLAN, we conclude that battery storage has a minor role to play because of minor critical excess power from the combination of a large capacity of electrolysers, heat pumps and a high wind/solar ratio. These insights can improve the parametrisation of possible excess power in the optimisation energy system models.

3. Comparison of theoretical framework

3.1. Methodology of EnergyPLAN

EnergyPLAN has been developed and expanded on a continuous basis since 1999 at Aalborg University, Denmark [3]. 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 with high levels of (variable) renewable energy 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.

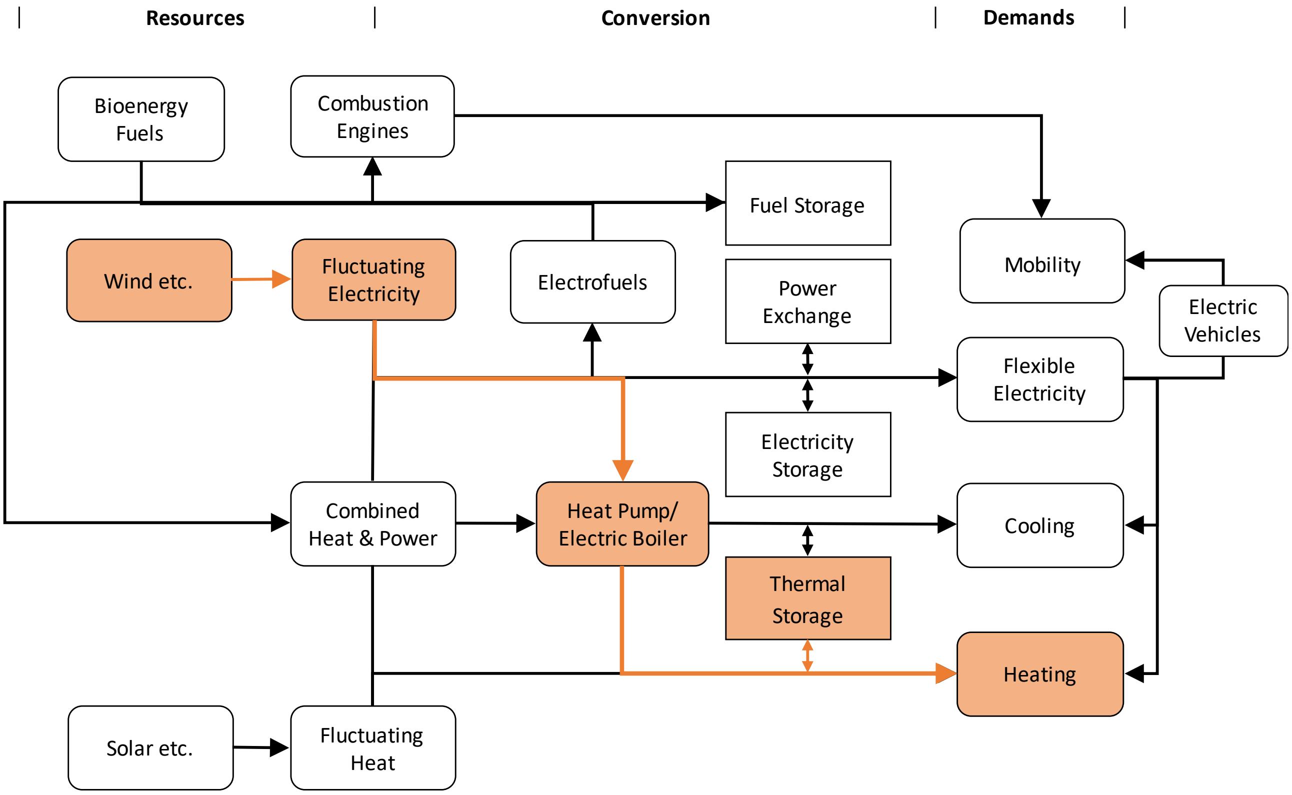

Figure 1: Energy flow in the Smart Energy System that outlines how excess renewable energy is integrated using a synergy between the electricity and heat sectors in combination with thermal storage.

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. This means it can answer questions about how the energy system operates at every hour within one year; when (renewable) resources are available, how the system can use these, and how it fulfils hourly demands. The identified synergies can increase the integration of renewable energy, which has resulted in the development of the Smart Energy System concept [4, 5]. For example, Figure 1 shows how, if there is an excess production of wind power, EnergyPLAN uses a synergy between the electricity and heat sectors to integrate (using heat pumps or electric boilers), rather than curtail, this excess production. 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 [6, 7].

EnergyPLAN has been used to model energy systems at local (eg [8]), national (eg [9]) and European (eg [6]) levels. Typically, a reference or baseline scenario is modelled in several years, based on others' projections modelled over time, since EnergyPLAN cannot represent inter-temporal decision making or evolutions. By replicating the reference models in several years, the operation can be shown. Then, alternative scenarios are developed and simulated within certain resource constraints. This produces a set of scenarios for the future, which can be based on different design principles and developments, which can be compared and quantitatively and qualitatively discussed.

EnergyPLAN is an deterministic operation simulation model, so main inputs for the model consist of hourly profiles for demands (for all sectors), hourly production profiles for (variable) renewable energy sources, the energy demands, and the different (constrained) capacities for production, conversion, and storage capacities, and technology cost data. The most relevant model outputs are typically the different capacities for various technologies under an operational system, their hourly interactions and resource demands, and the annual sums for the total primary energy used, the amount of CO_2 emissions resulting from the energy system, and the different costs. Documentation on the inputs, assumptions, and outputs can be found in [10].

Since EnergyPLAN is a simulation model, it can only describe the performance of different alternatives and does not inherently have an objective function or search for optimal design. The assessment parameters are (normatively) selected and analysed through the iterative process of alternative scenario design and analysis, and frequent dialogue with stakeholders. This requires a much higher level of framing, but through iteration also allows for a greater insight as to why the system operates and performs along the criteria as it does. This can be especially relevant in systems with high levels of (variable) renewable energy, and as the synergies between the various sectors of the energy system are explored.

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 that EnergyPLAN 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.

3.2. Methodology of JRC-EU-TIMES.

JRC-EU-TIMES models the energy system of the EU 28 and of neighbouring countries from the years 2010 to 2060. It produces projections (or scenarios) of the EU energy system under different sets of specific assumptions and constraints. The JRC-EU-TIMES model is used to analyse the role of energy technologies and their innovation for meeting Europe's energy and climate change related policy targets.

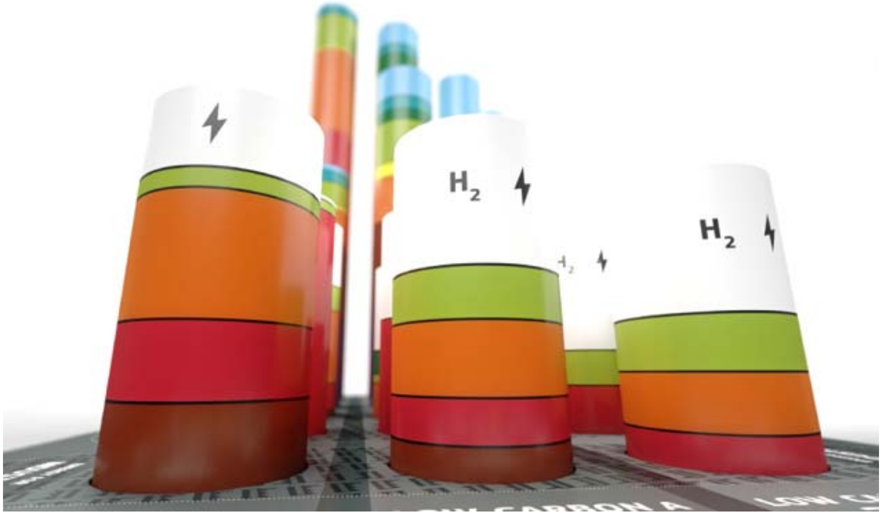

Figure 2: Visual representation of three scenarios of JRC-EU-TIMES

JRC-EU-TIMES is an improved offspring of previous European energy system models developed under several EU funded projects, such as NEEDS [11]. The JRC was partner in the NEEDS project in which the Pan European Times model was originally developed. Since then, the original project partners have developed different versions of the original model some of which are being used for EU funded research projects[2].

The JRC-EU-TIMES model is a linear optimization bottom-up technology-rich model which follows the paradigm of the TIMES model generator from the ETSAP Technology Partnership of the International Energy Agency, which combines a detailed technology specification with an optimisation approach [12]. The model solves for the cost optimum investment portfolio of technologies for the entire period under consideration[3], along the supply chains for five sectors, while fulfilling the energy-services demand. This implies simultaneously deciding on asset investments and operation, primary energy supply and energy trade.

The typical question that JRC-EU-TIMES can address is what technologies are competitive under various low carbon energy scenarios. For emerging technologies with a small uptake, JRC-EU-TIMES can estimate what technology improvements would be needed to make these competitive. This information is a standard output from LP (Linear Programming) models or can be derived from various sensitivities on the assumed technology performances.

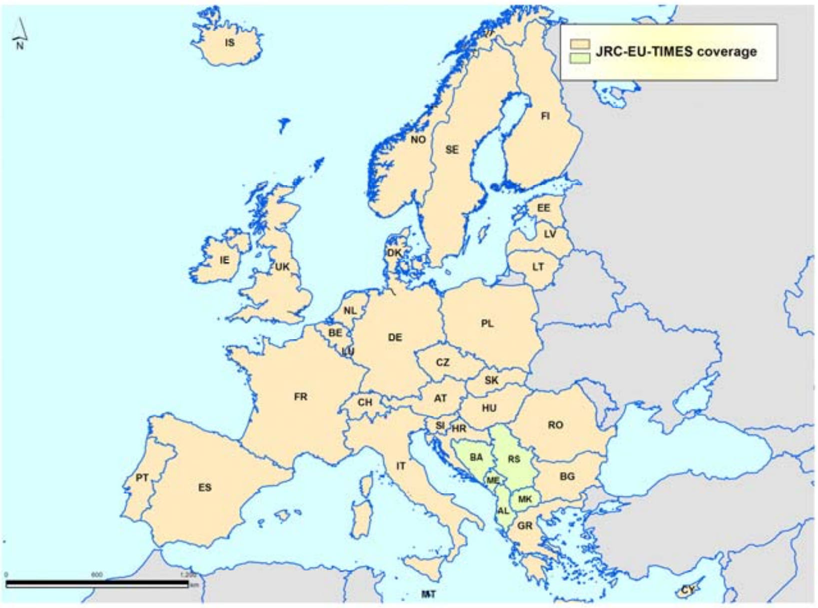

Figure 3: Regions considered in JRC-EU-TIMES

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[2] E.g. the REEEM project (http://www.reeem.org/)

[3] The TIMES paradigm also allows for alternative approaches such as limited foresight see [8].

As a partial equilibrium model, JRC-EU-TIMES does not represent the economic interactions outside of the energy sector. However, the macro-economic feedback between the economy and energy systems is considered through price elasticities of service demands. Moreover, it does not consider in detail the mathematical formulation underlying demand curves functioning and non-rational aspects that condition investment in new and more efficient technologies. Such issues have to be dealt with via exogenous constraints to represent non-rational decisions.

The most relevant model outputs are the annual stock and activity of energy supply and demand technologies for each region and period. This is accompanied by associated energy and material flows including emissions to air and fuel consumption, detailed for each energy carrier. Besides technical outputs, the associated operation and maintenance costs, the investment costs for new technologies, all energy and materials commodities prices (including for emissions if an emission cap is considered), are obtained for every time step.

JRC-EU-TIMES combines a social approach towards the time value of money and a private approach towards risk and the cost of financing based on the individual technologies. 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 is, 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 Net Present Value.

An overview on the JRC-EU-TIMES model main data inputs and major assumptions are described in [13]. Updated assumptions are described in [14], [15] and [16] (such as buildings, heating and cooling technologies, calibration, nuclear energy, and demand projections). Power-to-x and Direct Air Capturing (DAC) are mostly described in [17]. One of the scenarios of JRC-EU-TIMES is always aligned to the latest EU reference scenario[4].

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[4] Latest EU Reference Scenario available at https://ec.europa.eu/energy/en/data-analysis/energy-modelling

3.3. Comparison of the overall methodologies

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.

Table 1: Economic perspectives, energy sectors, time horizons and resolutions for the two energy models

Model	JRC-EU-TIMES	EnergyPLAN
Scope: Sectors Considered*	All Sectors	All Sectors
Type of Model	Optimisation	Simulation
Timeframe	Years/Decades	One Year
Time-Step	12 time-slices (24 in the power sector); explicit representation of excess power.	Hourly
Economic Perspective	Mix of Societal & Private End-User	Societal
Capacity expansion	Investment decisions based on optimisation under different sets of assumptions and constraints.	Fixed capacities
Power plant dispatch	Based on cost minimisation.	Predefined merit order or priority mechanism.

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

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 time-slices for smaller time-steps. JRC-EU-TIMES has 12 time-slices with an explicit representation of excess power, giving it 24 timeslices in the power sector. Due to these differences between EnergyPLAN and JRC-EU-TIMES the focus of these two models is different, even though the scope is very similar.

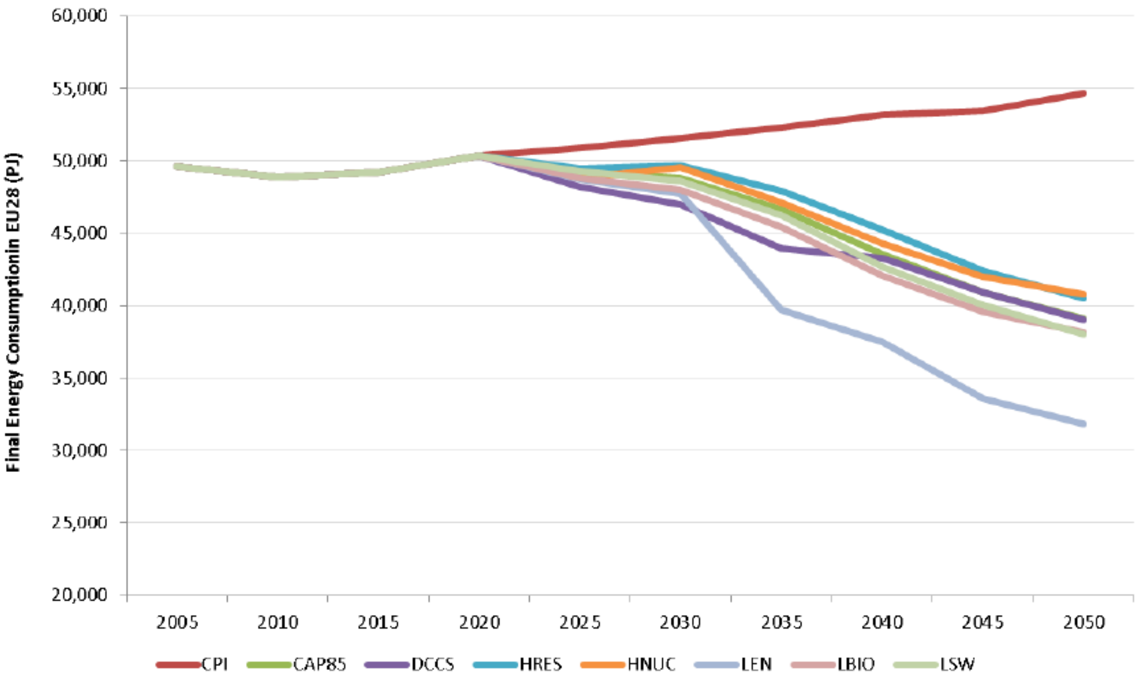
Table 2 systematically lists strengths and weaknesses of the overall approach of both models. Also, it shows how strengths from one model mitigate weaknesses of the other model by soft-linking. In chapter 5, a more detailed comparison is given of how both models deal with different aspects of the energy system with an example.

Table 2: Strengths and weaknesses of the overall approach of JRC-EU-TIMES and EnergyPLAN

<table>
<tr><th>Strengths JRC-EU-TIMES</th><th></th><th>Weaknesses EnergyPLAN</th></tr>
<tr><td>JRC-EU-TIMES can provide cost optimal capacity expansions and energy uses over time.</td><td></td><td>EnergyPLAN has no capacity expansion mechanism.</td></tr>
<tr><td>Optimisation allows finding the least cost combination of technologies, fulfilling all boundaries of the system.</td><td>→</td><td>Without optimisation, another decision mechanism, which may require additional knowledge, is needed.</td></tr>
<tr><td>Optimisation may uncover future scenarios that one would never expect and so would never simulate. The "perfect market" optimum will allocate resources in the most efficient way.</td><td></td><td>The simulated system fulfils all requirements put in place; however an even cheaper system may be overlooked. Predefined merit order or priority mechanisms may not always be the most efficient operation of a system.</td></tr>
<tr><th>Weaknesses JRC-EU-TIMES</th><th></th><th>Strengths EnergyPLAN</th></tr>
<tr><td>Limited sub-annual time resolution. This issue is also addressed in JRC-EU-TIMES with additional equations that are based on results of an hourly model that includes hundreds of possible combinations of wind, solar and storage capacities for each country.</td><td>←</td><td>Hourly time resolution. EnergyPLAN also allows a very fast analysis of possible combinations of assets in an integrated energy system.</td></tr>
<tr><td>An optimisation model will select the cheapest energy system even if many other possible systems exist with a near-optimal cost. Approaches exist to identify those near-optimal solutions.</td><td></td><td>Simulation allows analysing any thinkable energy system. Simulation allows you to discover any desired energy future pathways without cost as a driver.</td></tr>
<tr><th colspan="3">Strengths and weaknesses of both JRC-EU-TIMES and EnergyPLAN</th></tr>
<tr><td colspan="3">The technology representation is high in both models. Technologies can be introduced with a very high level of complexity and interaction, provided that the data are available.
Small deviations in some of the assumptions can have a very strong impact on model results [18]. This phenomenon is known as flip-flop behaviour.
As any model that makes future scenarios, assumptions are uncertain and the conclusions are only valid within this context (sometimes referred to as "perfect information" condition).</td></tr>
</table>

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. EnergyPLAN simulates one year at a time, so to model the transition between two separate years (for example from 2015 to 2050) EnergyPLAN users typically model a few sample years separately. For example, in Heat Roadmap Europe 3 [19] (also known as the STRATEGO project) EnergyPLAN 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.

JRC-EU-TIMES uses a different approach where the transition is modelled from the beginning to the end of the modelling period within the model itself, rather than as separate years by the user. For example, the JRC-EU-TIMES model was used [20] 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 externally modelled by the user year by year.



Reference: JRC-EU-TIMES

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 [20].

Including the transition internally within means that JRC-EU-TIMES can account for limitations during the evolution of the energy system more systematicallythan EnergyPLAN. 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. For example, people have a limited budget that they can spend on investment goods so this could impact the transition of household related capital intensive energy technologies.

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.

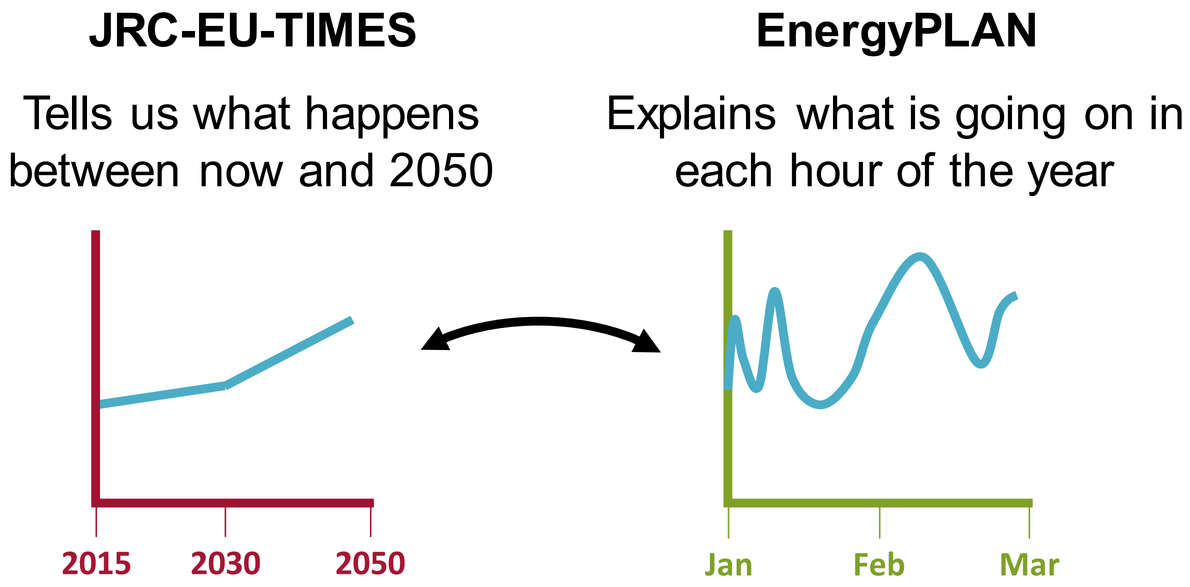


Figure 5: Connection between the JRC-EU-TIMES and EnergyPLAN models

The following figures explain the steps of the soft-coupling between EnergyPLAN and JRC-EU-TIMES. HRE4 combines the strengths of both tools so they function better together than they do apart.

In step 1, the original formulation of JRC-EU-TIMES is improved with knowledge from hourly simulations. For example in the power sector, long term models do not capture variability as accurate as hourly simulations and better approximations lead to higher costs or reduced options.

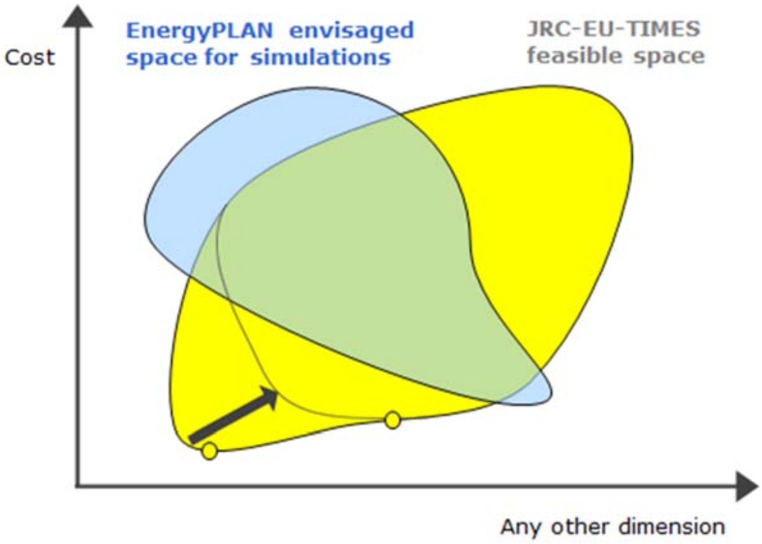


Figure 6: Step 1, adjustment of JRC-EU-TIMES based on results of hourly simulations; the yellow dots are the lowest cost solutions in JRC-EU-TIMES

In step 2, capacities and most final energy uses from EnergyPLAN are soft-coupled to JRC-EU-TIMES. JRC-EU-TIMES uncovered future scenarios that were not considered so far by EnergyPLAN. An example is the large use of electrofuels in some scenarios.

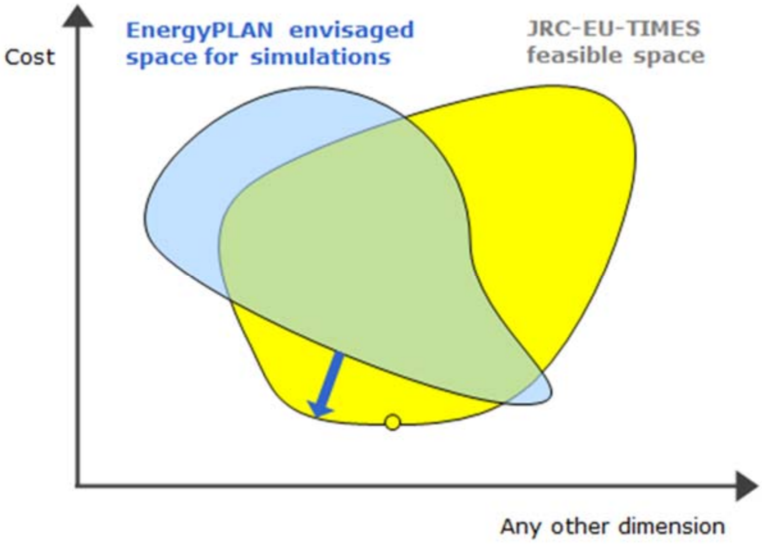


Figure 7: Step 2, EnergyPLAN is soft-coupled to JRC-EU-TIMES

In step 3, solutions can be identified by EnergyPLAN that are more optimal than the JRC-EU-TIMES solution. The simulation of an hourly model can uncover more efficient operations such as the example discussed in chapter 5 on the intertwined operation of electrolysers and batteries.

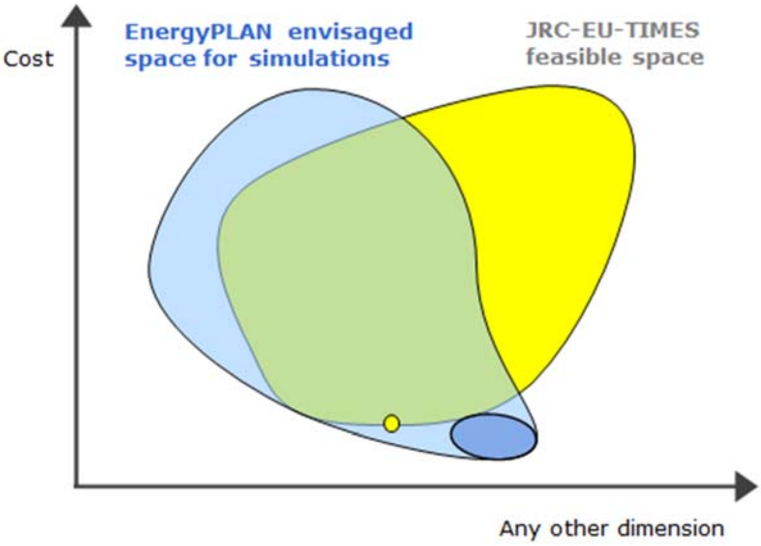


Figure 8: Step 3, more efficient operations are discovered by using EnergyPLAN

In a last step, not envisaged in HRE4, JRC-EU-TIMES could again be adjusted. Results would be closer but could still be different due to differences in the method and in the input data. This step has not been done within HRE4 as the final heat roadmaps are produced by EnergyPLAN.

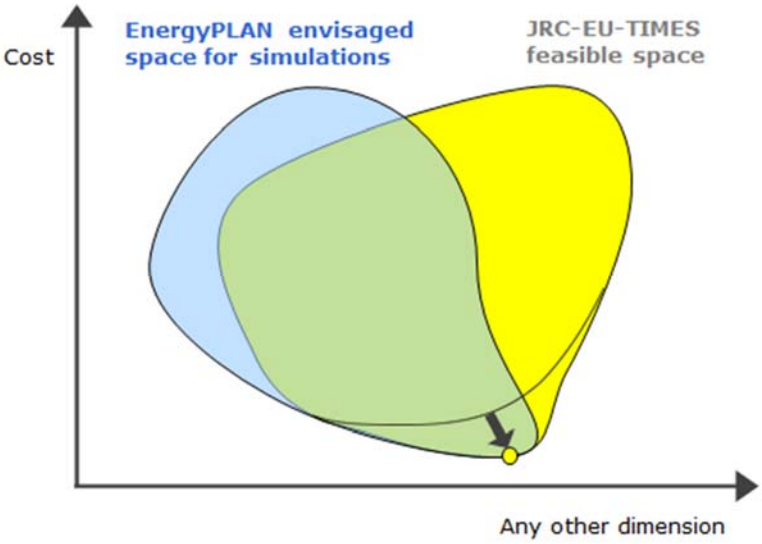


Figure 9: Adjustment of JRC-EU-TIMES based on more efficient operations discovered within EnergyPLAN.

3.4. Comparison of the H&C methodology

In this chapter we focus on the methodology regarding the modelling of Heating and Cooling demand and supply.

3.4.1. H&C in EnergyPLAN

In EnergyPLAN, district heating systems interact with other parts of the whole system. District heating is divided into three separate systems: boiler-alone systems; small CHP systems and large CHP and extraction plants. Cooling demand is divided into:

1. Cooling based on electricity supply (air conditioning etc.)
2. Cooling based on heat supply from district heating from the three DH groups mentioned above (based on absorption technologies)
3. Contribution to district cooling from natural cooling

Heat demand in individual houses is divided into:

1. Coal, oil, natural gas and biomass boilers
2. Micro CHP on either hydrogen, natural gas or biomass
3. Electric heating or heat pumps

The EnergyPLAN tool does include an hourly balance for district heating and cooling.

3.4.1. H&C in JRC-EU-TIMES

Heating & cooling technologies in JRC-EU-TIMES are aligned with [21]. This study provides techno-economic projections for smaller heating and cooling technologies including an outlook until 2050.The dataset for this study can be downloaded from [22]. Focus of this data catalogue is on the heating and cooling capacity. Data for two different sizes of capacity have been collected. This addresses the different applications (one-family house, multi-family building and office building) as well as the “existing” and “new” building. Specific ranges of capacities are indicated in the data sheet for each technology. The technologies included comprise heat only boilers (including wood pellets), air and ground sourced heat pumps, CHP, solar heating, pure electric heating and some combinations of the above.

The buildings' sector from JRC-EU-TIMES is described in [16]. There is a bottom-up estimation of thermal requirements based on EUROSTAT building categories (detached, semidetached, flats), building vintage (6 groups), and insulation measures (roof, walls, windows). The calibration to the JRC-IDEES database [23] is based on HDD, building geometry, insulation, and occupancy rates. For the baseline scenario within HRE4, the buildings module was not activated and instead delivered space heat and cool was aligned with outputs from the FORECAST model.

The buildings thermal requirements and calibration is based on nominal U-values (by country, period of construction and building component), the thermal requirements are calculated for three types of buildings (detached, semidetached and flats), per each period of construction (six periods), as well as for the entire stock (weighted average). This is a "bottom-up" calculation of the thermal requirements (kWh/m2) based on technical characteristics of the building.

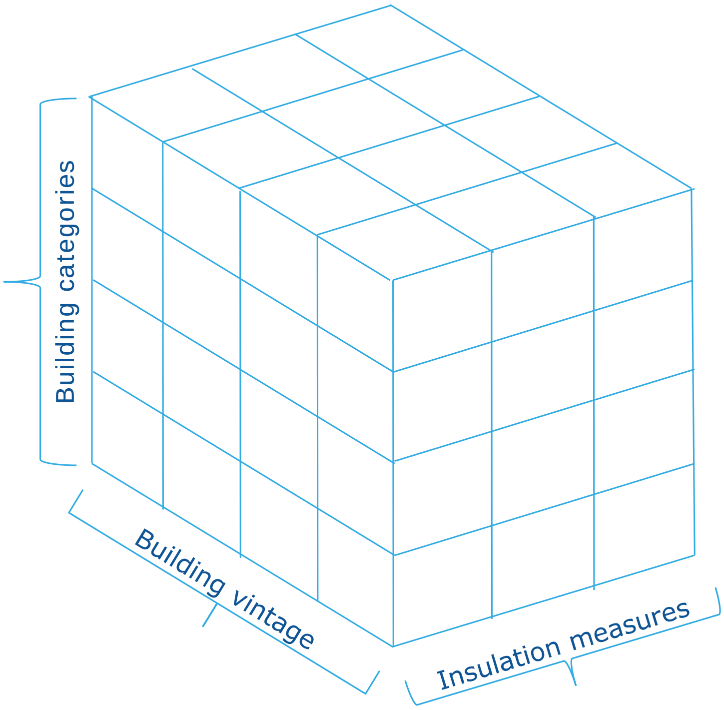


Figure 10:The 3 dimensions for modelling the buildings in JRC-EU-TIMES

Following corrections are taken into account:

1. differences from impact of insulation on average room temperature: 18 degree design versus much lower for poolryinsulated housse. A logarithmic-like curve, based on Hens et al. is included.
2. differences from stock that is not heated. For example, when families have multiple houses.
3. differences in actual heating intensity. For example, due to a different temperature preference, or due to insufficient resources to heat to a standard comfort level.

The insulation and savings options are based on improved U-values of refurbishment measures per each building component (and period of construction), the expected savings due to different refurbishment measures have been calculated. This is a bottom-up calculation of the new thermal requirements (kWh/m2) and savings, based on improved U-values. The new building components (new windows, insulated walls, etc.) are explicitly described. In this analysis savings are determined for seven different refurbishment measures, for all three building types and six different construction periods. Any possible combination of measures is allowed, in order to keep the model as much flexible as possible. Up to 29 single/composed retrofits are possible per each building type. The contribution of multiple measures has been assumed linear, hence the impact of single retrofit measure has been considered additive.

4. Overview of the links between HRE4 models

4.1. Links with other models

The primary purpose of each energy model in HRE4 is presented in Figure 11. The FORECAST and Peta4 models[5] mostly focus on the heating and 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.

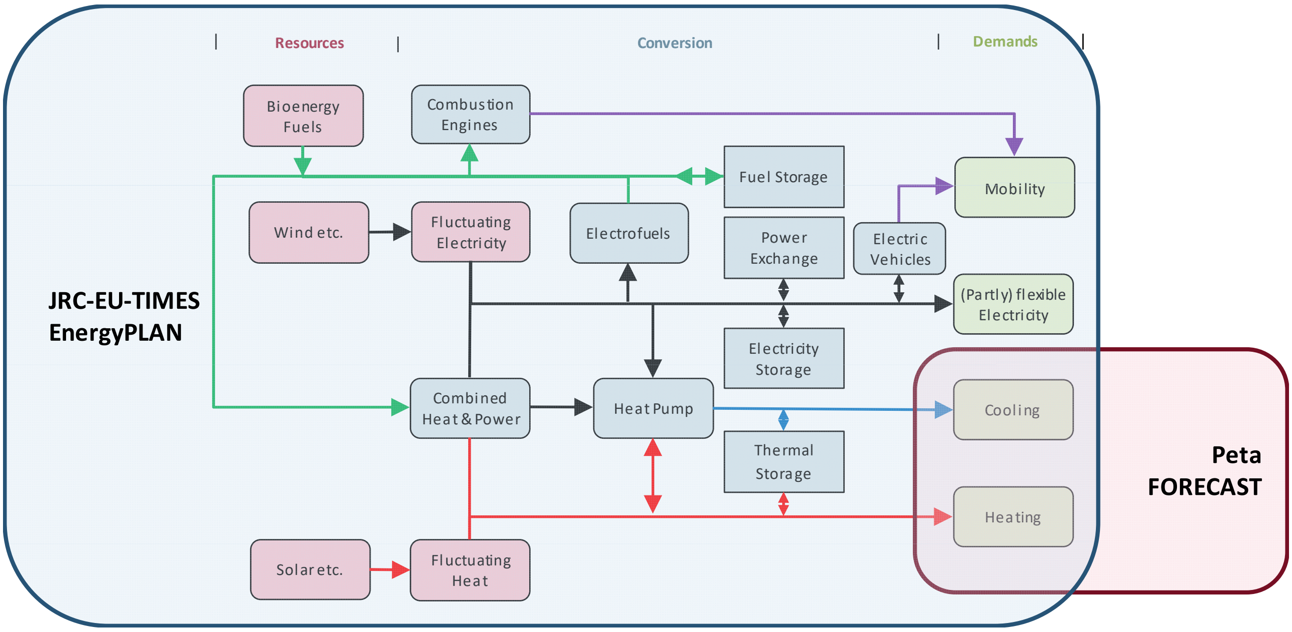


Figure 11: Primary focus of each energy model in HRE4.

Both JRC-EU-TIMES and EnergyPLAN obtain delivered heating and cooling demand and profiles data from FORECAST. 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 useful heat 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)

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[5] All modelling approaches are described in the different deliverables from HRE4, available at http://www.heatroadmap.eu/deliverables.php

B. **Delivered Energy:** Heat/cold produced by the heating/cooling unit
C. **Useful Energy:** Heat and cooling distributed to the end-user (such as space heat and hot water after some losses due to the internal heat distribution system and the building).

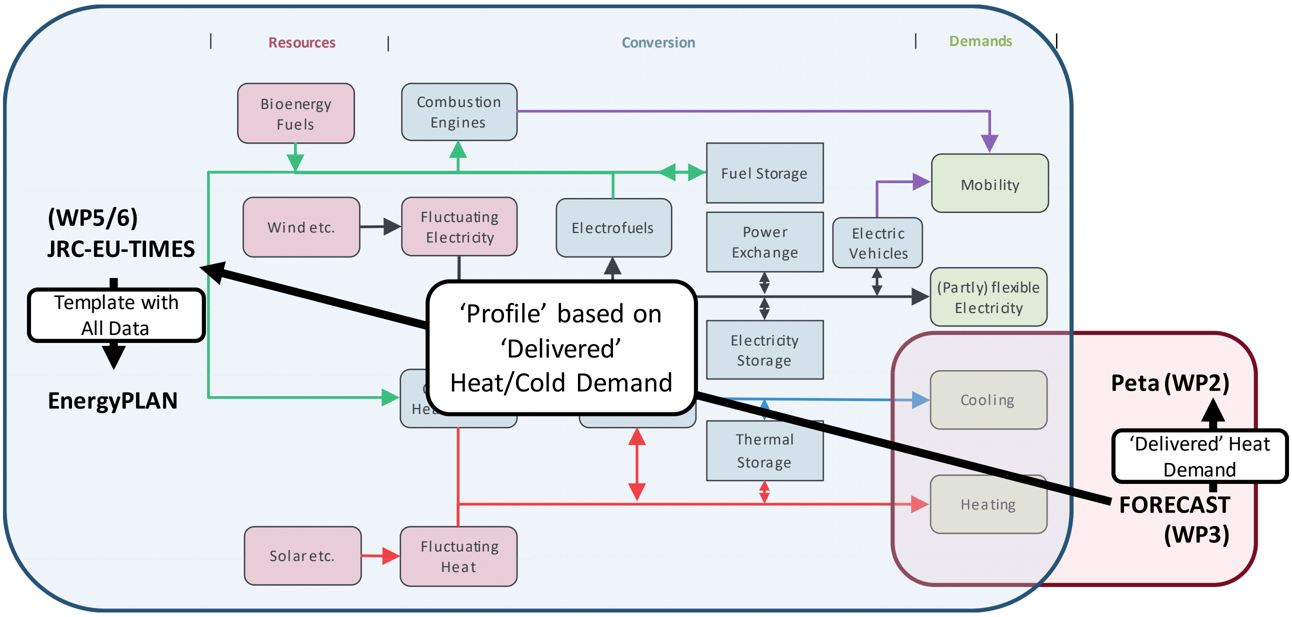
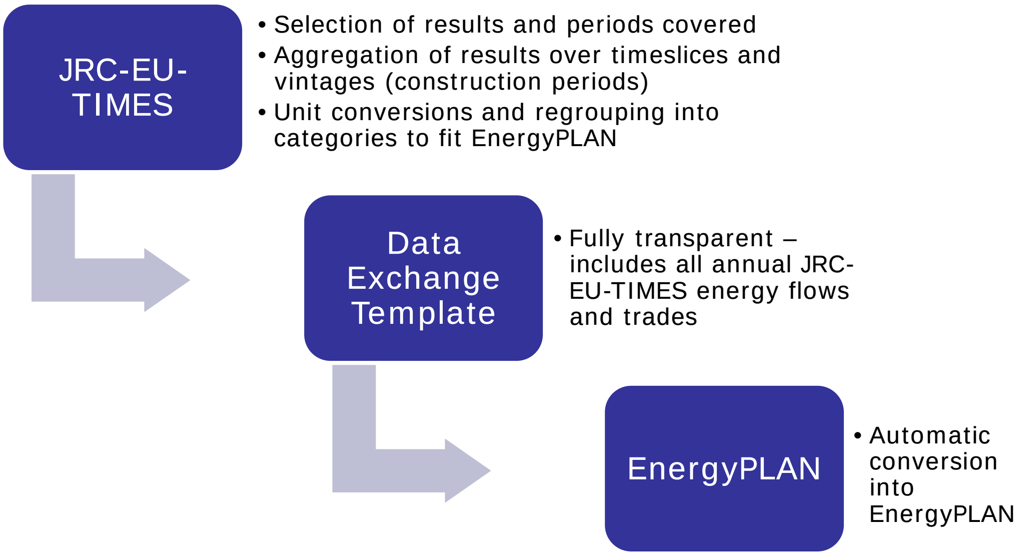


Figure 12: Connection points between the various energy models in HRE4.

The delivered heating and cooling demand determined by FORECAST gives the JRC-EU-TIMES model the inputs required to consider various supply options for the heating and cooling sectors.

4.2. Soft-linking EnergyPLAN to JRC-EU-TIMES

Finally, JRC-EU-TIMES and EnergyPLAN need to align all assumptions across the energy system so a complete 'data exchange template' is used to transfer all this information rather than just a single exchange point. An extensive range of data (such as energy demands, capacities, and efficiencies across the energy system) are exchanged between both models, by means of a "data exchange template". The 'Data Exchange Template' is a spread sheet tool to convert JRC-EU-TIMES outputs into EnergyPLAN input files. The conversion into EnergyPLAN is automatic for the different countries and each model year envisaged. The template includes one sheet for each of the following periods: 2010, 2020, 2030 and 2050. These periods correspond to some of the modelling periods of JRC-EU-TIMES. The template is fully transparent because it includes all annual JRC-EU-TIMES energy flows and trades in the sheet "All results".



JRC-EU-TIMES

- Selection of results and periods covered
- Aggregation of results over timeslices and vintages (construction periods)
- Unit conversions and regrouping into categories to fit EnergyPLAN

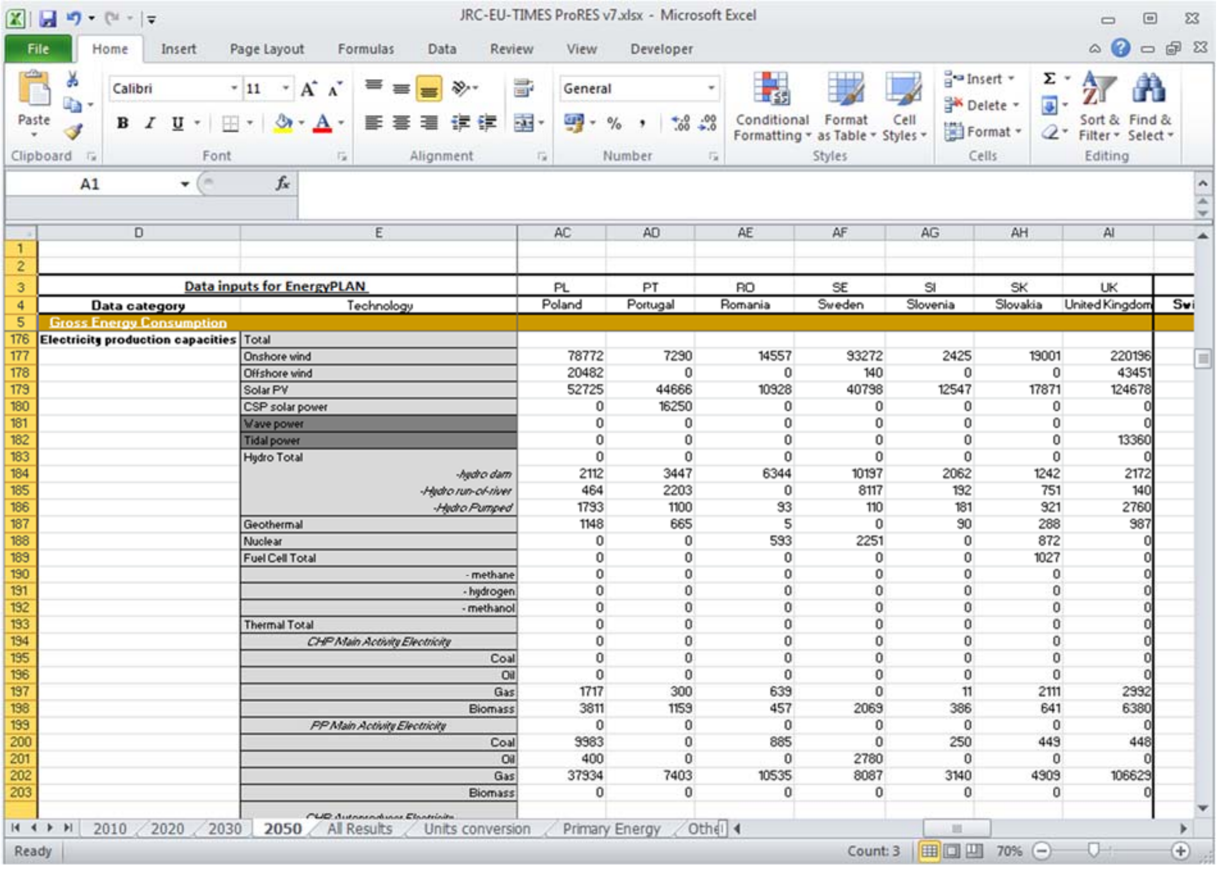
Data Exchange Template

- Fully transparent – includes all annual JRC-EU-TIMES energy flows and trades

EnergyPLAN

- Automatic conversion into EnergyPLAN

Figure 13: Creation of the data exchange template and how it connects JRC-EU-TIMES with EnergyPLAN



	D	E	AC	AD	AE	AF	AG	AH	AI
1									
2									
3	Data inputs for EnergyPLAN		PL	PT	RO	SE	SI	SK	UK
4	**Data category**	Technology	Poland	Portugal	Romania	Sweden	Slovenia	Slovakia	United Kingdom
5	Gross Energy Consumption								
176	**Electricity production capacities**	Total							
177		Onshore wind	78772	7290	14557	93272	2425	19001	220196
178		Offshore wind	20482	0	0	140	0	0	43451
179		Solar PV	52725	44666	10928	40798	12547	17871	124678
180		CSP solar power	0	16250	0	0	0	0	0
181		Wave power	0	0	0	0	0	0	0
182		Tidal power	0	0	0	0	0	0	13360
183		Hydro Total	0	0	0	0	0	0	0
184		*-hydro dam*	2112	3447	6344	10197	2062	1242	2172
185		*-Hydro run-of-river*	464	2203	0	8117	192	751	140
186		*-Hydro Pumped*	1793	1100	93	110	181	921	2760
187		Geothermal	1148	665	5	0	90	288	987
188		Nuclear	0	0	593	2251	0	872	0
189		Fuel Cell Total	0	0	0	0	0	1027	0
190		- methane	0	0	0	0	0	0	0
191		- hydrogen	0	0	0	0	0	0	0
192		- methanol	0	0	0	0	0	0	0
193		Thermal Total	0	0	0	0	0	0	0
194		*CHP Main Activity Electricity*	0	0	0	0	0	0	0
195		Coal	0	0	0	0	0	0	0
196		Oil	0	0	0	0	0	0	0
197		Gas	1717	300	639	0	11	2111	2992
198		Biomass	3811	1159	457	2069	386	641	6380
199		*PP Main Activity Electricity*	0	0	0	0	0	0	0
200		Coal	9983	0	885	0	250	449	448
201		Oil	400	0	0	2780	0	0	0
202		Gas	37934	7403	10535	8087	3140	4909	106629
203		Biomass	0	0	0	0	0	0	0

Figure 14: Extract from the data exchange template soft-linking JRC-EU-TIMES and EnergyPLAN

5. Insights from JRC-EU-TIMES and EnergyPLAN: the case of the Netherlands

The aim of this report is to describe how both models deal with different aspects of the energy system. In order to simplify the explanation about how the energy system is represented in both models, the results for the Netherlands, where heating is traditionally important, are used as an example.

5.1. Description of the scenario

EnergyPLAN is soft-linked to JRC-EU-TIMES so part of the data is identical. Full alignment on all dimensions (time, technological coverage, constraints) is impossible without making both models and the scenarios virtually identical. Scenarios are not fully aligned because the focus of JRC-EU-TIMES is the long term and the focus of EnergyPLAN is the short term. For the purpose of this exercise, we use a variant of the Heat Roadmap scenario defined in D6.4. This "HR variant" is different from the “conventionally decarbonized” scenario, also defined in D6.4.

The Heat Roadmap (HR) scenario in EnergyPLAN is based on the Baseline and ProRES scenarios developed by JRC-EU-TIMES [24] and reaches 87% reduction of energy related CO_2 within the 14 HRE4 countries, compared to 1990. A high level of savings on the demand side and efficient supply is included in this scenario. Flexibility in the power system is provided by electrolysers, increased use of large heat pumps as well as individual heat pumps. More information on the HR scenario can be found in D6.4.

The EnergyPLAN HR variant that we use in this report was aligned to JRC-EU-TIMES in the following ways: final energy of the transport sector, fuel mix of the industry sector, capacities and electricity production of all RES, electrolysers as well as battery storage, CO_2 emissions (by altering the fuel mix for PPs and CHPs). In this chapter we compare the EnergyPLAN HR variant with the JRC-EU-TIMES ProRES scenario only for the power and transport sector because for the other sectors the HRE variant is more aligned to the Baseline scenario.

5.2. Total gross energy use transition

The gross energy consumption covers all energy sectors but also includes non-energy uses. Similar to primary energy consumption, it does not include the international marine bunkers. The reader should be aware that, specifically in the Netherlands, there is a high consumption of heavy fuel for international shipping transport that is not included in any part of the analysis.

Table 3: Differences and common elements in the gross energy consumption

Model	JRC-EU-TIMES ProRES	EnergyPLAN HR variant
Differences	Lower gas consumption in the power sector because of higher electrolyser capacities in the power sector.	Higher biomass use. Lower use of gas and oil because non-energy use (plastics) not included in EnergyPLAN.
Common elements	Transport and power sector related gross energy consumption because of the soft-coupling. Identical wind and solar contributions.	

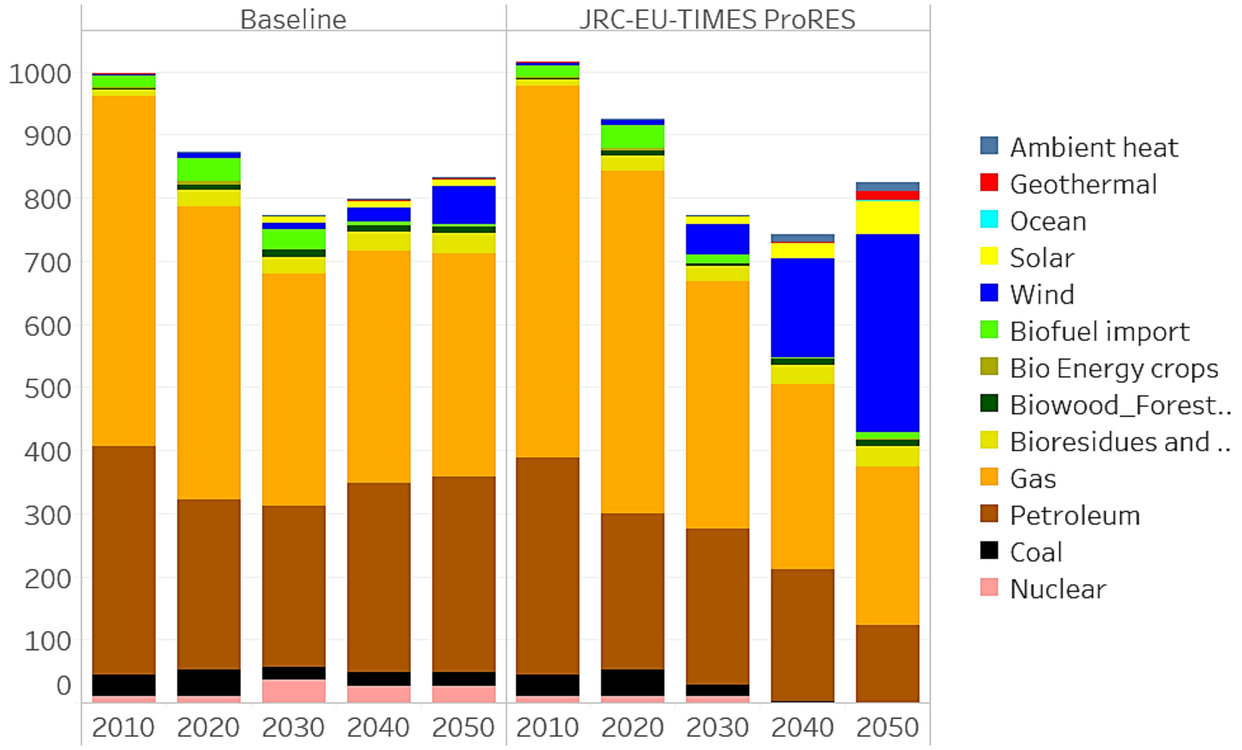


Figure 15: Gross energy consumption in the Netherlands in 2050 (TWh), JRC-EU-TIMES.

5.3. Final energy needs

The total final energy (Figure 16) remains stable or decreases, even though the strong growth in economic activity is respected. As an example, with less energy, the activity of cars, trucks and planes in the Netherlands increase by 2050 with respectively 20%, 30% and 120% (demand of energy services is not visible in the figure). In JRC-EU-TIMES ProRES, the electrification is strong for the buildings sector. Gas boilers are gradually abandoned and produce only 10% of the required heat by 2050, because of their CO_2 emissions. Heat pumps contribute to the supply mostly with ambient heat. Electrification in transport is revolutionary as by 2050, more than 80% of the cars are electric or hydrogen fuelled, driven by significant cost reductions. Most of the fuel that trucks and aviation consume is derived from electricity in the form of hydrogen or electrofuel. This large use of electrofuels is a result of the cost optimisation and the energy system wide CO_2 target in JRC-EU-TIMES. It is one of the most important links between JRC-EU-TIMES and EnergyPLAN because of the impact on the power sector.

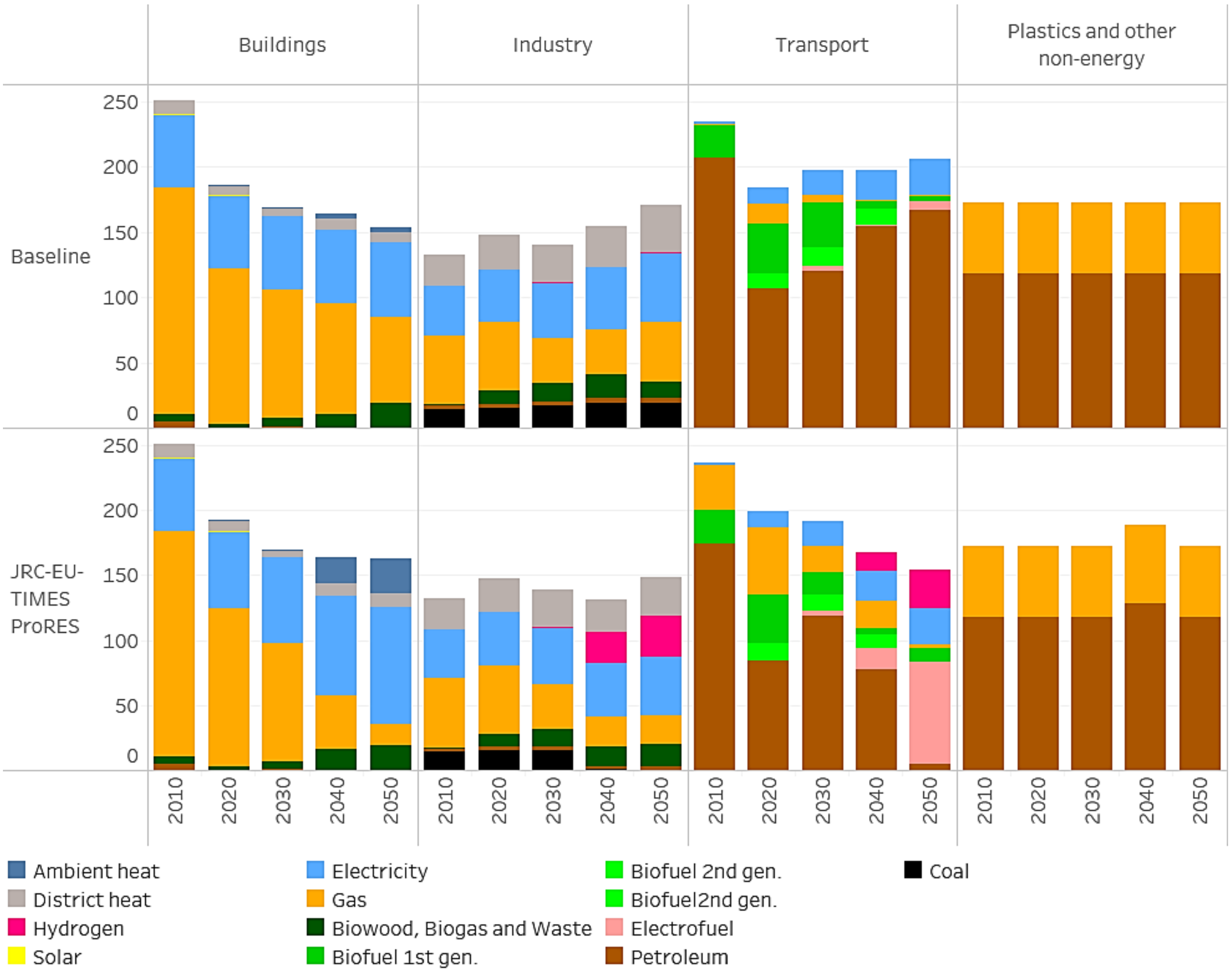


Figure 16: Final energy consumption in the Netherlands in 2050 (TWh), JRC-EU-TIMES; for the transport and industry sectors, the EnergyPLAN HR is aligned to the JRC-EU-TIMES ProRES scenario.

Table 4: Differences and common elements in the final energy consumption

Model	JRC-EU-TIMES ProRES	EnergyPLAN HR variant
Differences	Heating sector relies almost entirely on electricity.	Around 55% of the heating sector based on district heating using large heat pumps, industrial excess heat, cogeneration, solar thermal, geothermal and excess heat from electrolysis.
Common elements	For the transport and industry sectors, the EnergyPLAN HR is aligned to the JRC-EU-TIMES ProRES scenario. Final energy for those sectors is soft-linked, including the consumption of electrofuels.	

5.4. Flexibility in the power sector

EnergyPLAN allows a very fast analysis of possible combinations of assets in the power sector. From the hourly approach and the high interaction between production, storage and possible transformation of the power, EnergyPLAN gives an immediate answer about the impact of adding or removing capacity of a certain technology.

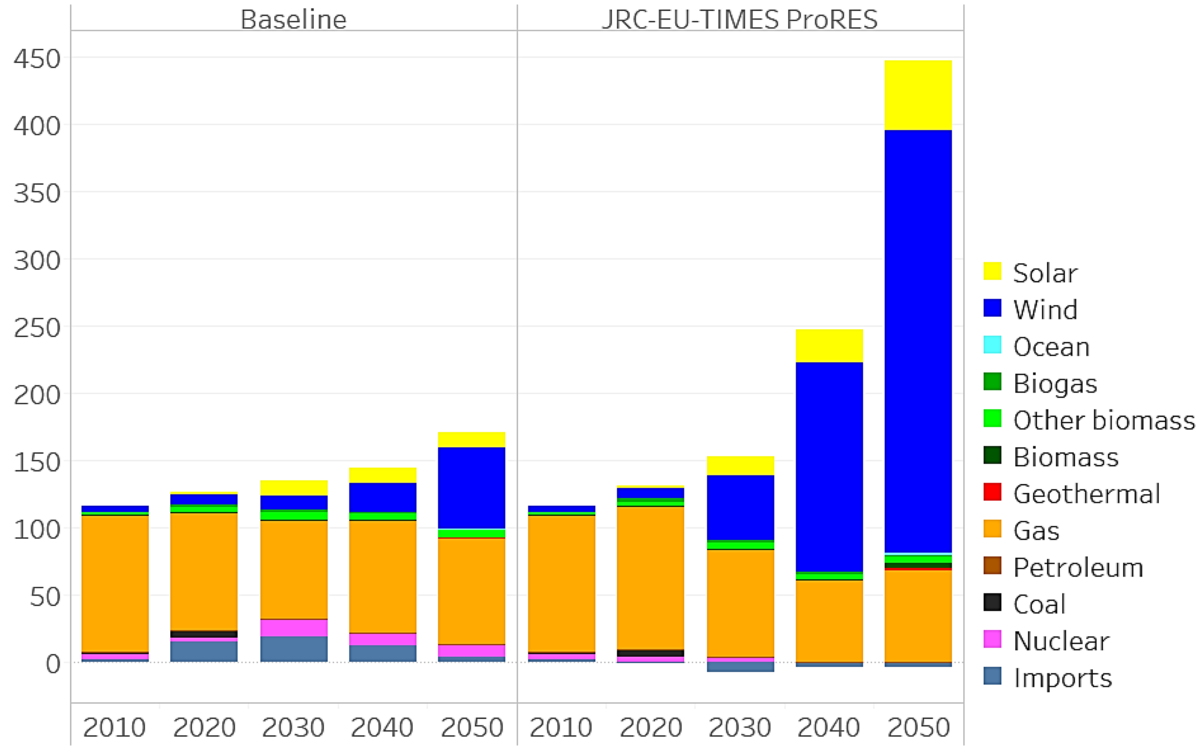


Figure 17: Electricity production in the Netherlands in 2050 (TWh), JRC-EU-TIMES.

Figure 18 and Figure 17 present the original result of JRC-EU-TIMES for the power sector. Table 5 presents the wind and solar power production and capacities of the HR variant scenario in the Netherlands that can be compared with the average electricity demand.

Table 5: Overview of wind and PV capacities and electricity production in both models

	Electricity production (TWh)	Capacities (GWe)
Total electricity demand	153	17 (average)
Wind onshore	120	44
Wind offshore	194	49
PV	52	49

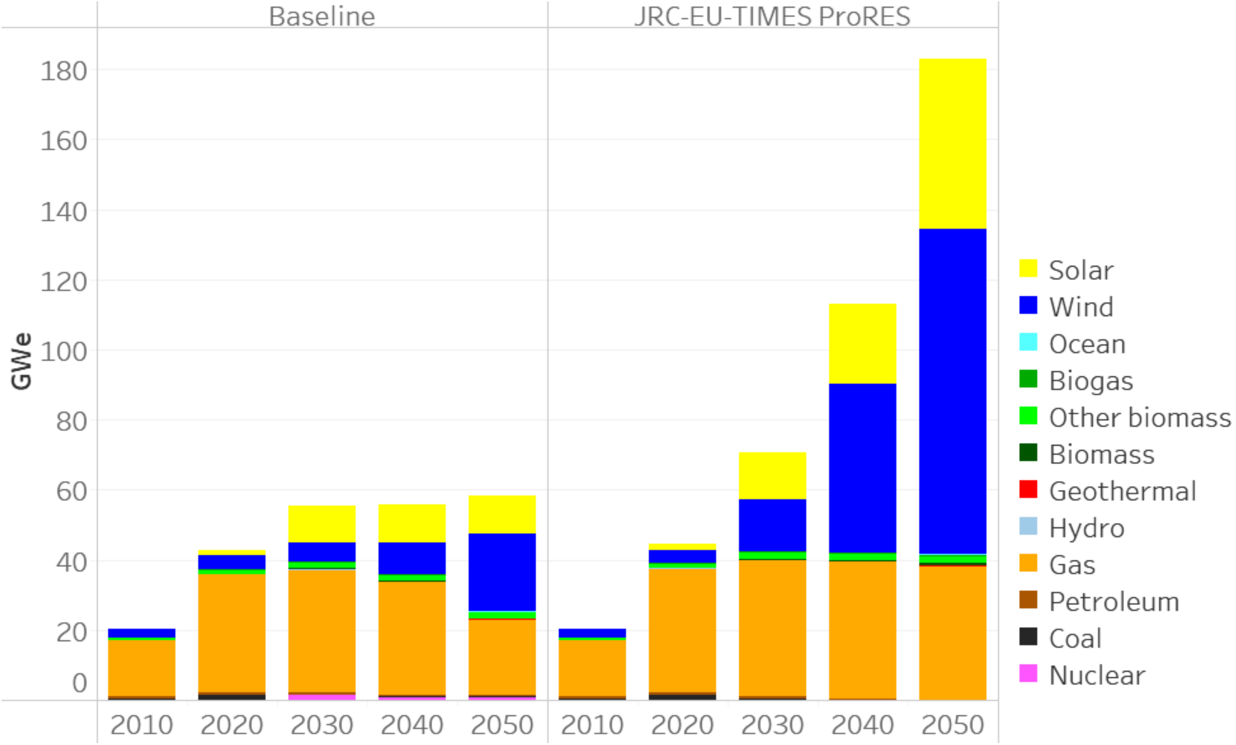
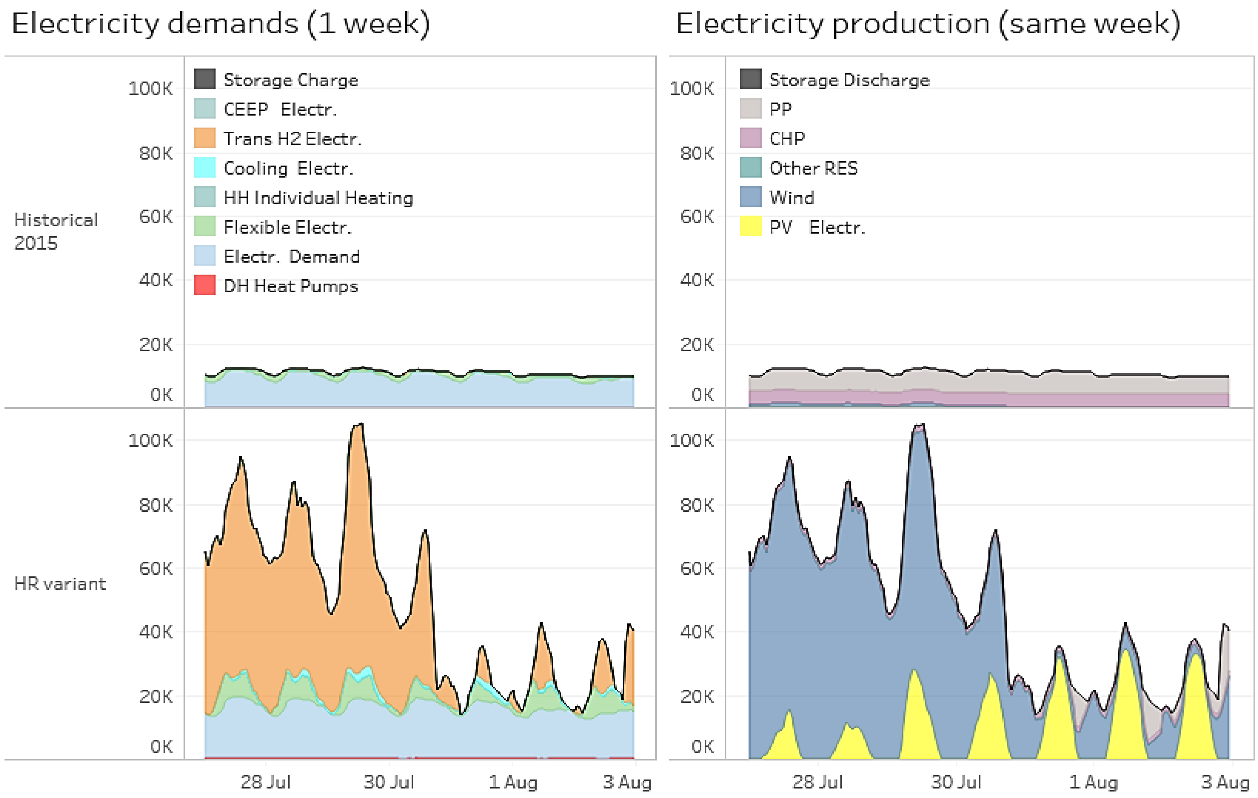


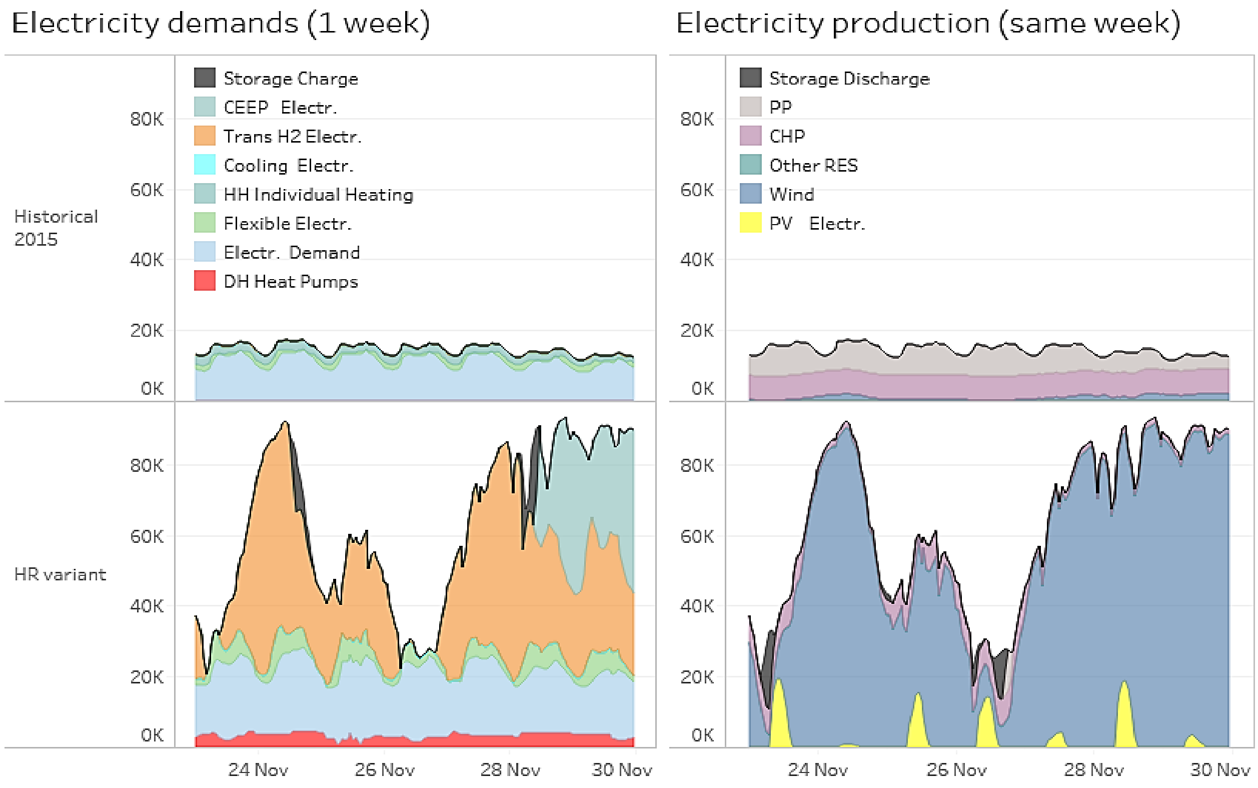
Figure 18: Electricity capacities in the Netherlands in 2050 (GWe), JRC-EU-TIMES and EnergyPLAN.

In Figure 19 we focus on two aspects within the HR variant scenario: the impact of electrolysers and storage. It can be noticed that, even though storage is available, it does not play a role because the electrolysers are active. The analysis with EnergyPLAN results in a new insight. When large amounts of electrolysers are used in a system with high wind capacity, there is often no critical excess or there is critical excess power for many subsequent hours. Storage with batteries does not play a role if there is no critical excess power and it also does not play a role when the timeframe is too large because the storage capacities are too small.


Electricity demands (1 week)

Electricity production (same week)

Figure 19: EnergyPLAN electricity demand and production in a summer week (TWh).


Electricity demands (1 week)

Electricity production (same week)

Figure 20: EnergyPLAN electricity demand and production in a winter week (TWh)

In Figure 20, the red coloured area is the electricity demand from all heat pumps (both DH and individual). We conclude that the amount of electricity needed is small in comparison with the regular electricity demand and the electricity needed for transforming it into hydrogen and derived fuels.

Table 6: Differences and common elements in the power sector

Model	JRC-EU-TIMES ProRES	EnergyPLAN HR variant
Differences	From the parametrisation, storage reduces the amount of excess power, even when a high capacity of electrolysers is available. This could be improved by introducing electrolysers in the calculations of estimating the possible excess power and improve the parametrisation.	Storage has a minor role to play because of minor critical excess power from the combination of a large capacity of electrolysers and a high wind/solar ratio.
Common elements	Same amounts of variable RES as soft-linked. Same amounts of hydrogen produced for direct use as well as the production of electrofuels.	

5.5. Investment costs

In Figure 21, investment costs are presented for wind, PV, hydrogen and biomass technologies. We compare the lump sum investment costs because the conversion into annualised costs is done in a different way and for that reason difficult to compare. For JRC-EU-TIMES, the cumulative investment is shown for the entire modelling period up to 2050. For EnergyPLAN, the total investment is shown to construct the full 2050 capacities, starting from zero.

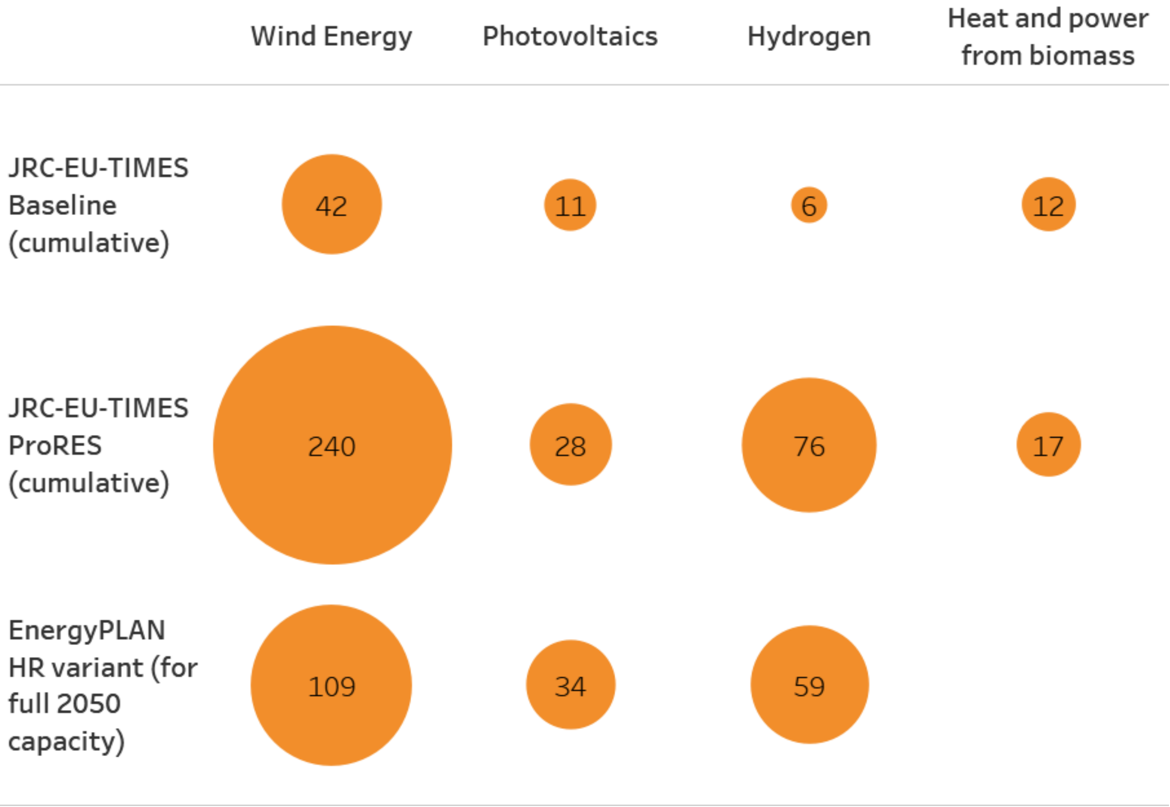


Figure 21: JRC-EU-TIMES (up to 2050) and EnergyPLAN (2050) investments in some key technologies (BEUR).

The comparison is not straightforward as investments are done gradually in JRC-EU-TIMES whereas there is only one lump sum investment in EnergyPLAN. Having this in mind however, we conclude that investments are largely similar as capacities are soft-linked to a large extent. Cumulative investments from JRC-EU-TIMES are larger as they include replacements of end-of-life capacities. The 240 BEUR investment in wind for example includes all replacements between today and 2050, whereas the 109 BEUR is for the one-off installation of 93 GWe. For PV however, the investment is larger in EnergyPLAN due to a different CAPEX assumption. Within JRC-EU-TIMES, the CAPEX assumptions are scenario dependent and make alignment also not straightforward. In the original JRC-EU-TIMES ProRES scenario, there is a high learning for PV.

Table 7: Differences and common elements in the power sector

Model	JRC-EU-TIMES ProRES	EnergyPLAN HR variant
Differences	Investments are done gradually per period. Numbers of total investments include replacements.	Investments are for the one-off installation of a certain capacity.
Common elements	Investments are largely similar as capacities are soft-linked to a large extent.	

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