Synergies between the Energy Efficiency First Principle and 2050 Renewable Energy Systems in Europe

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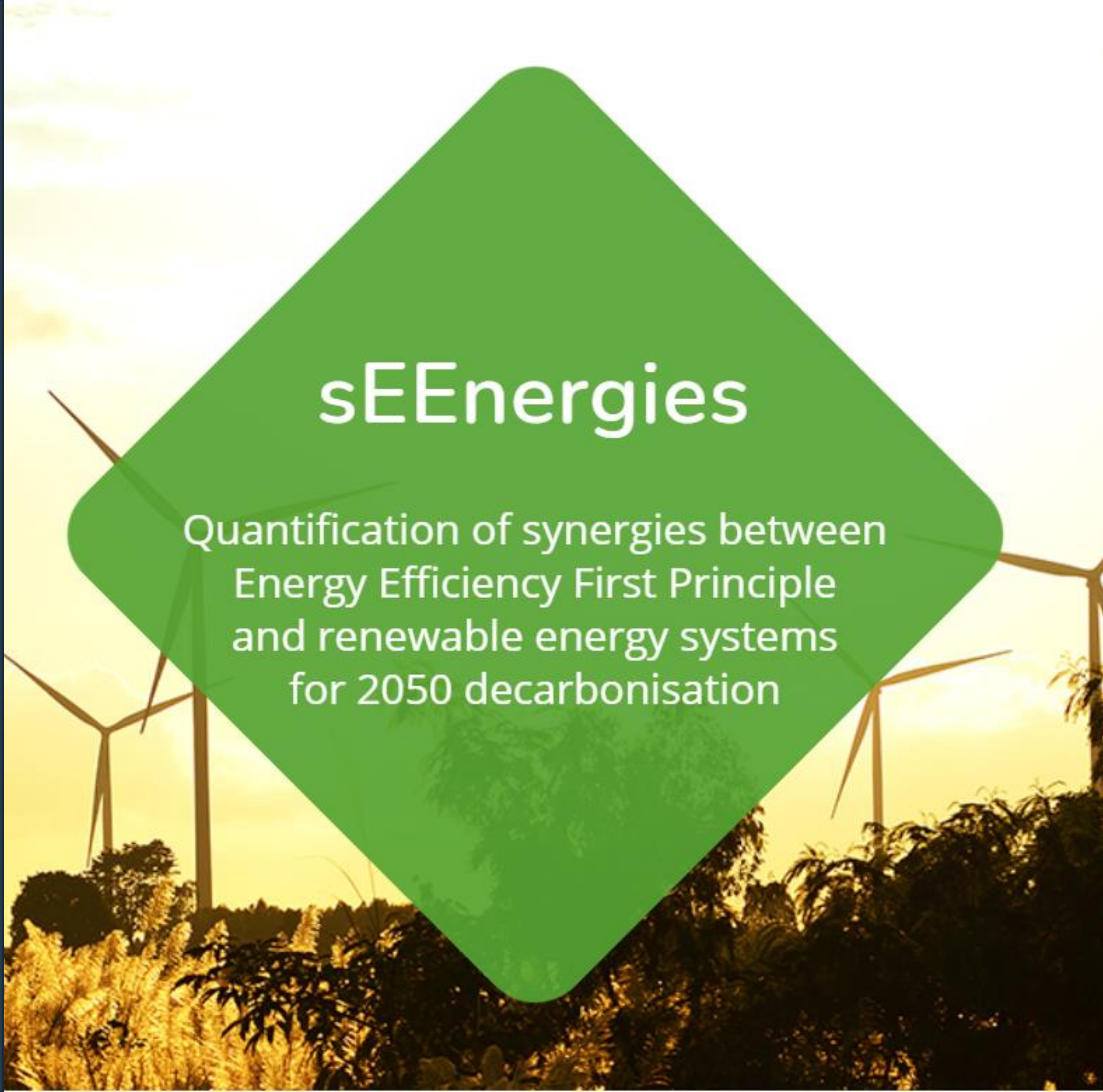

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Project

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Hogskolan i Halmstad (HU), Sweden

TEP Energy GmbH (TEP), Switzerland

Universiteit Utrecht (UU), Netherlands

Europa-Universität Flensburg (EUF), Germany

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sEEnergies

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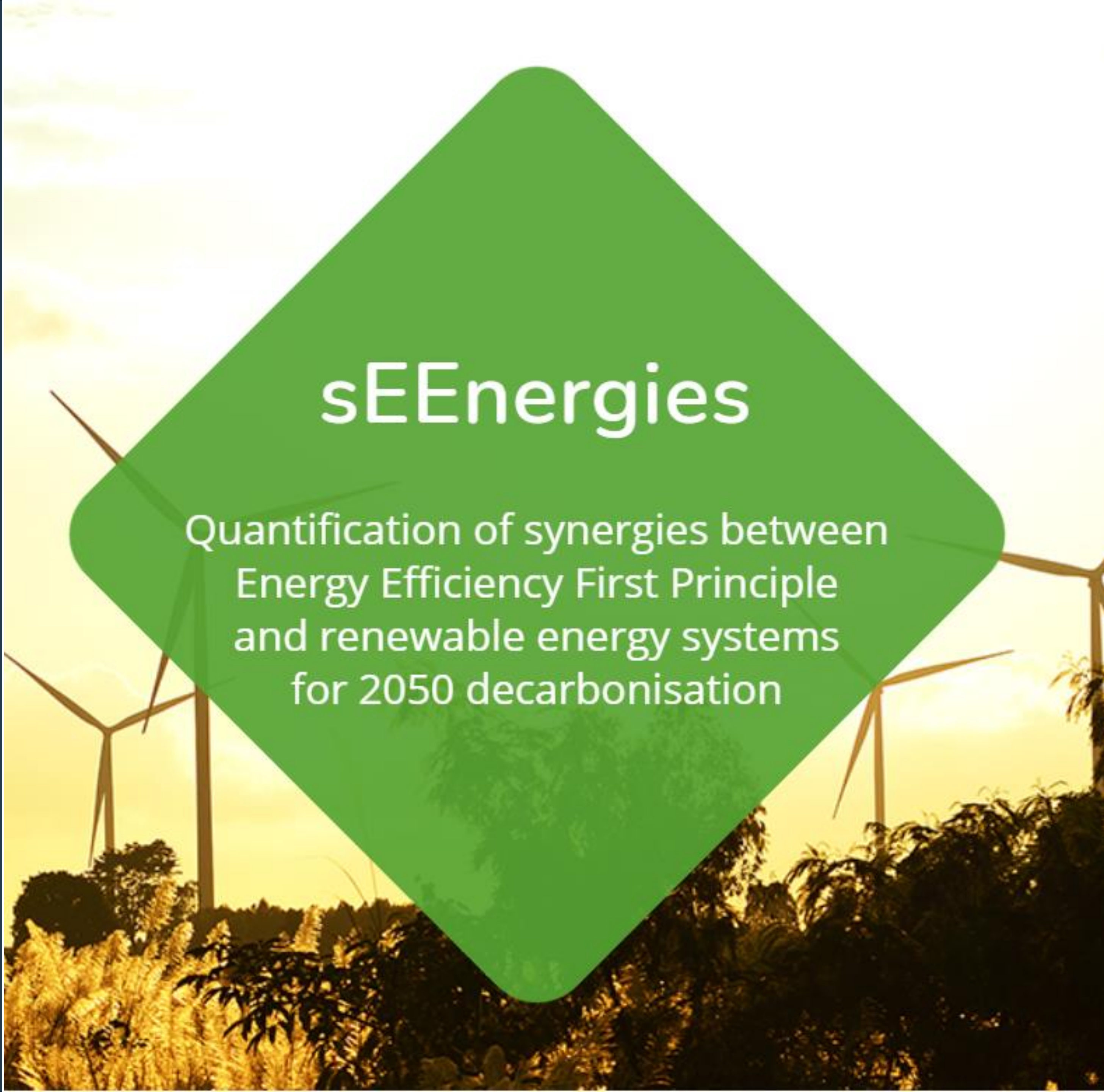
I. PROJECT OVERVIEW

- sEEnergies Objectives
- What is the Challenge?
- Project Setup and Model Approach
- Results Overview



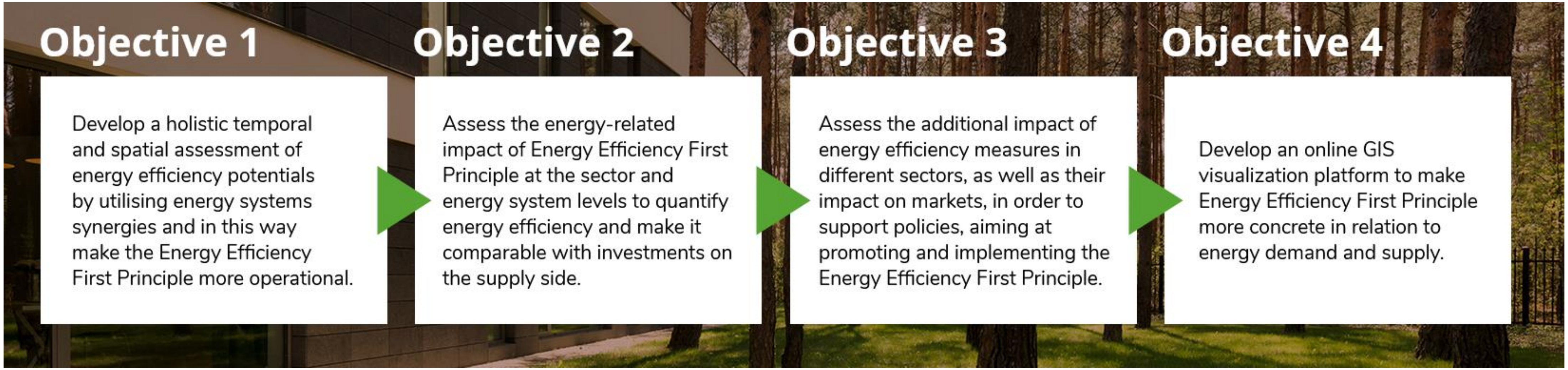
I. Project Overview

sEEnergies objectives

- To define and operationalise the **Energy Efficiency First Principle** (EEFP).

To combine and complement existing sectorial bottom-up knowledge with hour-by-hour modeling of the energy systems and spatial analysis in the EU. → Develop an analytical decision support tool.

To provide advances on the state-of-the-art of the understanding of EEFP consequences for each sector. → Enable policy makers and other target groups to easily find the results concerning their sector of interest.



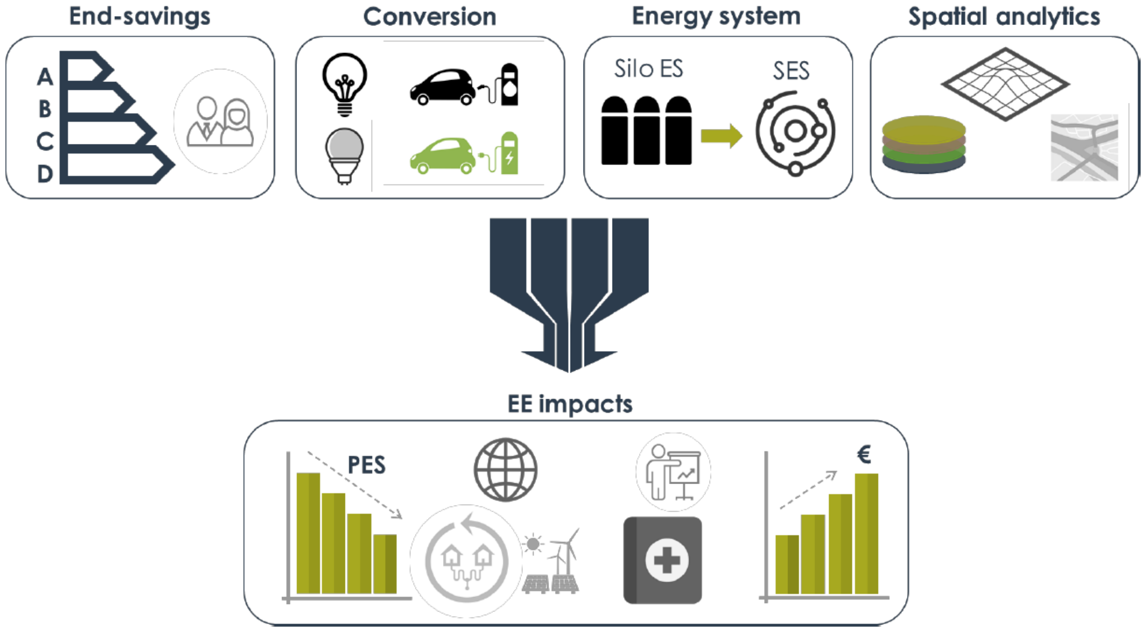
I. Project Overview

What is the challenge?

According to the European Climate Foundation the Energy Union EEFP can be explained as:

Efficiency First is the fundamental principle around which EU's Energy System should be designed. It means considering the potential value of investing in efficiency (including energy savings and demand response) in all decisions about energy system development - be that in homes, offices, industry or mobility. Where efficiency improvements are shown to be most cost-effective or valuable, taking full account of their co-benefits, they should be prioritized over any investment in new power generation, grids or pipelines, and fuel supplies.

In practice, Efficiency First means giving EE a fair chance in the models and impact assessments that policy-makers use to make decisions, strengthening those laws that already target efficiency, and integrating it into all other Energy Union policies. That includes funding decisions and infrastructure planning. Applying this principle will help to correct the persistent bias towards increasing supply over managing demand, a bias towards increasing supply over managing demand, a bias which has impeded Europe's ability to create a least-cost, jobs-rich, low-carbon energy system.



Key Questions

- How do we prioritise energy efficiency measures today that also have an effect in the future?
- What are the supply chain effects of energy savings in future energy systems?
- What does the future look like?

I. Project Overview

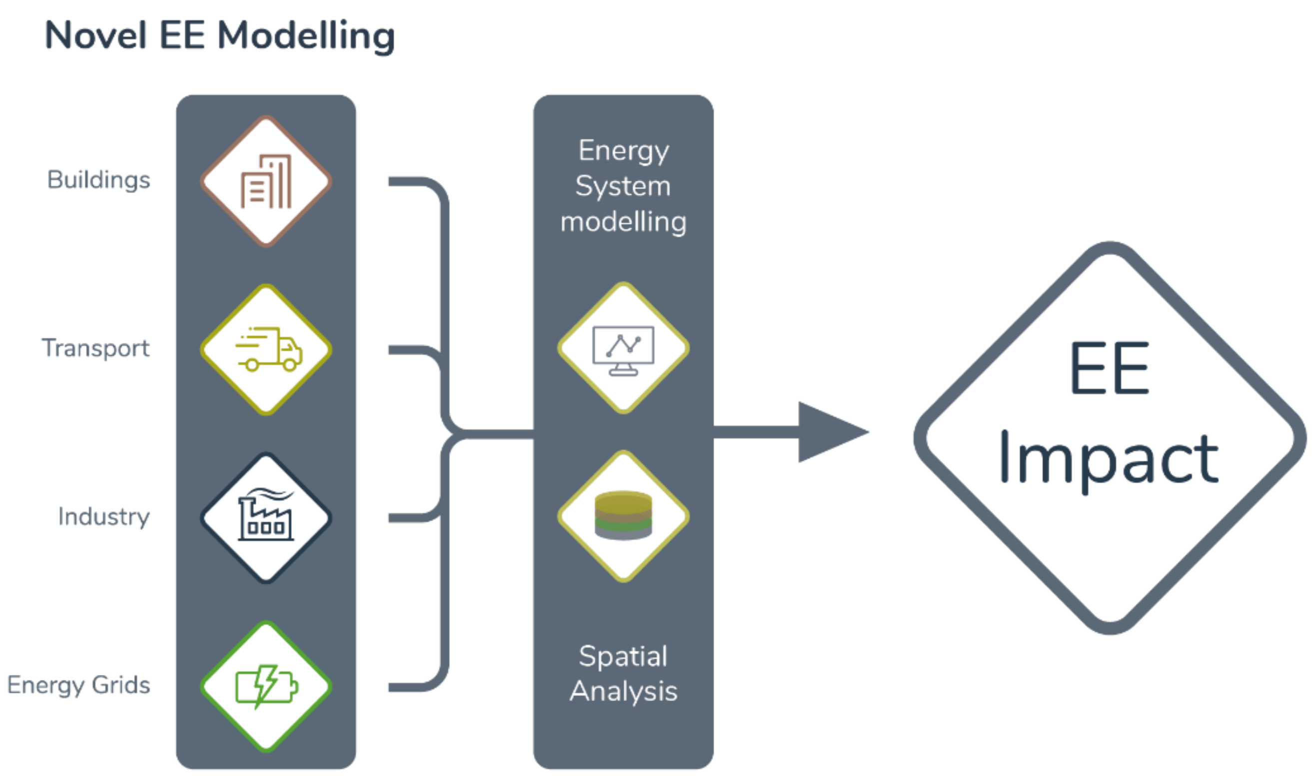
Project set up and model approach

Changes in one energy sector can contribute to impacts in another sector, so it is only possible to have a comprehensive assessment and quantification of the EEFP policies impacts if we look at the energy systems from a holistic perspective and take into consideration the synergies between sectors.

Bottom-up sectorial approach and grid assessment, together with energy system modelling and spatial analytics is combined in the novel EE modelling approach.

Embedded in the applied project methodology is the identification of synergies across the supply chain and towards additional impacts not directly linked to the energy system.

For each sector we will take as starting point the state-of-the-art including best practices, policies in place and energy and nonenergy impacts of EE, for the EU and for the 28 Member States.



I. Project Overview

Results Overview

BUILDINGS

EE potentials in the building envelope and electricity savings considering the cost aspects of refurbishment measures.

Balances between onsite and system renewable energy and EE measures.

Energy saving and EE cost curves for the built environment for member states using detailed building level data.

Comprehensive analyses of the use of excess heat from industry and low temperature district heating.

TRANSPORT

Holistic assessment of EE potentials by analysing strategies for more efficient vehicles, modal shift, and transport demand measures.

Use of state-of-the-art mobility and technology knowledge combined with GIS spatial analyses.

Development of scenarios for the development in mobility and transport using EE, electrification, and new technologies.

INDUSTRY

Quantification of industrial EE potentials in all industrial sub-sectors and member states.

Use of state-of-the-art knowledge combined with GIS spatial analyses for using industrial symbioses.

Development of scenarios for industry where each sub-sector can be analysed in depth considering EE potentials and potential structural industrial changes.

I. Project Overview

Results Overview

sEEnergies

ENERGY GRIDS

- Analysis of the behaviour and costs of different energy grids (electricity, thermal and gas grids) as well as energy storage solutions.
- Comprehensive overview of the key technologies, performance indicators, costs and future perspectives per energy grid.
- Investigation of the future role of gas grid and type of gases that will be part of the gas network and market.

SPATIAL ANALYSIS

- Consideration of the geographical dimension of EE measures to relate plausible EE measures to their spatial context and viability.
- Mapping of EE potentials using geographical information systems (GIS) and analysis of input data on sectoral EE potentials.
- Development of web-based GIS interface for the visualisation and presentation of data and results of sEEnergies.

ENERGY SYSTEMS

- Bottom-up country level analysis with high level resolution on each energy sector.
- Modelling and assessment of the impact of energy efficiency measures at system level.
- Investment roadmap based on the evaluation of the most critical EE improvements combined with an analysis of additional non-energy impacts.
- Development of sound science-based knowledge to support policy making aiming to implement the EEFP.

II. BUILDINGS

REFURBISHMENT MEASURES AND THEIR COSTS AND IMPACT ON FUTURE ENERGY DEMAND IN BUILDINGS

- Background
- Methods
  - Energy Carrier Prices
  - Building Typologies and EE measures
- Results
  - Single Level Building – Cost Aspects of Refurbishment Measures
  - Aggregated Cost Curves on the Building Stock
  - EE Potentials in the Built Environment
  - Heating Supply
- Conclusions

II. Buildings – Background

Refurbishment Measures and their Costs and Impact on Future Energy Demand in Buildings

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Buildings sector accounts for 40-50% of the overall consumption for electricity, heating and cooling.

- Current EE measures focuses almost solely on improvements to the building envelope and would enable 25% energy savings in the EU.
- State-of-the-art research shows that buildings level EE could be higher than 30% and that combining these savings with changes in the supply system can further increase the EE and lower costs.
- EE potentials are higher in the supply system than in the end use, however there is a synergy between the two. In the future, smart meters, digitalisation, demand response, and plus energy buildings may affect the EE potentials.

The question is what the risks are with non-compliance and whether further goals can be set for EE on the demand and supply side for buildings and to what extend electricity, gas or thermal grids have advantages for EE?

- As the building stock and its current performance standard is very heterogeneous in different European countries, additional sources for cost development of different building types and materials shall be applied by expanding the existing Heat Roadmap Europe dataset to all European countries.

OBJECTIVES

To assess the energy efficiency potentials and their related costs in both residential and non-residential buildings

- To collect and develop data from the EU28 countries on energy efficiency potentials in the building sector, which are required for an overall assessment of the efficiency potentials in integrated energy systems.
- To shed light on the cost aspects of different refurbishment measures and their contribution to reduce energy demand. The cost and efficiency assessment is a base for the comparison with the costs of using renewable energies for building related energy services.

II. Buildings – Methods

Energy Carrier Prices

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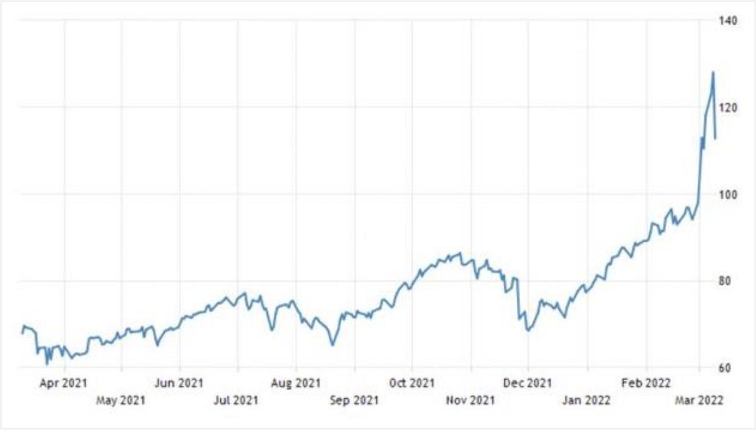
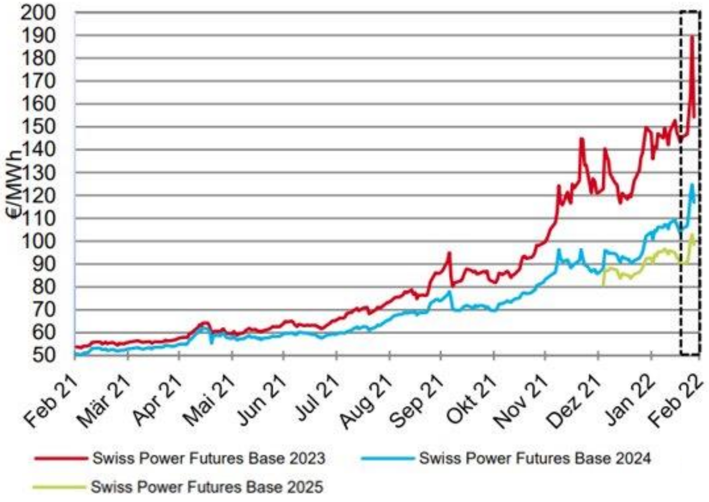
Crude oil (brent)



Source: trading economics

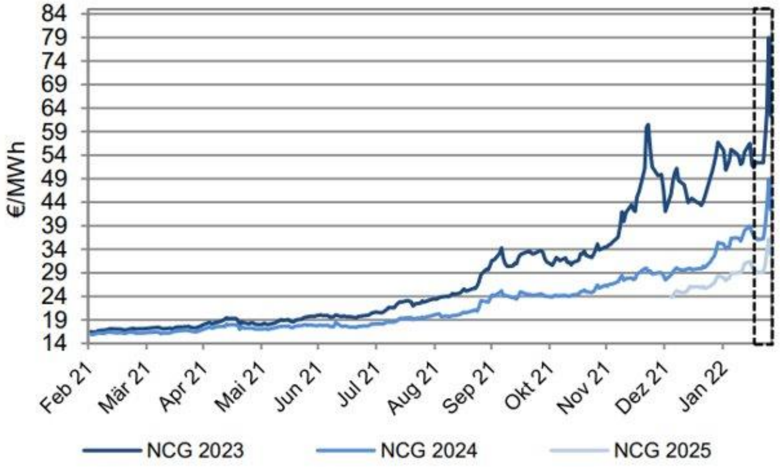
Additional relevance for construction material as input for insulation material such as expanded polystyrene.

Electricity



Source: EEX

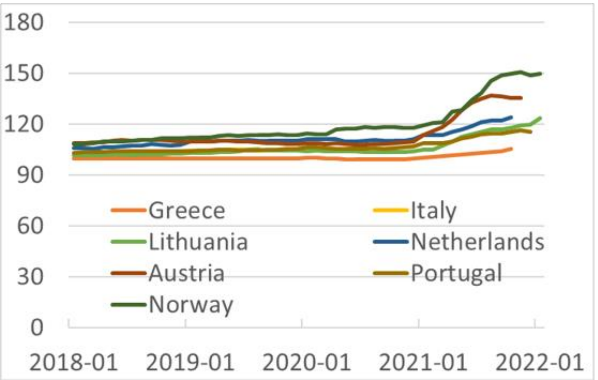
Natural gas



Source: Swiss market

Recent impacts

- With the Covid pandemic fading in the last months of 2021 and in the beginning of 2022, we saw relevant increases in material prices for construction and a partial interruption of supply chains. The shift in construction pricing is likely to influence in the short to mid-term the development of the refurbishment sector.
- Energy carrier prices soaring in the last months of 2021 and in the beginning of 2022 could shift the equilibrium towards energy efficiency.
- Policy interventions to be addressed which are currently under discussion.



Eurostat monthly index for input prices for materials (national currency, 2015 = 100)

II. Buildings – Methods

Building Typologies and EE measures

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Building Types

ID_BuildingType	Building Type	Acronym Building Type
1	Single-family houses	SFH
2	Multi-family houses	MFH

Building Construction Periods

ID_Building Age Class	Building Age Class
1	Before 1961
2	1961-1990
3	1991-2008
4	2009-2020
5	after 2020

Two main pathways for achieving higher savings are explored:

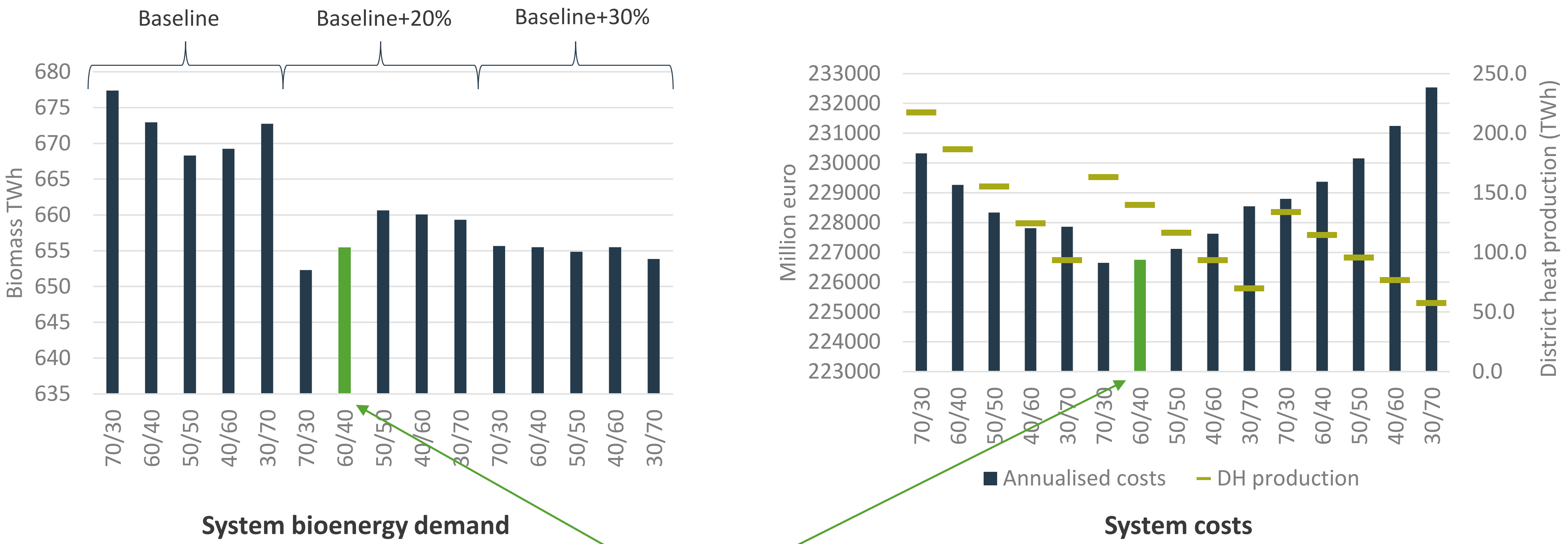
1. Building owners, who are already taking energy-improving renovations in the baseline scenario (package 1 to 5), are encouraged to use their momentum to invest in more efficient refurbishment packages (shares of packages 1 to 5 are distributed between 2 to 16)
2. Building owners who are not implementing energy-renovation measures (package 1) in the baseline scenario are driven to take simple and cost-effective EE measures.

ID	Energy-refurbishment measure
1	Façade painting
2	Only windows (low)
3	Window and wall (low)
4	Windows and walls and roof (middle)
5	Windows and walls and roof and floor (high)
6	Building on package 5, windows and walls and roof and floor (higher)
7	Building on package 5, windows and walls and roof and floor (highest)
8	Building on package 5, windows and walls and roof and floor ("passivhouse")
9	Windows (high) and roof (higher)
10	Only walls (low)
11	Windows(higher)
12	Windows and wall (higher)
13	Windows (middle) and roof (middle) and floor (high)
14	Windows and roof and floor (higher)
15	Roof (middle) and floor (high)
16	Roof and floor (highest)

II. Buildings – Methods

Heating Supply in Buildings

Country X



Selected scenario: 60% district heat and 40% individual heat

- Selection of 15 energy system scenarios analysed for *Country X*
- Three heat demand levels for buildings: Baseline, Baseline+20%, and Baseline+30%
- The scenarios differ by splitting heat supply between district heat and private heating in different shares.

II. Buildings – Results

Single Level Building – Cost Aspects of Refurbishment Measures

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Investment in the building envelope

- Per building type
  - Single and multi family houses
- Building age depending
  - 5 different age classes
- Measures for 4 different building elements in building packages (1 to 16, mutually exclusive)
  - Wall
  - Window
  - Roof
  - Basement
- Per EU country

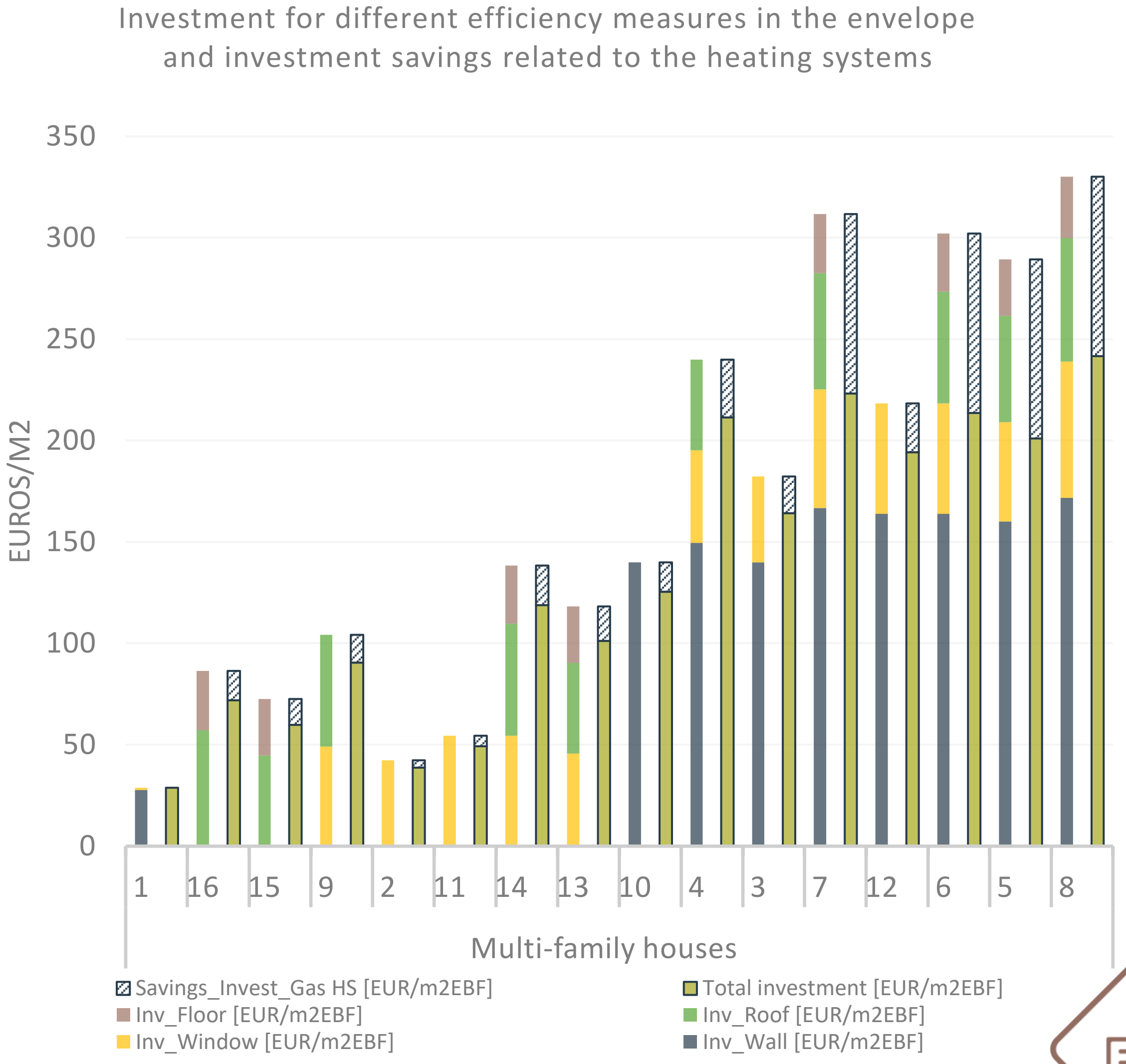
Investment in the heating system

- Savings on the heating system investment
- Energy savings
  - Depending on energy carrier price

Cost-effectiveness depends on:

- Energy carrier price
- Marginal heat generation cost
- Discount rate (mortgage rate)
- Assumed lifetime

→ **Net present value (NPV) of measures can be positive or negative for identical buildings.**



EBF = energy reference area

II. Buildings – Results

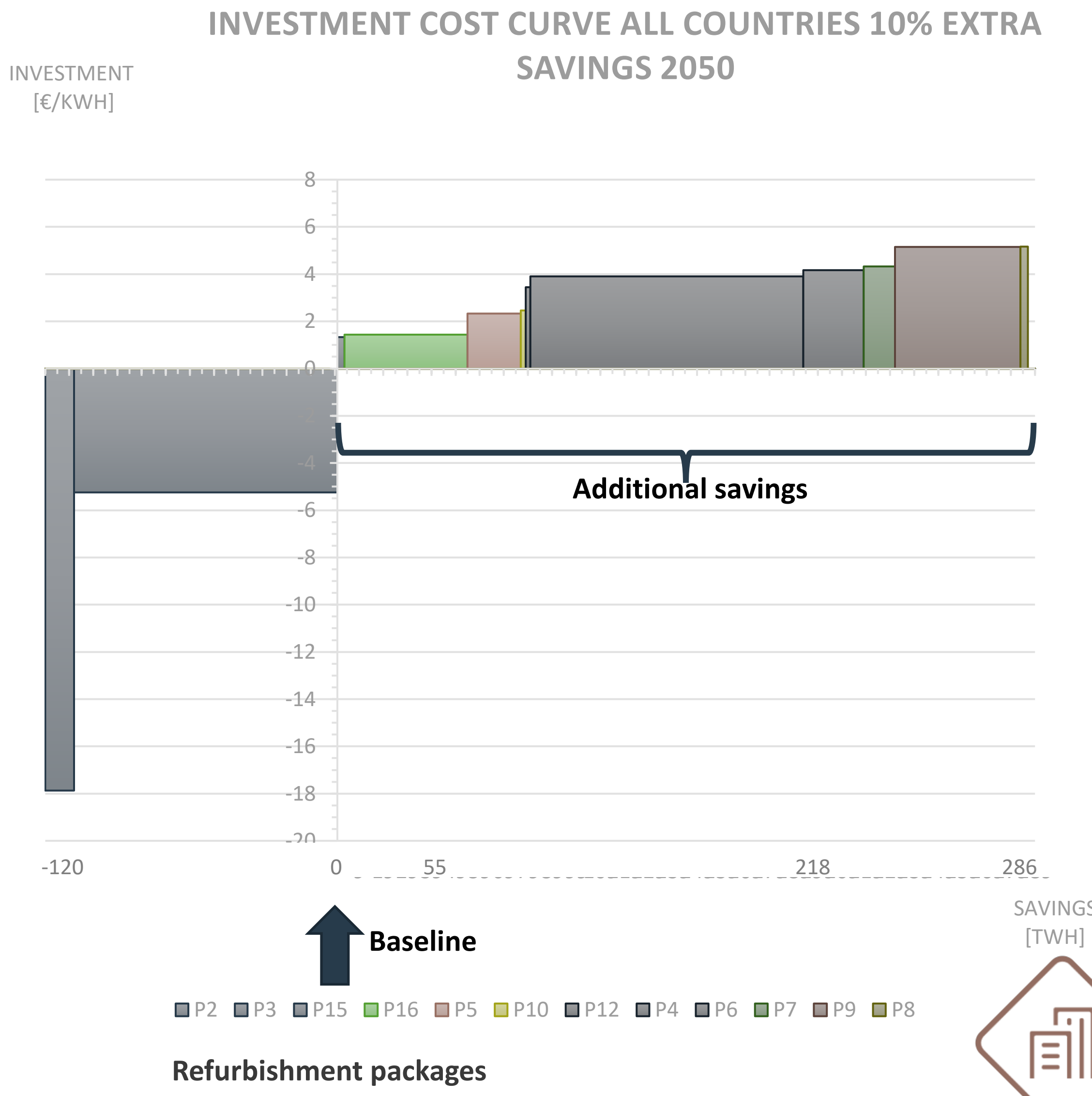
Aggregated Cost Curves on the Building Stock

Aggregated cost curves for building envelope measures per country for additional savings beyond the baseline.

Energy reference area and average useful energy demand per m^2 and building type.

Investment in the building envelope

- Based on approach for single building
- Aggregation on building stock level and country
- Providing additional savings to a baseline
    - Negative savings for packages in the baseline which currently (in the baseline) are not considered
    - Positive savings for additional measures and additional costs
- Cost structure depending on the set of measures and starting point of building stock.



II. Buildings – Results

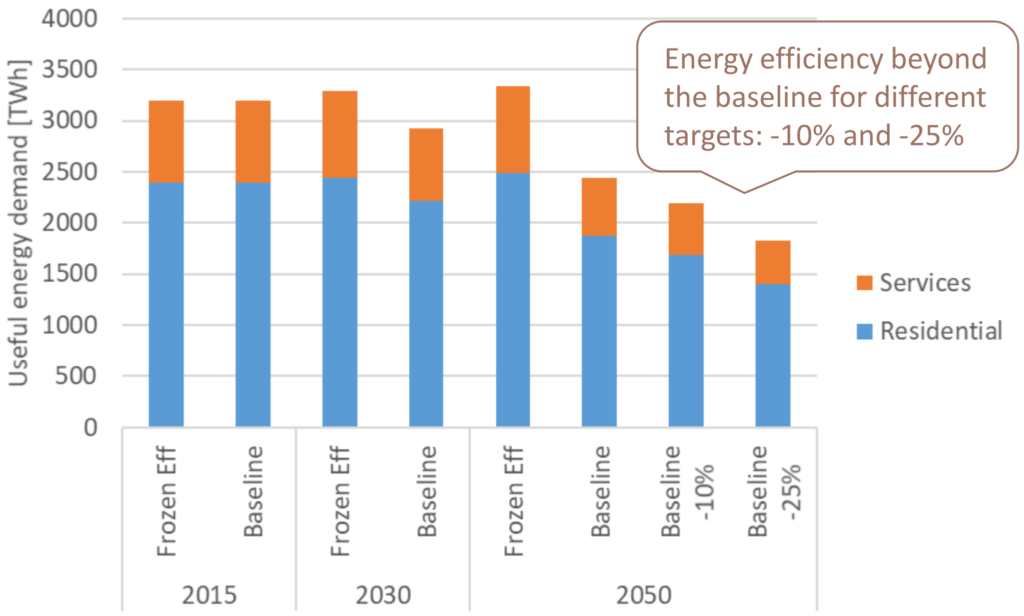
EE Potentials in the Built Environment

Starting from frozen efficiency (FE) demand (i.e., buildings not undergoing energetic refurbishment until 2050; incl. new buildings).

Baseline scenario includes moderate energy refurbishment of the building stock.

- Per building type and building age class.
- Does not include ambitious energy efficiency improvements (e.g., further changes in building codes).
- Does not include the targets of the renovation wave.

Savings beyond the baseline for different additional saving targets (-10% and -25%).



Additional savings are substantial, but nevertheless limited

- Up to 2050 less than 30 years left
- Due to lifecycles and various barriers (technical, social, awareness, financial) retrofit rate may be increased to a limited extent only, despite the targets of the renovation wave

→ **Also in 2050 there is still heat to be deployed**

II. Buildings – Results

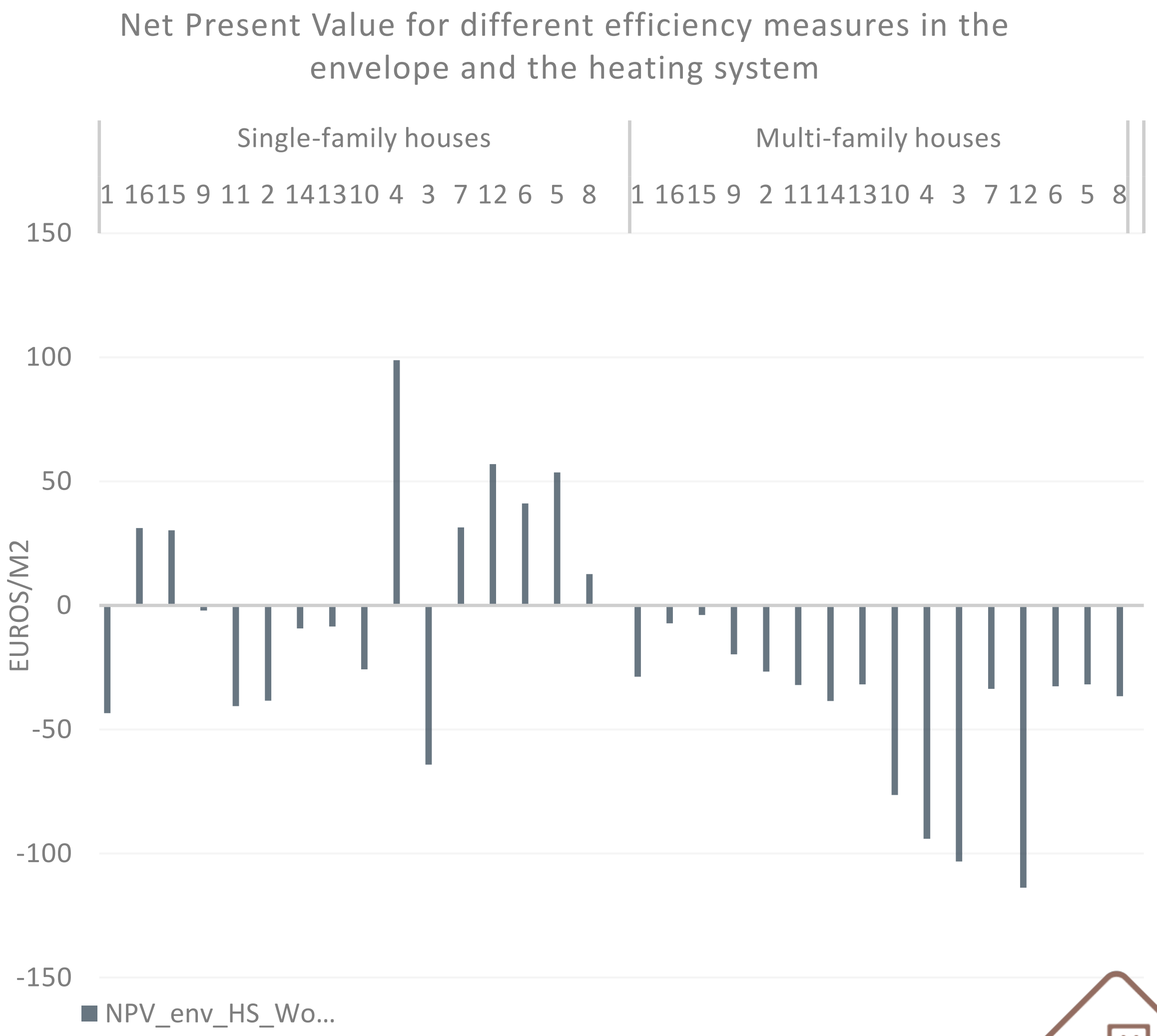
Aggregated Cost Curves on the Building Stock

Depending on energy carrier price and marginal heat generation cost, the NPV of the measures can be positive or negative for identical buildings.

Investment in the building envelope

- Based on approach for single building
- Aggregation on building stock level
- Providing additional savings to a baseline
- To achieve 25% additional useful energy savings, additional investments at the level of +40% are needed in 2050
- More buildings are undergoing refurbishment, therefore more cost effective measures applicable
- To reach the 20% additional savings in 2030 doubles the overall investment costs, but respective investments are also needed in the baseline until 2050 to reach similar demand reductions.

-> One can either refurbish buildings to higher standards or refurbish more buildings to achieve similar levels of energy demand

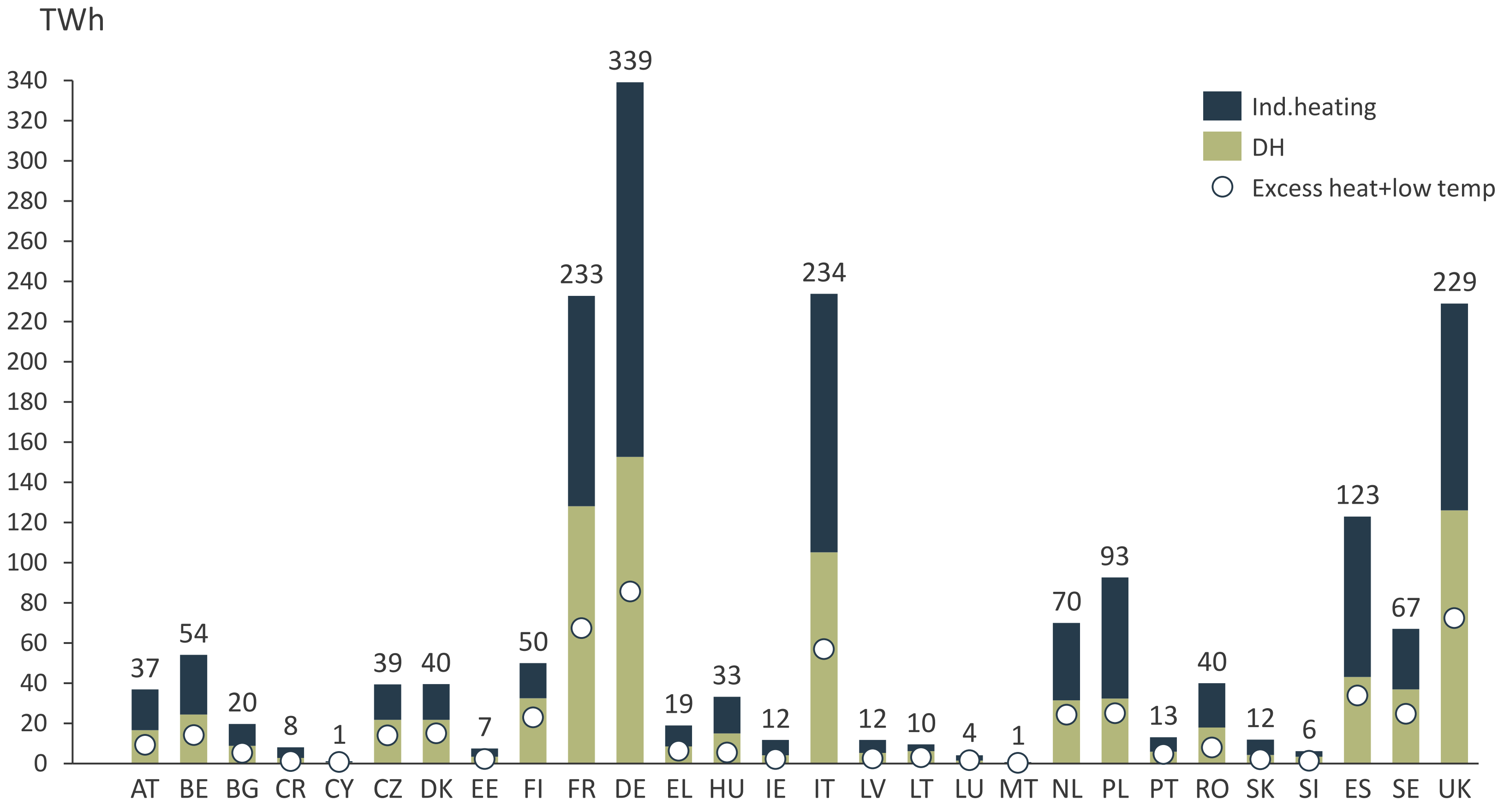


II. Buildings – Results

Heat Supply from Individual and District Heating in Different Countries

Heat supply from individual and district heating

- Cost effective to develop a 50% share of district heat in 2050.
- In most countries, the excess and low temperature heat supplies over half of the district heat and over a quarter of the entire heat supply in the country.
- Around 60% of district heat can be supplied with excess heat from other processes (e.g. industry) and low temperature heat (e.g. sewage)
- Individual heat is supplied mostly with heat pumps.
    - Assuming a heat demand of 7,000 kWh per building, a total of 140 million individual heat pumps are estimated to be needed in 2050.



II. Buildings – Results

Heating Supply

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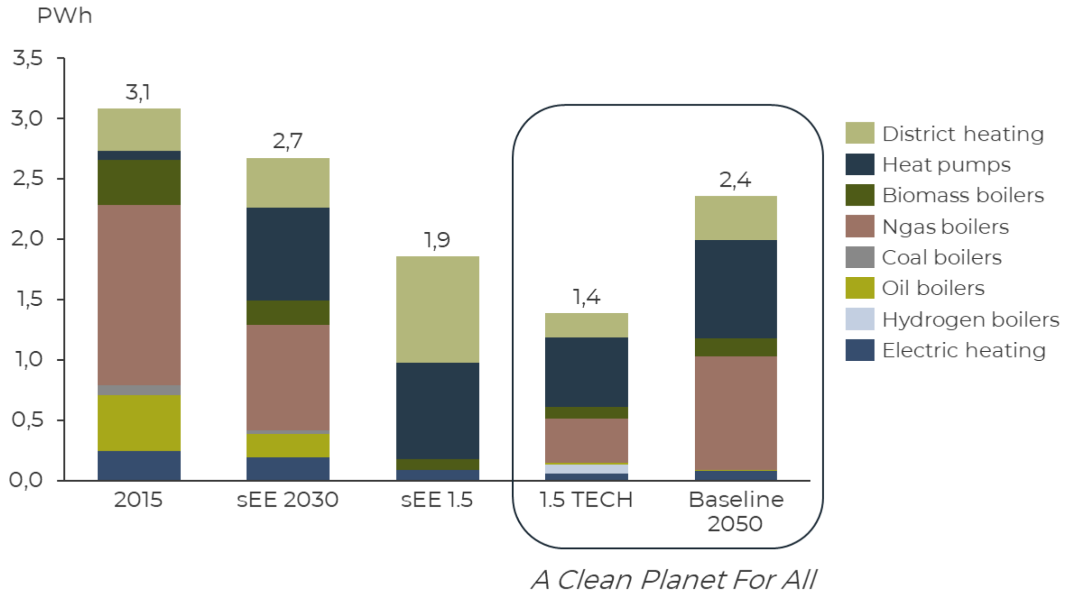
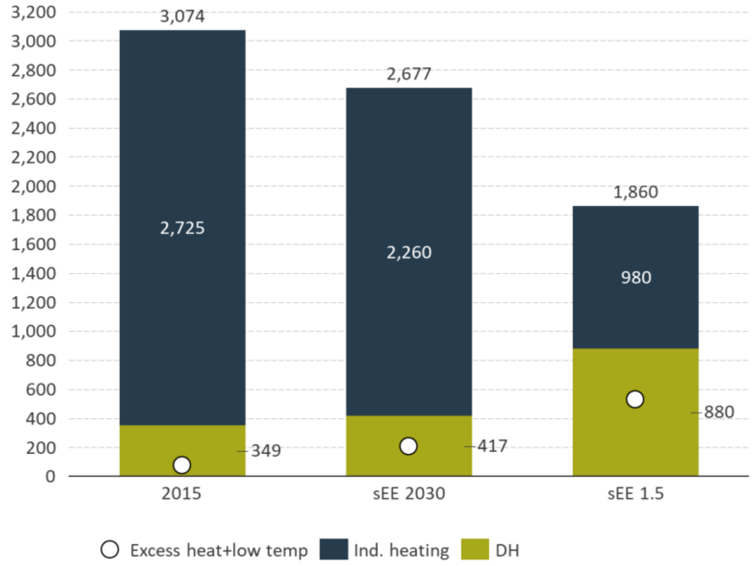
Total Heat Demand by Source of Heat



District Heating Heat Production



- District heating is cost-effective even with lower heat demands due to energy refurbishment in buildings and the decommissioning of large heat producing power plants since the heat supply arises from numerous heat sources.
- This means the heat supply mix can become more diversified than focusing only on individual heat pumps.
- For countries that have district heating already, supply of abundant renewable heat can make the district heating cost-effective and low resource demanding and the mix of heat sources is expected to grow.

- Heat demand in existing buildings should be reduced by approximately 40%.
- Half of the heat demand is supplied by district heating in 2050, the remaining 50% is covered by individual heat pumps. Excess heat and low-temperature heat sources such as industrial waste heat, geothermal, solar thermal, large-scale heat pumps and electrolysis, can supply 60% of district heating, while the remaining 40% is produced with CHP, waste incineration and boilers.
- Total excess + low temp heat utilised: 630 TWh or about 1/2 of the total production.
- no

II. Buildings – Conclusions

Refurbishment Measures and their Costs and Impact on Future Energy Demand in Buildings

- The most cost-efficient measures for building refurbishment considered are simple measures such as improving roof and basement insulation.
- With an energy-efficient retrofit of the building envelope, up to 25% of heating energy demand can be saved in addition to the baseline scenario. Higher savings can be achieved if some moderate add-on costs are accepted. Such measures might become cost-effective with higher energy prices.
- Country specific policies are needed to increase the refurbishment depth for different building categories as well as different age classes.
- Deep refurbishment needs to be implemented in the first step to avoid additional costs due to double work. Buildings which are foreseen for refurbishment need to be refurbished at deeper levels so as to avoid that these buildings need to refurbished in short time afterwards to achieve lower energy demand levels.
  - Momentum for refurbishment can be used to mobilise additional savings which are otherwise untapped.
- Majority of the extra savings are achieved by implementing more ambitious renovation measures – linked to specific building age classes.
- The introduction of low investment cost solutions, high-efficiency materials, and/or the promotion of standardized refurbishment procedures help to reduce architectural, technical, financial, and regulatory barriers.
- Around 50% of heating is supplied by district heating and around 60% of district heat can be supplied with excess heat from other processes (e.g. industry) and low temperature heat (e.g. sewage)and individual heat is supplied mostly with heat pumps.

CLICK HERE for Policy Brief

CLICK HERE for Reports on Buildings (WP1)

CLICK HERE for Webinar on Buildings

III. TRANSPORT

COMPREHENSIVE ENERGY EFFICIENCY POTENTIALS IN TRANSPORT AND MOBILITY

- Background
- Methods
    - Overall Approach
    - Traditional and EE Development Scenarios
    - EE Development Scenario Assumptions
- Results
    - Annual Growth Rates and Modal Shift Rates
    - Peak Car Phenomenon
    - EE Technology Development
    - Energy Demand
    - Annual Costs
- Conclusions

III. Transport – Background

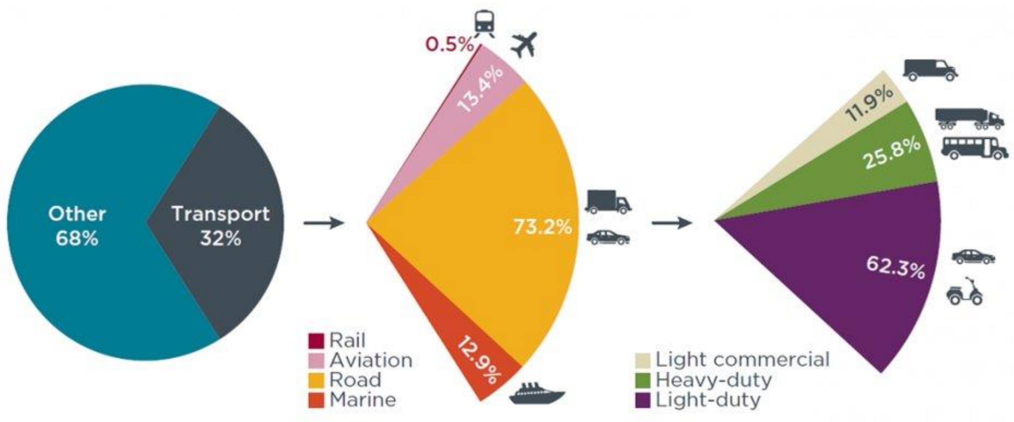
Comprehensive Energy Efficiency Potentials in Transport and Mobility

sEEnergies

Transport accounts for about 30% of the final energy consumption.

- Measures have been local to improve public transport infrastructure, bike lanes, electric charging stations combined with policies on demanding more and more energy-efficient vehicles on the EU level.
- If 80% of the fuels for personal transport was replaced by electric vehicle drive the savings would be about 30% for the transport sector as a whole.
- There are however many additional potentials: modal shift, other technologies such as hydrogen fuel cells and electrofuels, more EE in the heavy-duty transport and aviation, car-sharing platforms, and urban and infrastructure planning.

  The question is what the collective EE potentials are and what the additional effects could be on electricity grids, power generation, and costs?



Distribution of EU28 Transport CO_2 emissions by mode of transport 2015 (Source: Clean Energy Wire Factsheet)

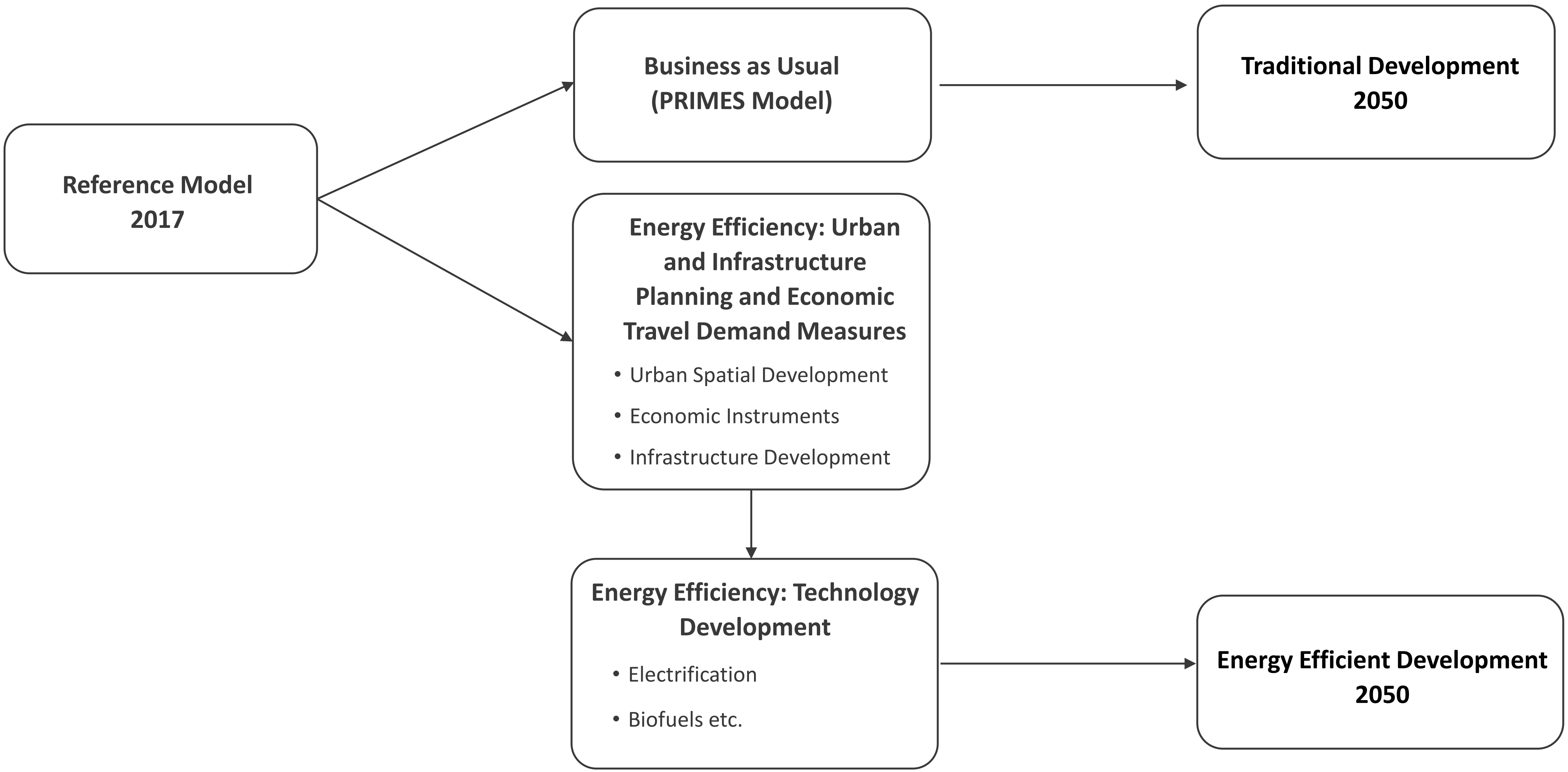
OBJECTIVES

To assess EE potentials in transport sector

- Analysis of three main strategies for lowering energy use within the transportation sector
  1. Making each separate mode of transport more energy-efficient
  2. Modal shift from energy-demanding to more energy-efficient modes of transport
  3. Reducing the movement of persons and goods.
- Development of different transport scenarios with detailed breakdown of possible efficiency measures.
- Development of broad understanding of the economic and social impacts of implementing EEFP in the transport sector.

III. Transport – Methods

Overall Approach



III. Transport – Methods

Traditional & EE Development Scenarios

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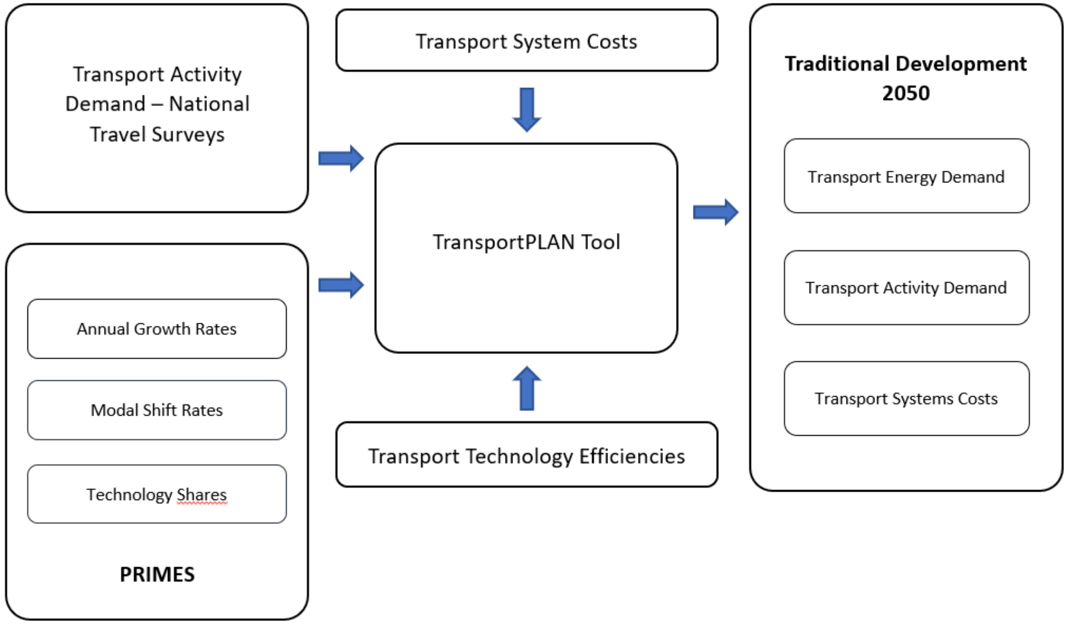
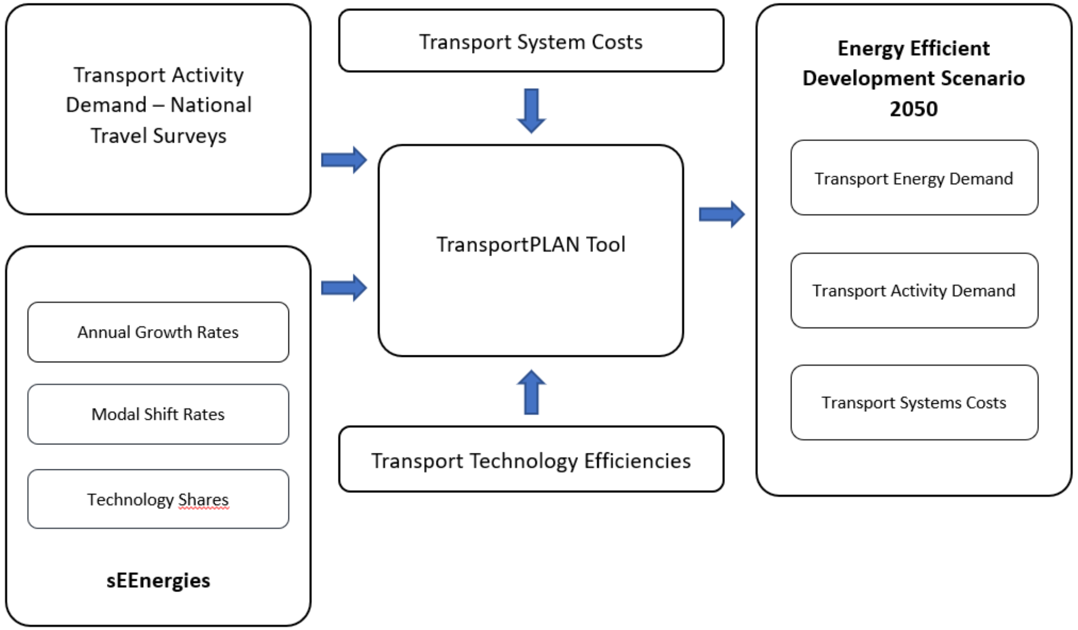
Traditional Development 2050



Energy Efficient Development Scenario 2050



TransportPLAN

- Throughout the process of collecting data, everything was gathered in the transport system scenario tool TransportPLAN.
- The tool allows for a detailed decomposition of the entire transport sector; hence it is possible to:
  - adjust transport behaviour for each mode of transport related to trip distance,
  - quantify the energy efficiency potentials related to the implementation of alternative transport technologies, both in terms of energy consumption and costs

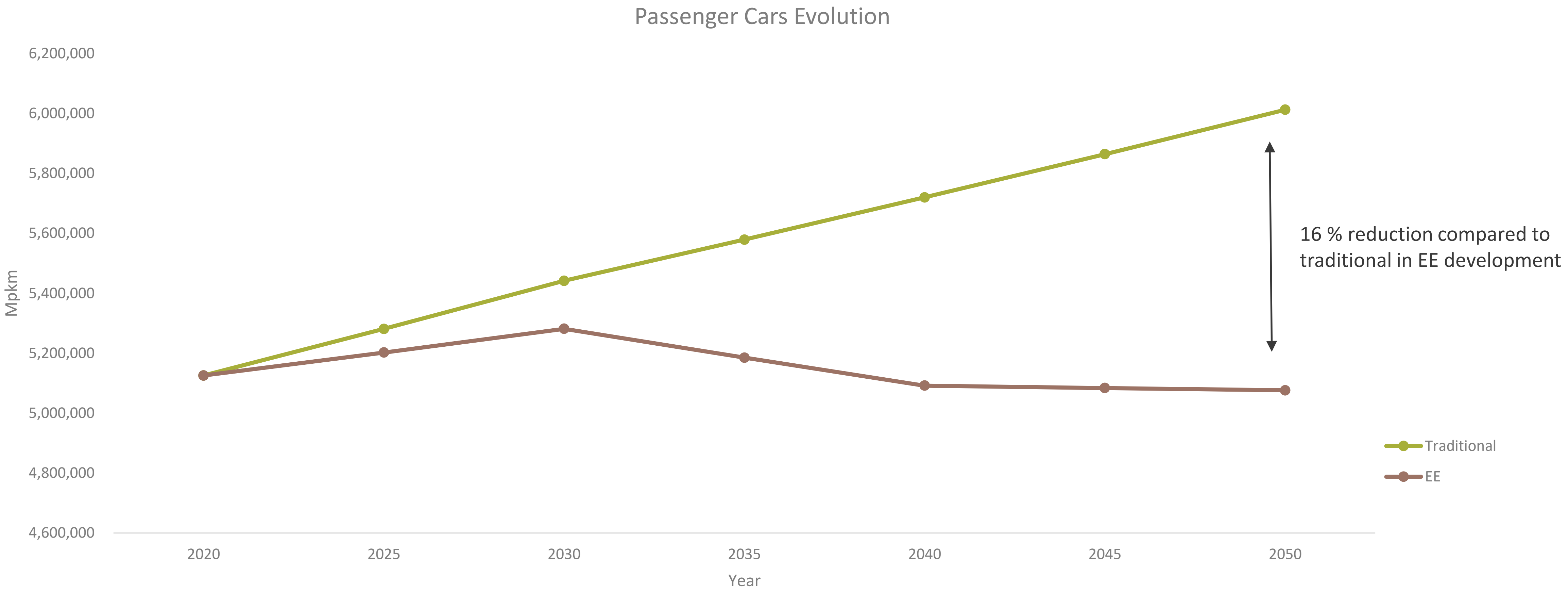
III. Transport – Methods

Energy Efficient Development Scenario Assumptions

Changes over the period 2020-2050	Northern Europe		Western & Central Europe		Southern Europe		Eastern Europe	
	BAU	EE	BAU	EE	BAU	EE	BAU	EE
Urban spatial development	Continuation of trends 2000-2015	Strong densification Reduced residential distance to center	Continuation of trends 2000-2015	Strong densification Reduced residential distance to center	Continuation of trends 2000-2015	Strong densification Reduced residential distance to center	Continuation of trends 2000-2015	Strong densification Reduced residential distance to center
Highway capacity increase	According to TEN-T + other motorway construction	None	According to TEN-T + other motorway construction	None	According to TEN-T + other motorway construction	None	According to TEN-T + other motorway construction	None
Airport construction	To accommodate growth	None	To accommodate growth	None	To accommodate growth	None	To accommodate growth	None
Railroad construction	According to INEA	Intensified in urban regions	According to INEA	Intensified in urban regions	According to INEA	Intensified in urban regions	According to INEA	Intensified in urban regions
Road pricing and parking fees	Very limited	Extensive urban schemes	Very limited	Extensive urban schemes	Very limited	Extensive urban schemes	Very limited	Extensive urban schemes

III. Transport – Results

EE Urban Spatial & Infrastructure Development – Annual Growth Rates and Modal Shift Rates



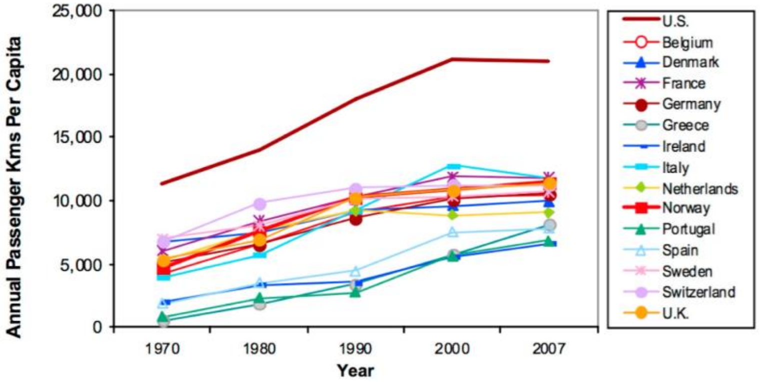
III. Transport – Results

Peak Car Phenomenon

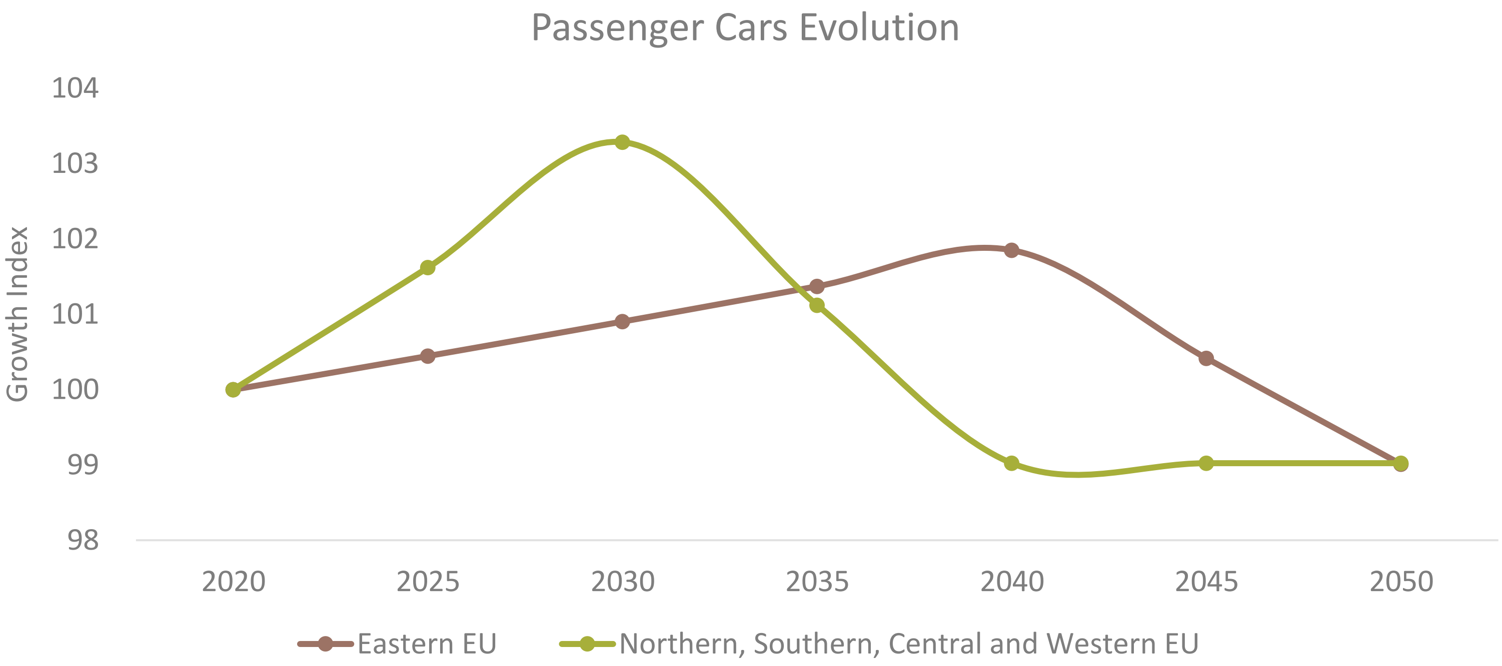
The peak car phenomenon has been observed in some developed economies and it is likely that this phenomenon will occur in most of Europe.

Most likely it will be observed in Western Europe earlier than Eastern Europe.

Evolution of car travel per capita in OECD countries



Source: Litman (2009)



III. Transport – Results

EE Technology Development

sEEnergies

	Baseline	Biofuels	Hydrogen (H2)	Electrification and e-fuels	Electrification +
Passenger Cars	35% BEV 19% PHEV 4% FCEV 4% Gaseous 18% Gasoline 20% Diesel	35% BEV 40% Biodiesel 25% Bioethanol	35% BEV 65% FCEV	100 % BEV	100 % BEV
Buses	5% BEV 36% Hybrid 21% Gaseous 38% Diesel	5% BEV 95% Biodiesel	5% BEV 95% FCEV	95 % BEV 5% Electrofuels	95 % BEV 5% Electrofuels
Rail	87 % Electric, 13 % Diesel	87% Electric 13% Biofuels	87% Electric 13% Hydrogen	100% Electric	100% Electric
Aviation	3% bio-jetfuel 97% kerosene jetfuel	100% Bio-jetfuels	50% Bio-jetfuels 50% Hydrogen	19% Electric 81% E-kerosene	22% Electric 78% E-kerosene
Shipping	13% Gaseous 87% Diesel and HFO	100% Biofuels	50% Hydrogen 50% E-methanol	50% Electric 50% e-methanol	50% Electric 50% e-methanol
Trucks	1% BEV 29% Hybrid 18% Gaseous 51% Diesel	50 % Biogas 50 % Biodiesel	1% BEV 99% FCEV	27% BEV 73% E-methanol	27% BEV 73% ERS-BEV
Vans	26% BEV 1% FCEV 19% PHEV 54% Diesel	26% BEV 38% Biodiesel 36% Biogas	26% BEV 74% FCEV	95% BEV 5% Electrofuels	95% BEV 5% Electrofuels
Rail	87 % Electric, 13 % Diesel	87% Electric 13% Biofuels	87% Electric 13% Hydrogen	100% Electric	100% Electric
Aviation	100 % Kerosene jetfuel	100% Bio-jetfuels	50% Bio-jetfuels 50% Hydrogen	100% E-kerosene	100% E-kerosene
Shipping	100 % Diesel and HFO	100% Biofuels	50% E-ammonia 50% E-methanol	50% E-ammonia 50% E-methanol	50% E-ammonia 50% E-methanol

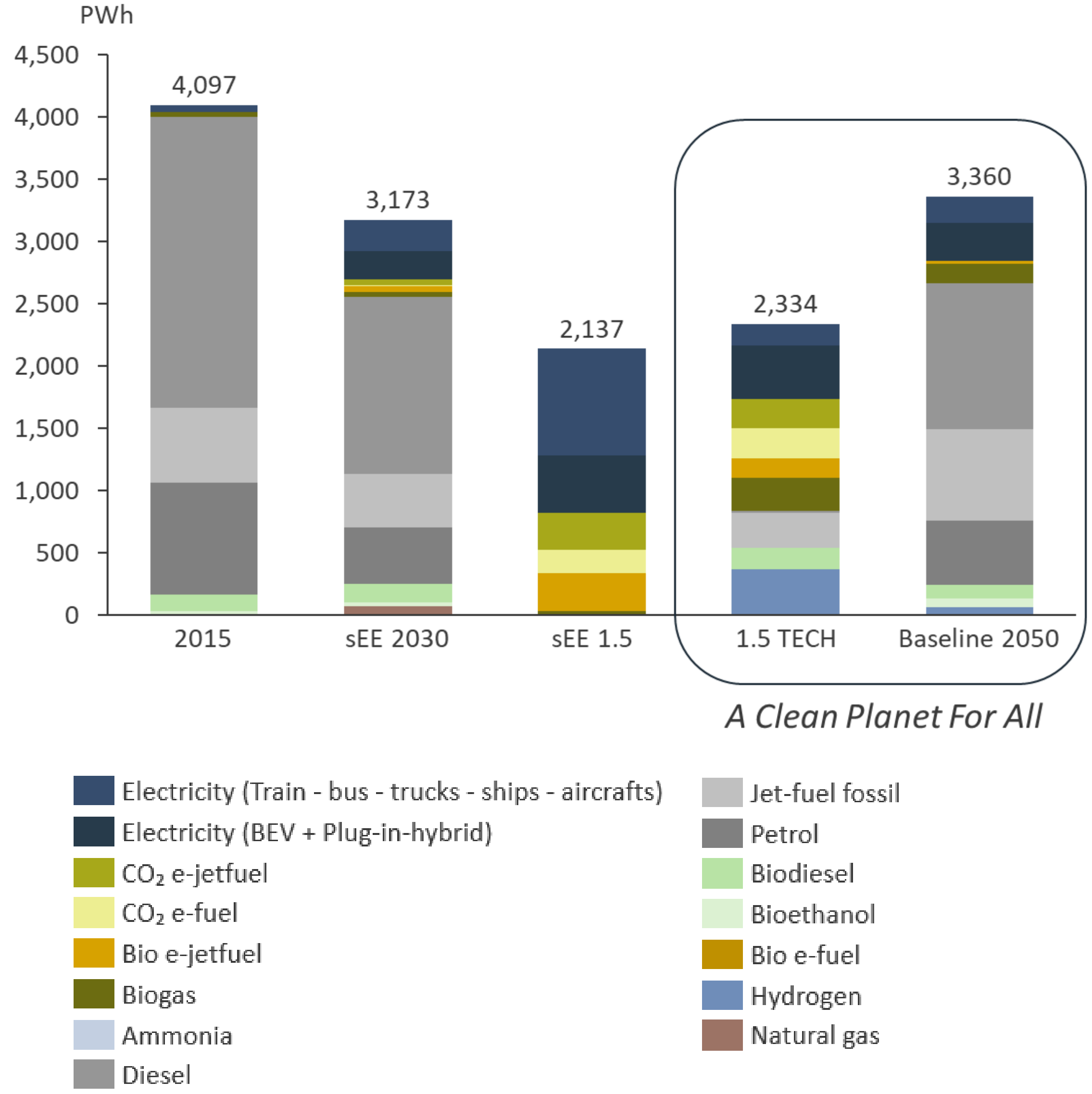
It is estimated that all trips with trucks under 200km can be electrified. That corresponds to 27% of the total transport demand.

19% of aviation corresponds to all national and 25% of all intra-EU flights.

22% of aviation corresponds to all national and 35% of all intra-EU flights.

III. Transport – Results

Energy Demand – Energy Efficiency Development

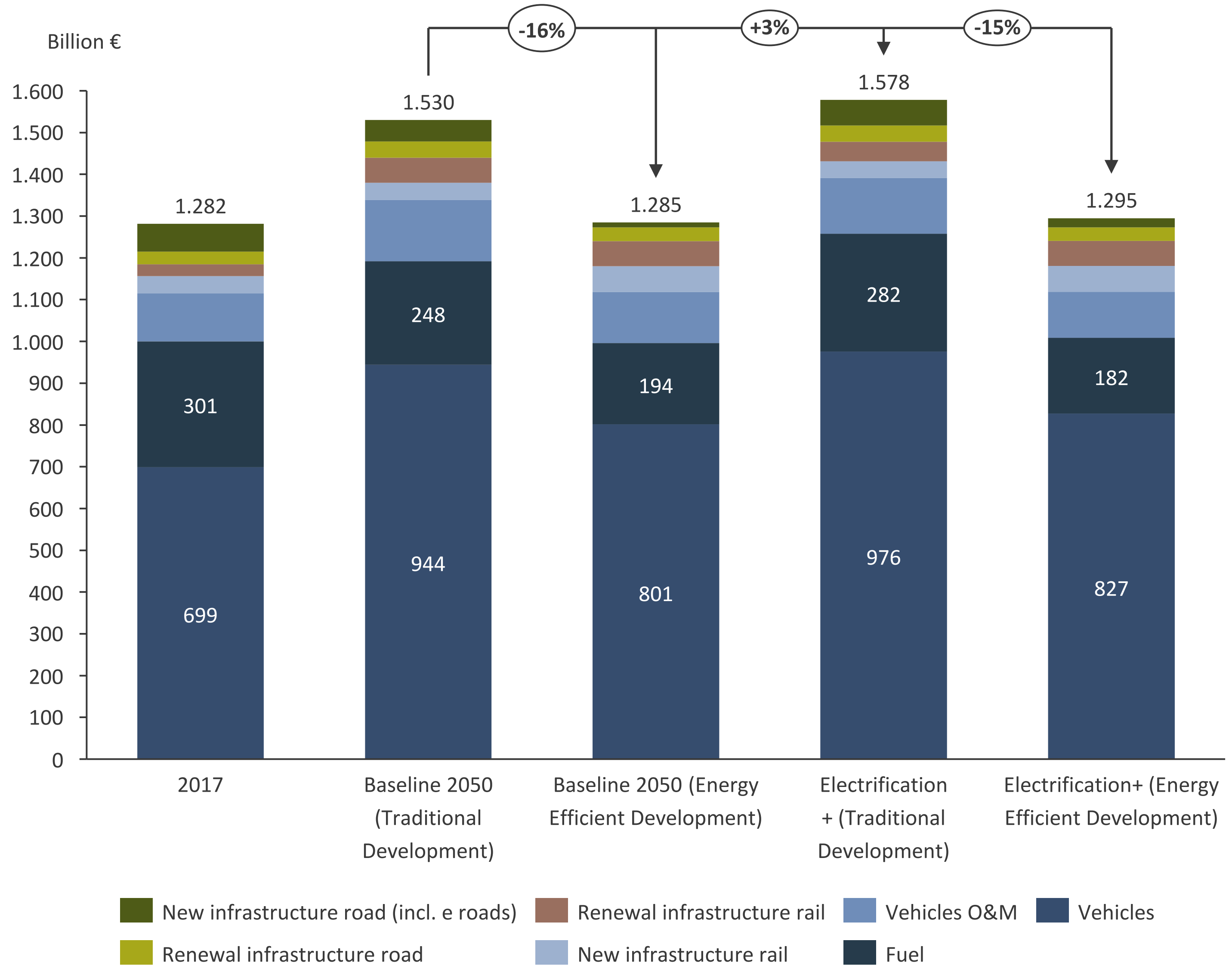


Scenario Conclusions

- There are four technology scenarios in sEEnergies combined with two urban developments as well as two scenarios from the EU. sEE 1.5 uses Electrification+ with an energy efficient urban development. Here compared with the EU Baseline 2050 with an energy efficient urban development.
- Following the path of an energy efficient urban growth scheme could reduce the annual transport energy demand between 20%-27% in 2050.
    - EE urban development has a significant impact on final energy demand due to reduction in light vehicle use decreasing by 16% from a traditional urban development perspective.
- A deep electrification of all sectors ensures the largest reduction in annual energy demand, but requires technology development within battery technology and infrastructure investment in a trans-European network of Electric Road Systems (ERS).
    - By combining technology development with sustainable urban spatial development, all fossil fuels can be removed from the energy mix.
    - Indirect electrification produces electrofuels, which are mostly produced after 2030 and consumed for heavy vehicles such as aviation and shipping.

III. Transport – Results

Annual Costs



Scenario conclusions

- Annual transport system costs increase in all energy efficient transport technology scenarios under the traditional urban development scheme. **Especially the cost of electrofuels increases the annual costs compared to the Baseline scenario**.
- In the Electrification+ scenario, where some electrofuels for heavy-duty transport and maritime transport and aviation are replaced by electricity the annual costs are increased the least.
- If the development of the transport demand follows the trajectory of the energy efficient urban growth scheme, the increase in the annual costs of the energy efficient technology scenarios is reduced and **the annual costs of the Electrification+ scenario is on par with the Baseline scenario in 2050.**

III. Transport – Conclusions

Comprehensive Energy Efficiency Potentials in Transport and Mobility

sEEnergies

- Energy efficiency both in urban development and technology is crucial for decarbonisation of the European transport sector.
- Energy-efficient urban development will reduce the passenger kilometres driven by a car by 16 % compared to traditional urban development. In order to achieve this, new investments need to be made predominantly in more efficient modes of transport and that higher transport demands are not induced in in-efficient modes of transport.
- Energy-efficient urban development combined with extensive electrification will reduce the primary energy demand for the transport sector in Europe by around 50% compared to the baseline in 2050.
- Extensive electrification key for efficiency gains and avoiding additional costs. In 2020, 2.7 million passenger EVs were on the streets of Europe, in 2030 it will be 95 million and finally in 2050: 254 million EVs.
- Well to wheel efficiency: BEV 73% vs ICE 13%.
- Electrification of the parts of heavy-duty trucks, short-distance navigation and aviation possible
    - Electric Road Systems (ERS) provide good alternative for heavy duty trucks where battery electrification is limited.
    - Electrofuels should be prioriotised for navigation and aviation.
- The proposed development does not only reduce the primary energy use, but there is also a number of non-energy benefits – for instance health benefits by replacing car driving with bicycle riding.
- The transport related health costs in Europe will be reduced from 205.5 billion € in 2015 to 54 billion € in 2050.

CLICK HERE for Policy Brief

CLICK HERE for Reports on Transport (WP2)

CLICK HERE for Webinar on Transport

CLICK HERE for sEEnergies Publication on Electrification Scenarios

CLICK HERE for sEEnergies Publication on EE Urban Spatial Development

IV. INDUSTRY

IN-DEPTH QUANTIFICATION OF INDUSTRIAL ENERGY EFFICIENCY POTENTIALS

- Background
- Methods
  - Sector Modelling Process
  - IndustryPLAN
- Results
  - Future Material Production
  - Future Industrial Energy Demand
  - Energy Savings Cost Curves
  - Modelled Scenarios
  - 100% RE Industry Scenarios – Aggregate EU27+UK and Individual Countries
- Conclusions

IV. Industry – Background

In-depth Quantification of Industrial Energy Efficiency Potentials

Today, industry accounts for 25% of final energy demand in the EU.

- Many of the savings within industry are more cost-effective than savings in buildings, also from a private economic perspective. Heavy industry as an example have a potential of 25% EE. However, these are not implemented due to too long payback periods, due to lack of knowledge or focus, and due to lack of targeted polices for different types of industries.
- Savings overall may be up to 40% combining electrification and other methods based on detailed knowledge about the industrial subsectors.
- Future projections of industrial energy demand generally have a strong focus on the energy intensive sectors. In most cases limited detail is provided for other sectors (often grouped together as "other industry"). Non-process related energy use (such as space heating) cannot be distinguished easily.

  The question is what the potential is in the Energy Union and what the effects of EE may be in different future industrial developments?

- The integration of industrial excess heat into district heating might be the key element to reduce the energy demand of the heating sector. Mapping industrial excess heat is also essential when analysing the potential for creating industrial symbiosis, which will be also considered in this project.

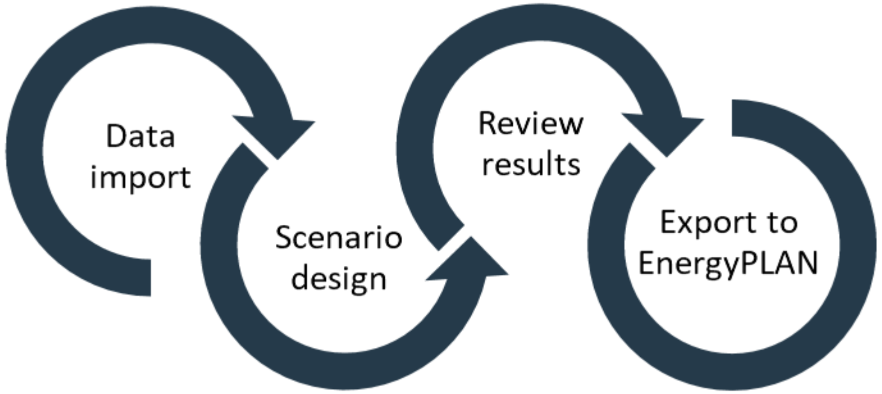
OBJECTIVES

To assess EE potentials in industry sector

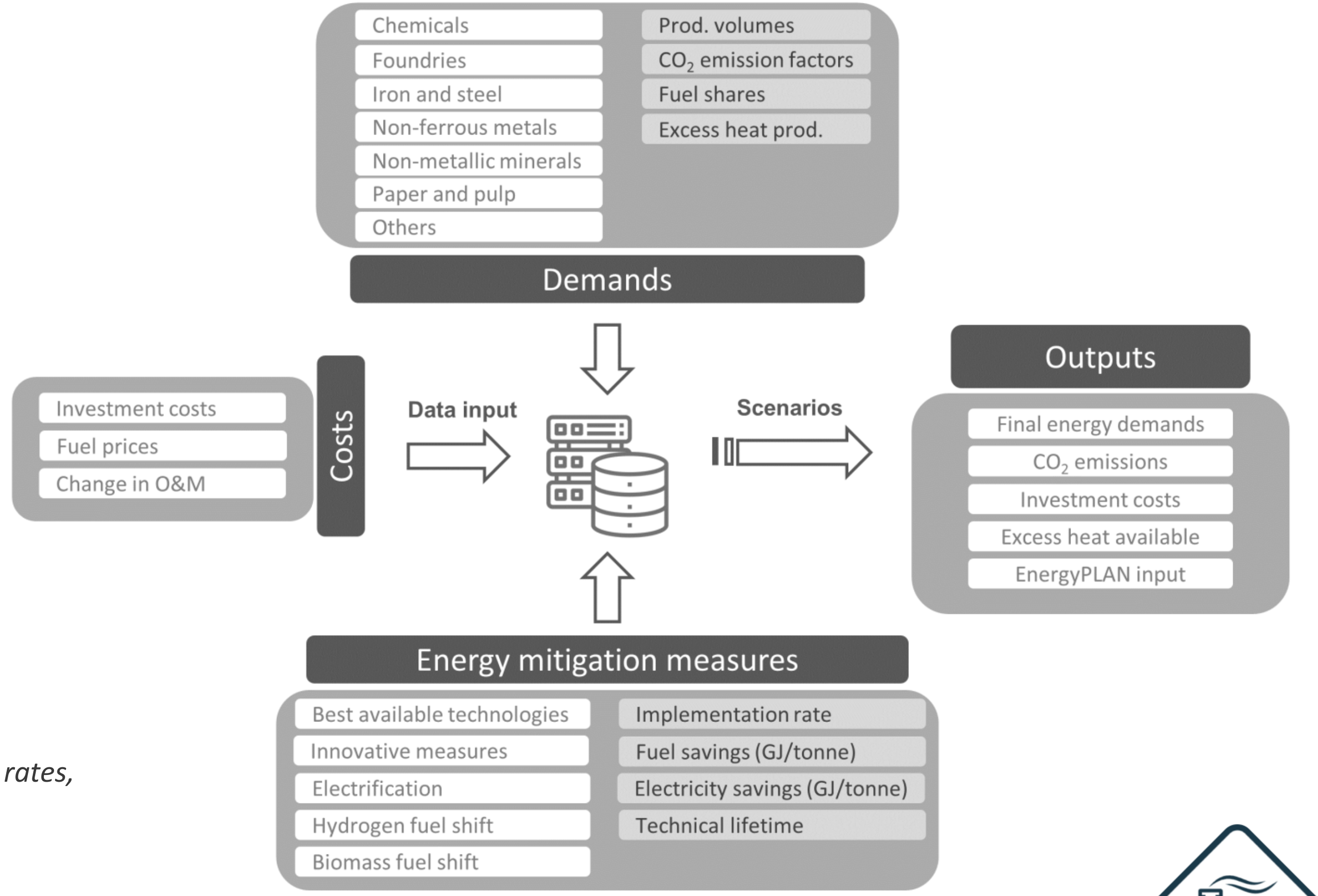
- Quantification of EE potentials in all industry sub-sectors, in all EU-28 countries.
- Development of scenarios for reference years 2030 and 2050.
- Development of an IndustryPLAN model for the in-depth analysis of each industry sector in each Member State.
- Outputs of IndustryPLAN model to serve as inputs for EnergyPLAN model in WP6.
- Development of broad understanding of economic and social impacts of implementing the EEFP in industry.

IV. Industry – Methods

Industry Sector Modelling Process



IndustryPLAN Tool



Bottom-up Details in IndustryPLAN

- Future material production
  per product and country
- Energy intensities
  per product, energy carrier and temperature level
- Details on Best Available Technologies and Deep Decarbonisation Technologies
  Investment costs, Change in Operation & Maintenance costs, Current diffusion rates, Future Implementation rates
- Waste heat availability from industrial flue gases
  per process and temperature level, with and w/o waste heat recovery

IV. Industry – Results

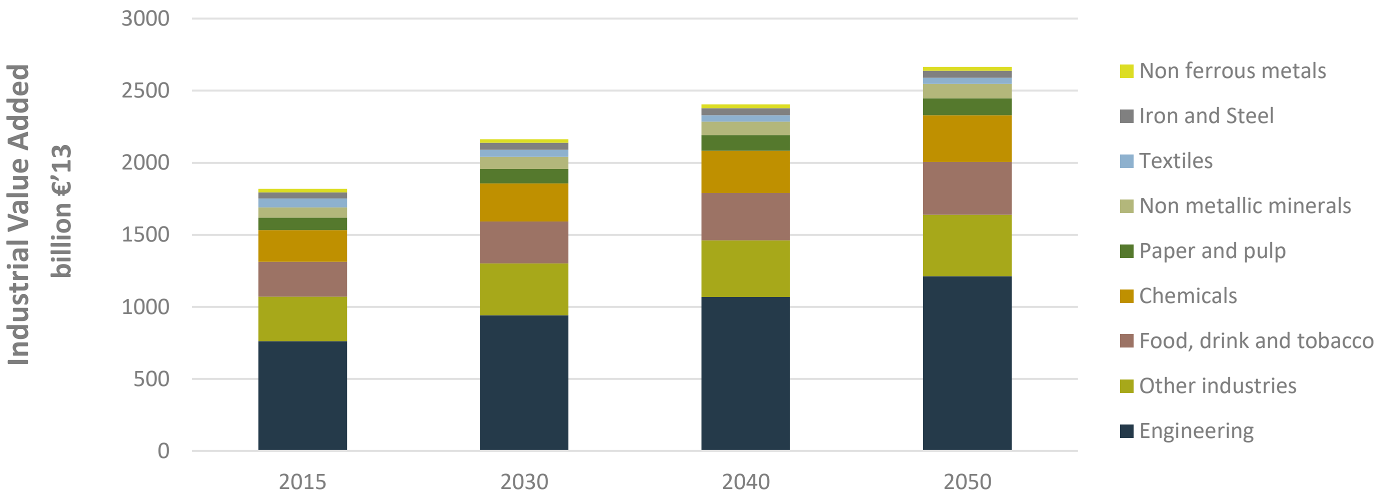
Future Material Production

Reference Scenario

PRIMES: BATs and incremental increase in recycling levels.

Final energy consumption per country and per industrial sub-sector is equal to the reported reference scenario in PRIMES 2016.

Main assumption: current policies are continued but not tightened.

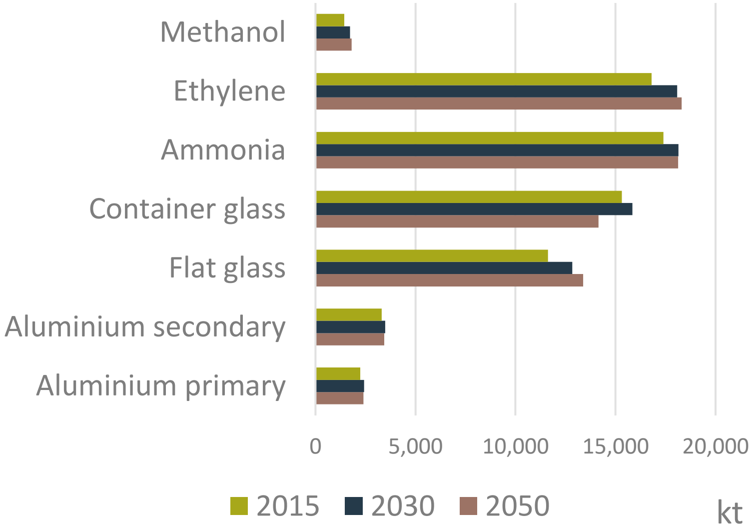


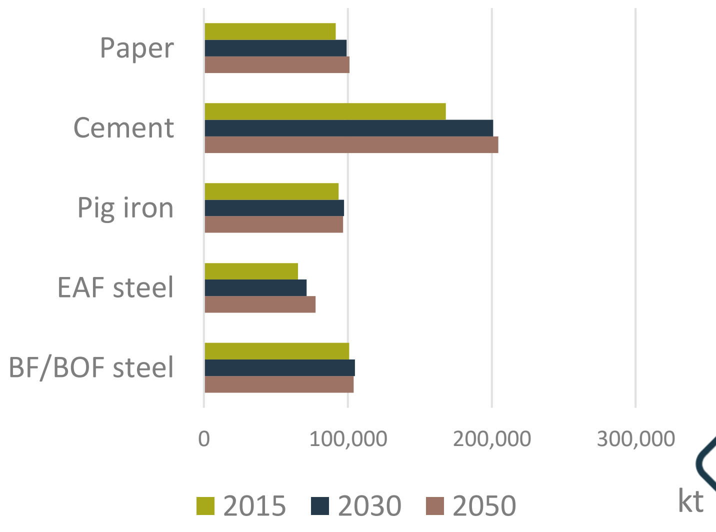
Frozen Efficiency Scenario

No uptake of energy efficiency. Energy efficiency remains to the 2015 level.

Same socio-economic changes (i.e. industrial value added and production volumes) with the Reference scenario.

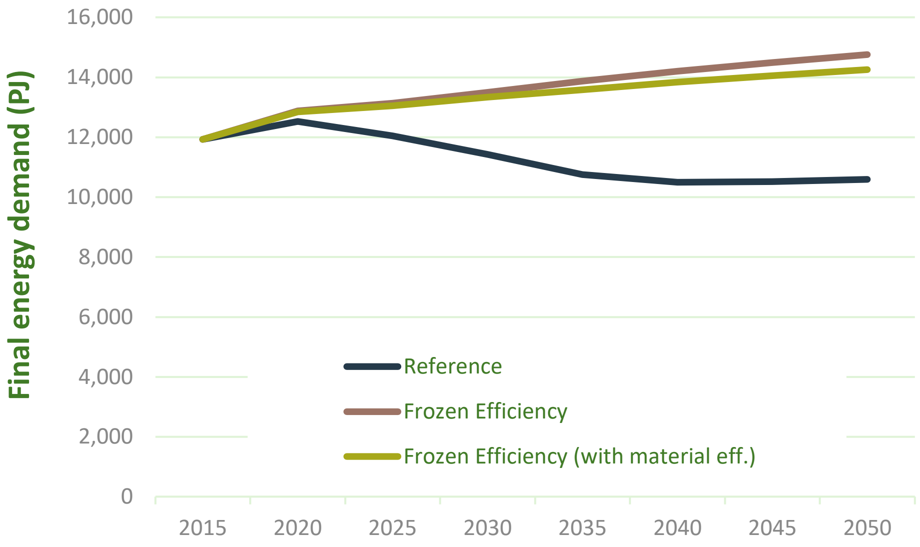
Main assumption: no energy efficiency or technological changes are allowed.

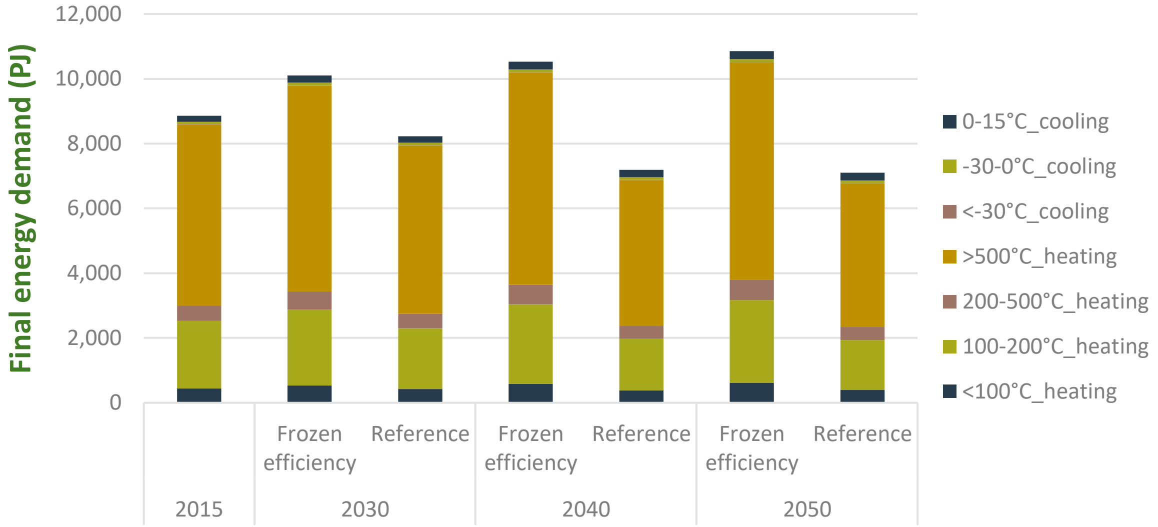


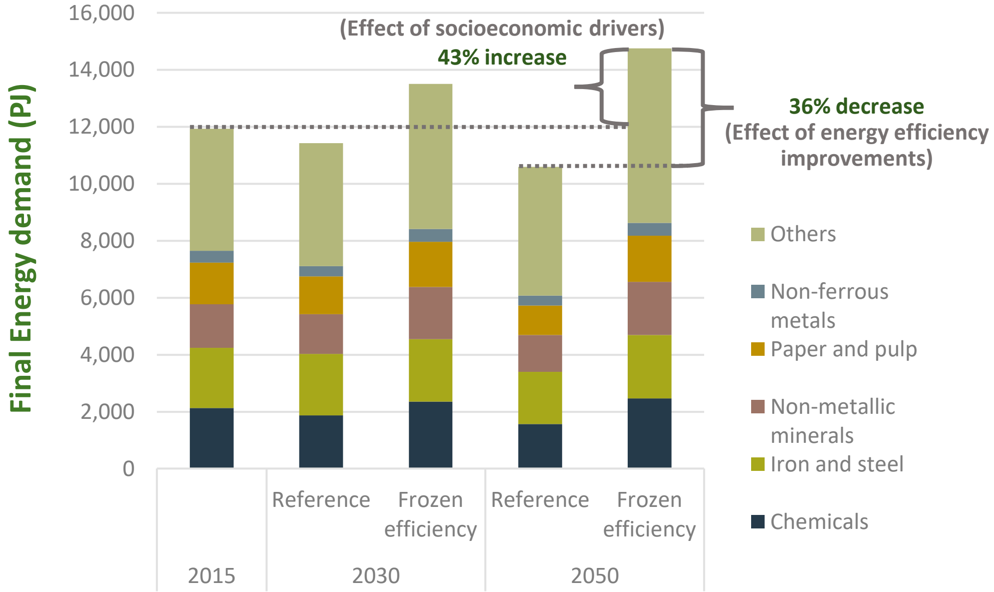


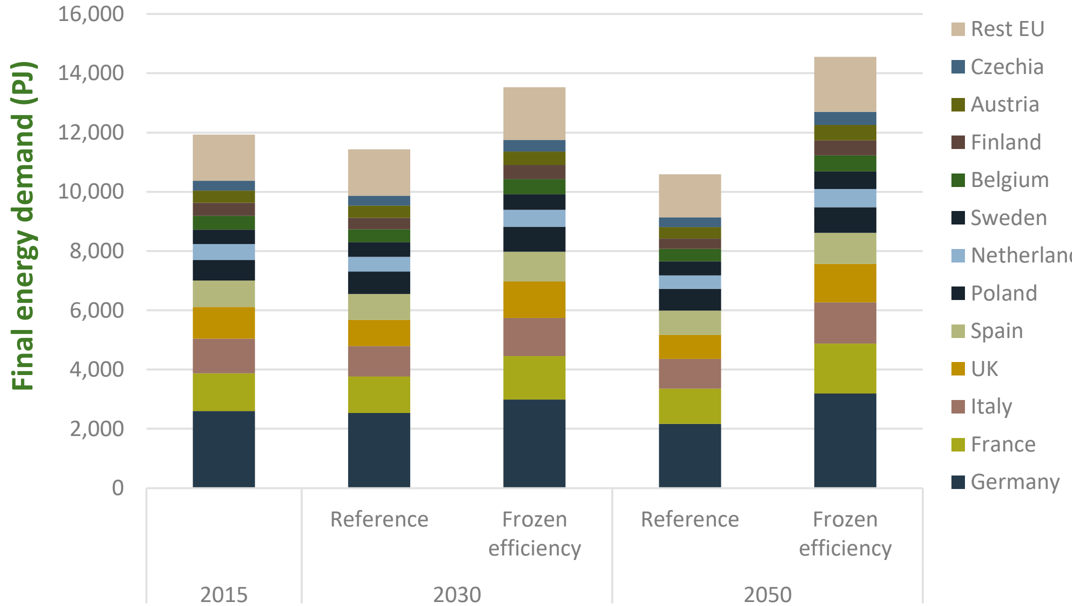
IV. Industry – Results

Future Industrial Energy Demand





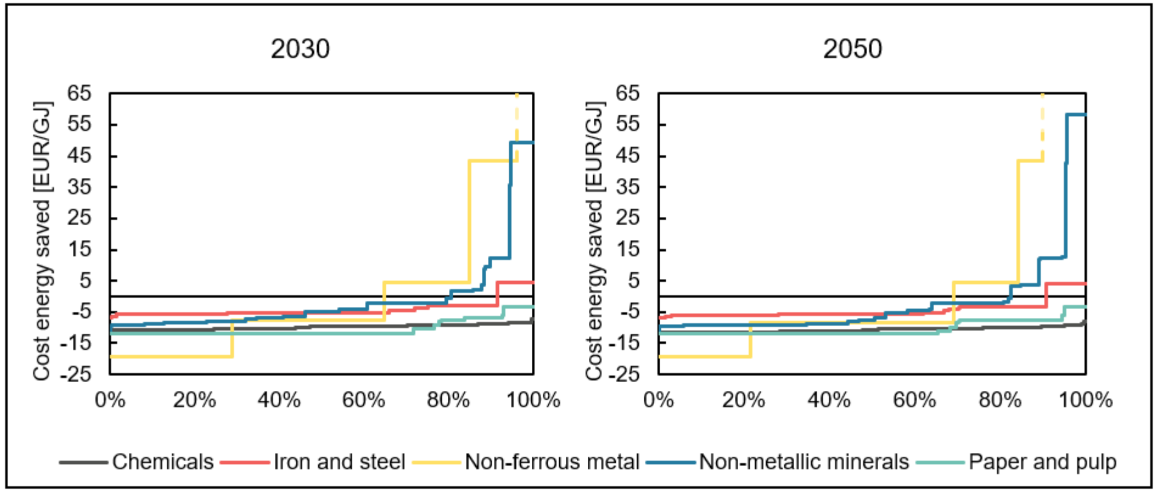




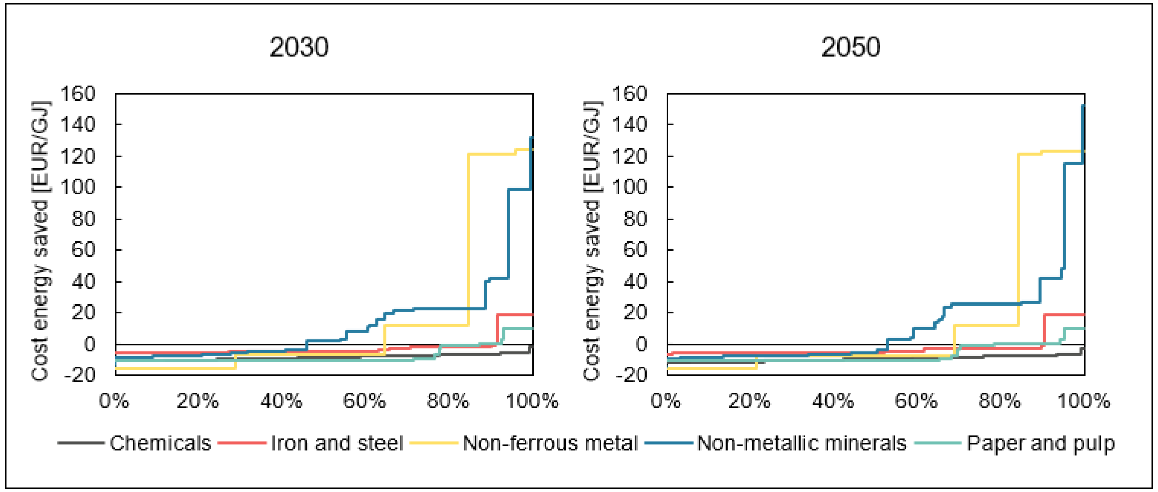
IV. Industry – Results

Energy Savings Cost Curves

Cost of conserved energy BAT measures (3% discount rate)



Cost of conserved energy BAT measures (15% discount rate)

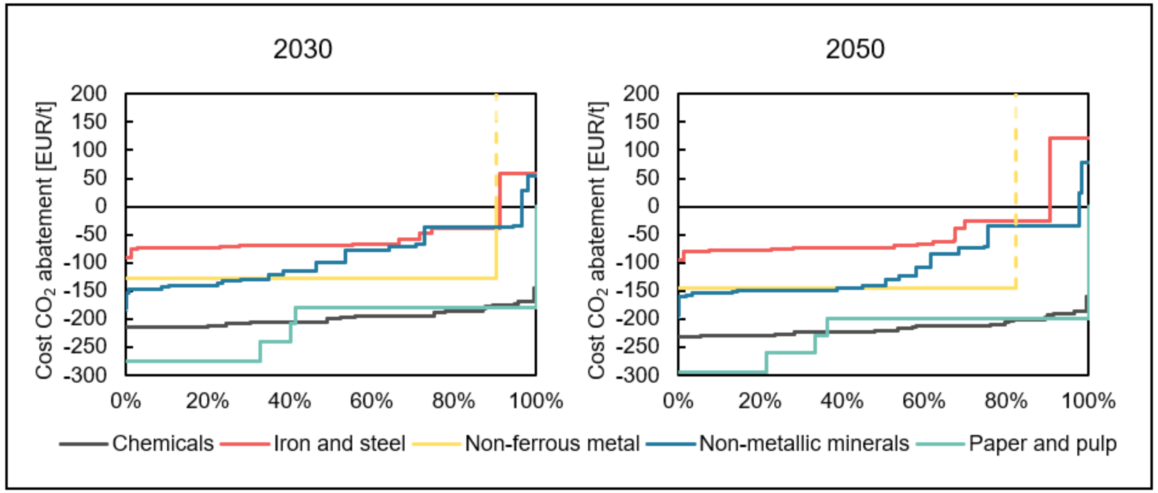


- **~80% of energy savings** from BAT technologies can be realised as **cost saving** measures.
- **Top-end measures** in **non-ferrous metals** (aluminium) **and non-metallic minerals** (cement) **are expensive.**
- Cost-curves **based on technical lifetimes** – **industries may have other requirements.**
- Cost-curves **based on long-term natural gas price projections.**
  - **Current high prices** would make EE improvements **more attractive.**
- Note that non-ferrous metals extend beyond the graph to 114.98 EUR/GJ in 2030 and 114.09 EUR/GJ in 2050.
- Based on long-term fuel price projections, including a natural gas price of 7-9 EUR/GJ. Currently natural gas is trading at 25-35 EUR/GJ, hence energy savings in sub-sectors supplied by natural gas would be even more attractive.
- Taxes are not considered due to a socioeconomic perspective.

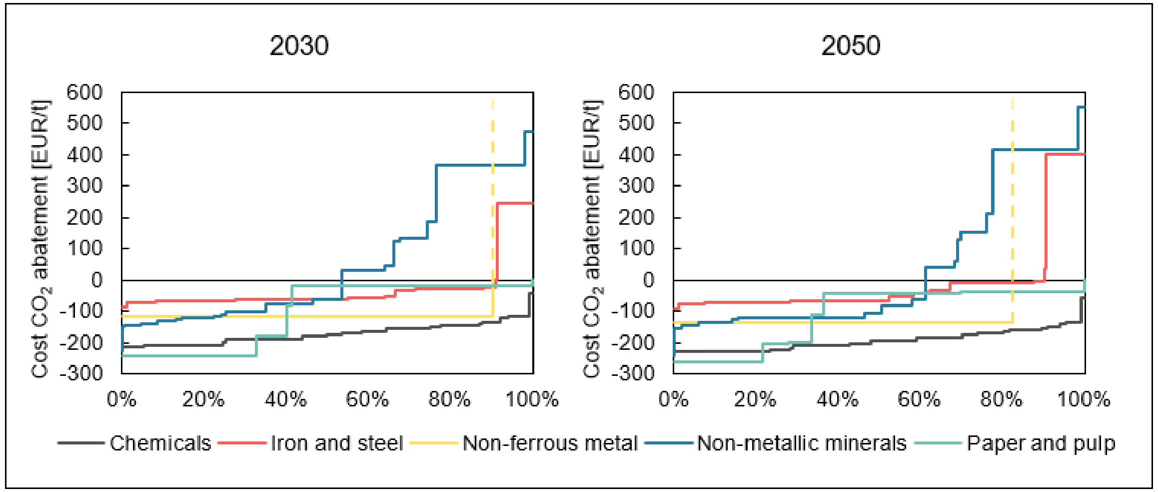
IV. Industry – Results

Energy Savings Cost Curves

Cost of CO_2 abatement for BAT measures (3% discount rate)



Cost of CO_2 abatement for BAT measures (15% discount rate)



- **~80% of the CO_2 reduction** potential can be realised as **cost reducing measures.**
- **Differences from previous energy savings cost curves a result of fuel distribution across sub-sectors.**
  - **i.e. Iron and steel with a large share of low-cost coal with high CO_2 emissions.**
- Paper and pulp is largely electrified already, resulting in a low CO_2 reduction potential.
- Note that non-ferrous metals extend beyond the graph to 1,934.60 EUR/t in 2030 and 1,760.69 EUR/t in 2050.
- Based on long-term fuel price projections, including a natural gas price of 7-9 EUR/GJ. Currently natural gas is trading at 25-35 EUR/GJ, hence energy savings in sub-sectors supplied by natural gas would be even more attractive.

IV. Industry – 100% RE Industry Scenarios

Modelled Scenarios

sEEnergies

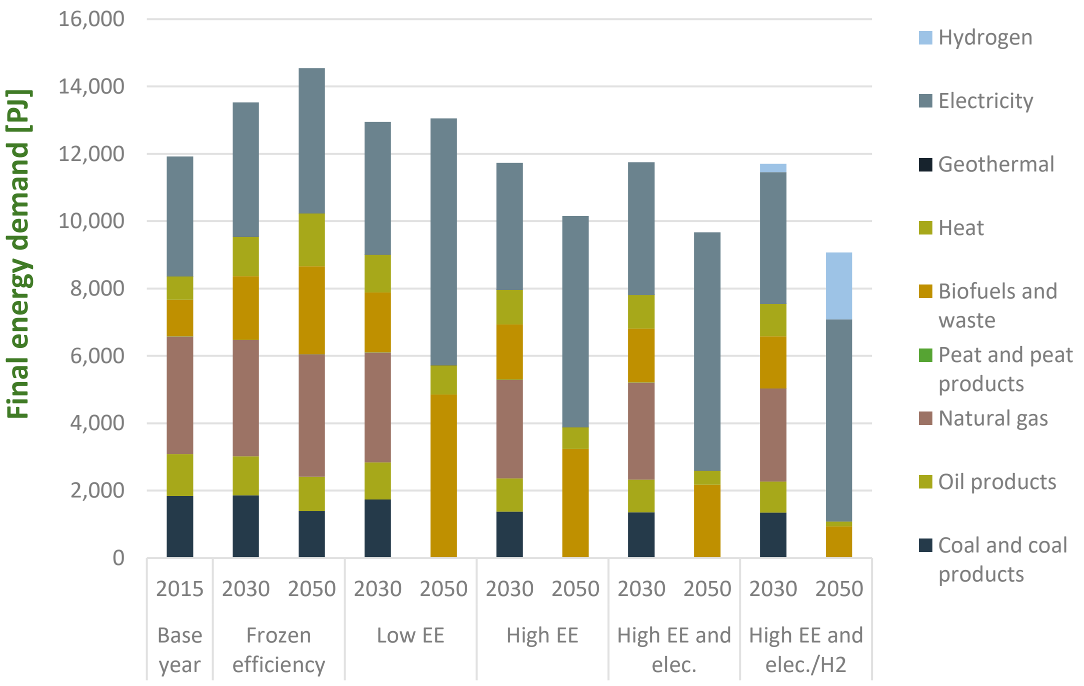
Scenario	Iron & Steel	Non-metallic Minerals	Non-ferrous Minerals	Chemicals	Paper & Pulp
1 Low EE scenario • No increase in recycling • Limited implementation of EE measures (BATs) and electrification • Limited electrification • Extensive biomass fuel shift					
2 High EE scenario • High increase in recycling • Extensive implementation of EE measures • Limited electrification • Medium biomass fuel shift	Share of EAF steel increase from 39% to 67%	Clinker to cement ratio decreases from 76% to 60%	Share of secondary aluminium increases from 60% to 70%	-	Share of paper from recovered fibres increases slightly
3 High EE and electrification • High increase in recycling • Extensive implementation of EE measures • Extensive implementation of electrification • Low biomass fuel shift	DR electrolysis (Ulcowin, Siderwin, Ulcolysis), electric furnaces	Thermal plasma torches (cement); electric melters (glass)	Induction furnaces (aluminium)	Hydrogen is used as feedstock (ammonia, ethylene, methanol); Heat pumps and electric boilers for steam generation	Heat pumps and electric boilers for steam generation
4 High EE, electrification and hydrogen • High increase in recycling • Extensive implementation of EE measures • Extensive implementation of electrification • Extensive implementation of hydrogen measures • Low biomass fuel shift	Hydrogen based direct reduction (H-DR)			Hydrogen used as feedstock (ammonia, ethylene, methanol); Hydrogen boilers for steam generation	Hydrogen boilers for steam generation

IV. Industry – Results

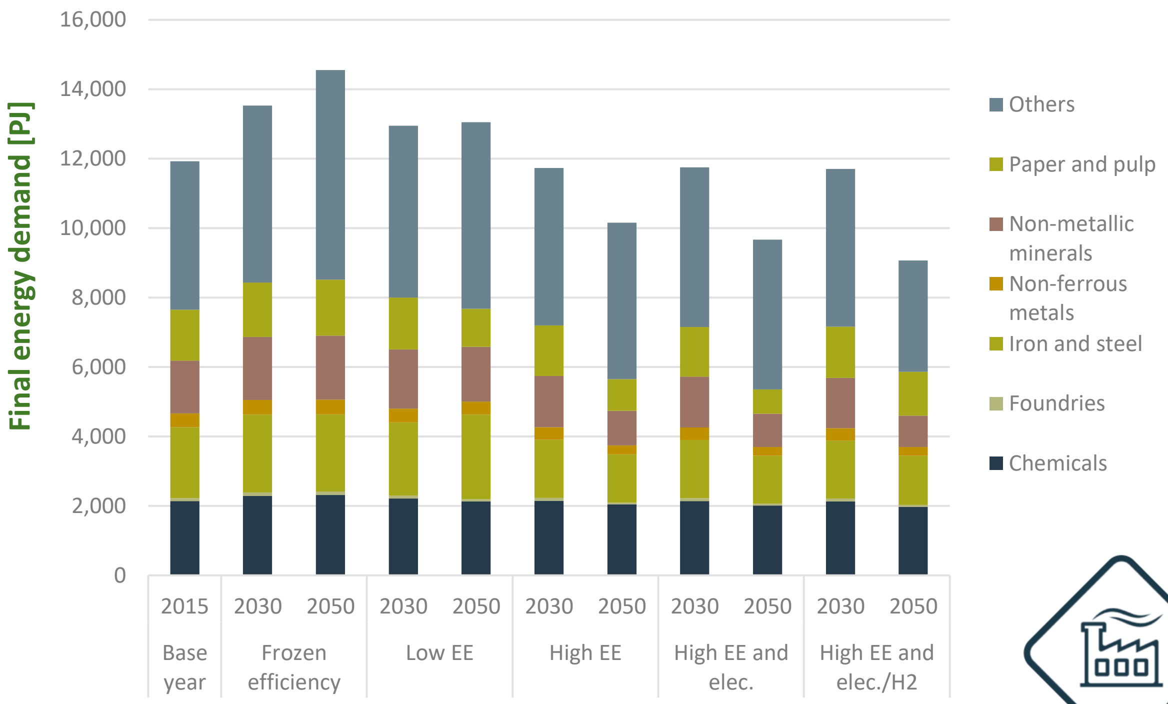
100% RE Industry Scenarios – Aggregate EU27+UK

- **All scenarios** (even low EE) **can negate the increasing industry demand** in the Frozen Efficiency scenario.
- **Foregoing focus on EE and electrification results in large biomass demands.**
- **Hydrogen potential is (relatively) limited** – especially before 2030.
- **Electrification is by far** the **most important measure** for enabling the industry transition.
- Note that energy system effects (outside of industry) are not considered.
    - e.g. relevant for the production of hydrogen which with production through electrolysis would require significant electricity.

Final energy demand by scenario disaggregated by fuel type

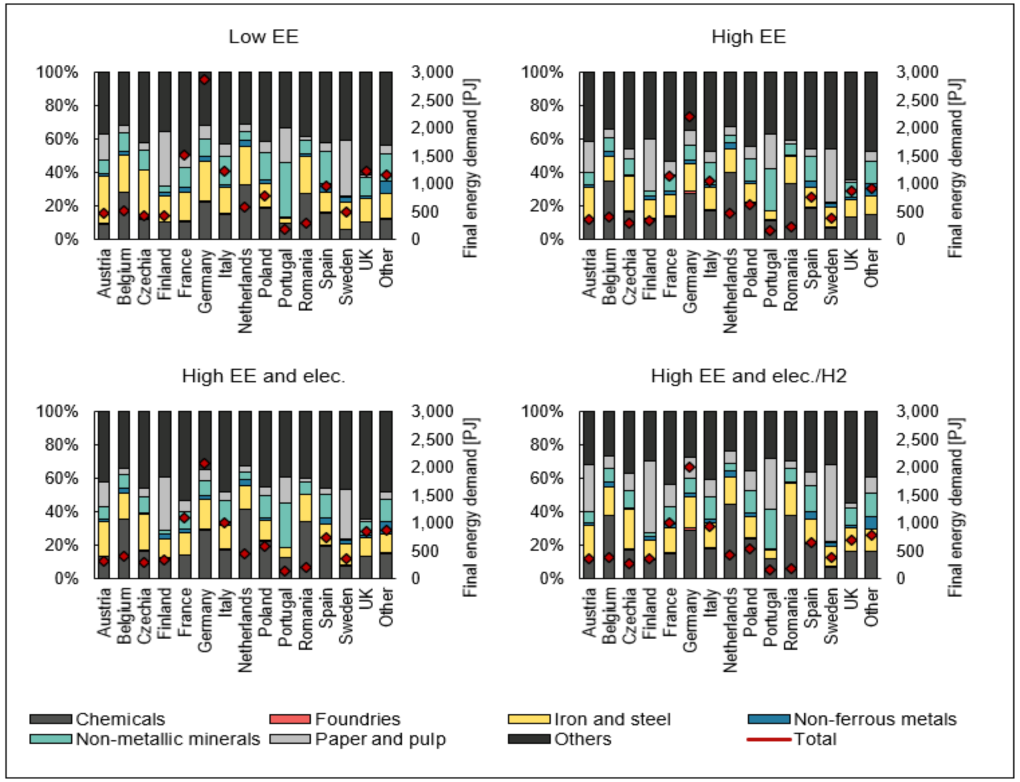


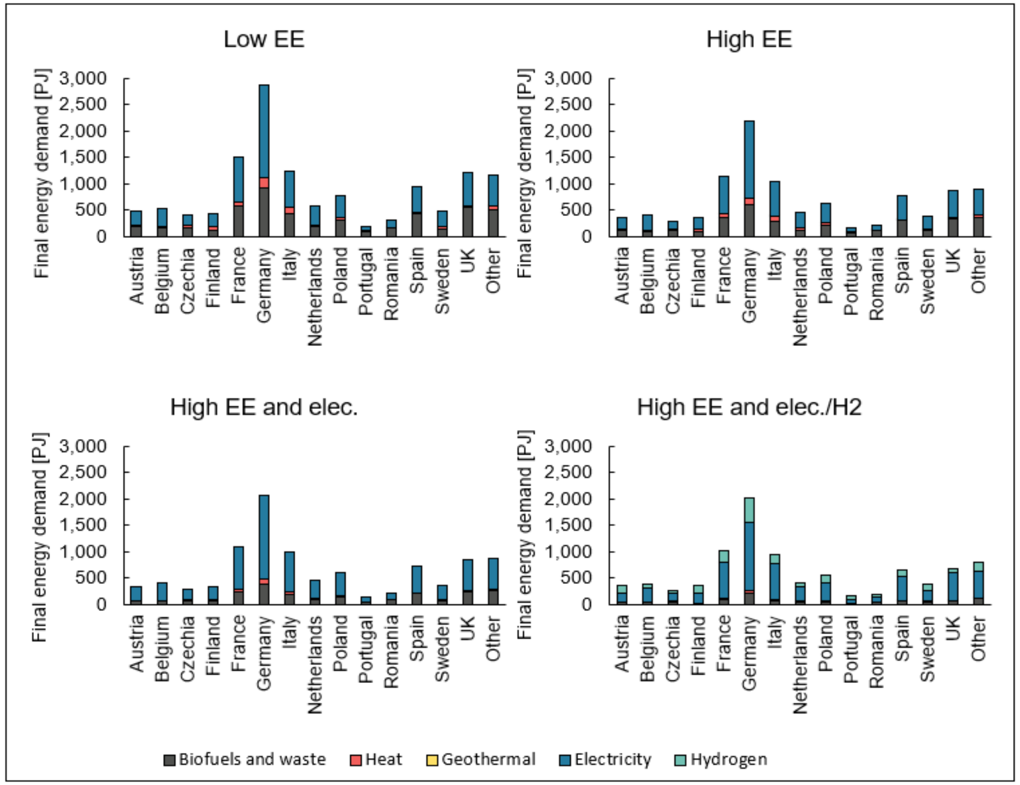
Final energy demand by scenario disaggregated by industrial sub-sector



IV. Industry – Results

100% RE Industry Scenarios – Individual Countries





Germany dominates European industrial energy demands – also in high EE scenarios.

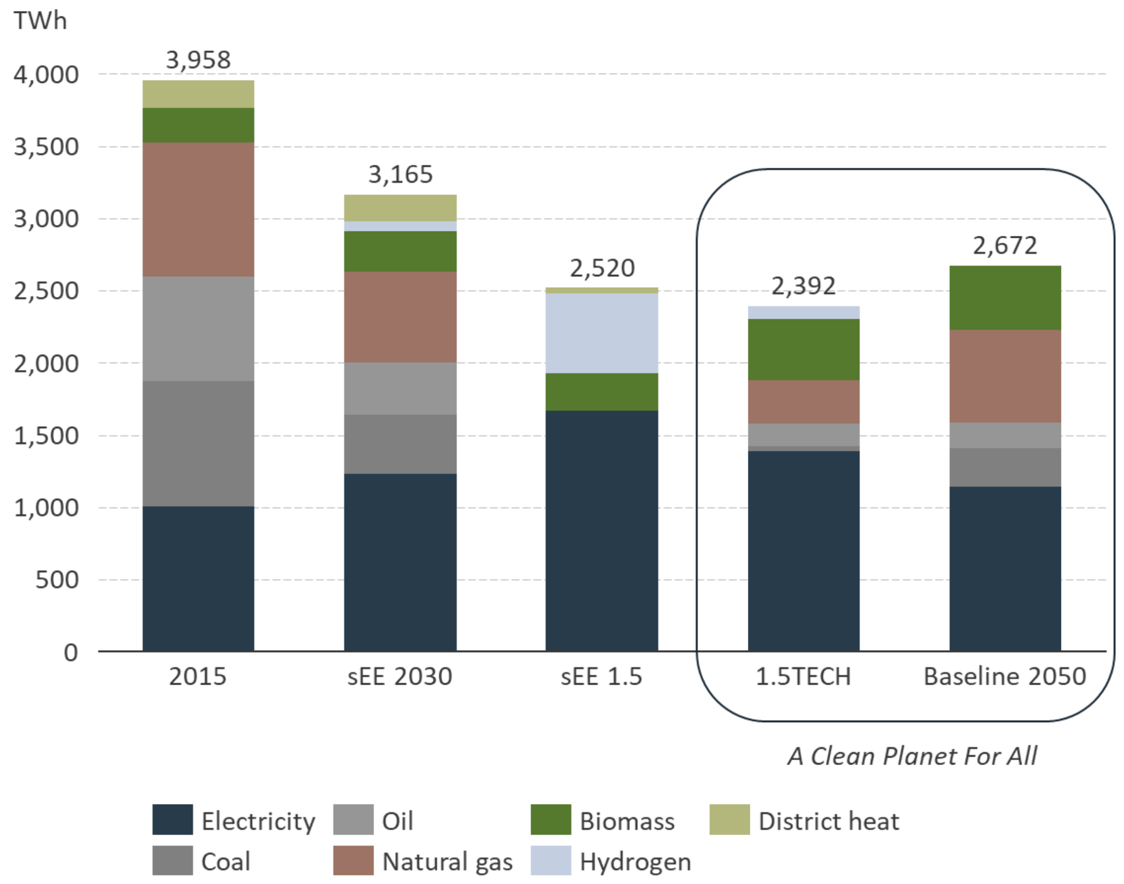
All countries can achieve substantial energy savings across all sub-sectors.

“Others”sub-sector constitutes significant portion of demand in most countries → Leaves room for further disaggregation in future studies.

- **EE improvements can significantly reduce need for biofuels** in all countries.
- **H_2 constitutes relatively small share of total demand**, even in scenario with high implementation rate.
  - Mainly applied in chemicals and iron & steel sub-sectors.

IV. Industry – Results

Final Energy Demand



Industry Final Energy Demand

- Industry sector can reduce final energy demand by 36% from 2015 to 2050.
- In total there were 184 energy efficiency measures adopted in seven industrial subsectors, including
  - best available technology measures
  - innovative measures
  - electrification
  - hydrogen
- In sEE1.5, electrification of industry accounts for 66% of the final energy demand.
- Hydrogen consumption increases to 22% of the final energy demand.
  - This limits the bioenergy demand in industry to only 10% of the energy mix meaning it can be utilized elsewhere in the energy system, however it increases from its original 6% in 2015.
- District heat demand in industry falls from 5% to 1.5% of the energy mix from 2015 to 2050.
- By 2030 electrification increases to 39% of the total final energy demand up from 25% in 2015. This is largely in the “others” category for lower temperature sub-sectors such as engineering and the food industry.

IV. Industry – Conclusions

In-depth Quantification of Industrial Energy Efficiency Potentials

sEEnergies

- Four different pathways to 100% renewable energy in industry presented.
  - Extensive scope covering all EU countries and all industry sub-sectors in a bottom-up approach.
  - IndustryPLAN enables the identification of synergies between industry and renewable smart energy systems and facilitates the implementation of the Energy Efficiency First Principle for industry.
- Increased energy efficiency uptake and recycling can reduce the industrial energy demand intensity in the EU by 16% in 2030 and by 36% in 2050.
- By 2050, fully decarbonised scenarios are possible for the European industry sector.
- Most energy and CO_2 saving measures can be implemented at a negative cost – from a socio-economic perspective.
- A lacking emphasis on EE improvements and electrification results in extensive biomass consumption if pursuing 100% renewable energy.
- Hydrogen produced from renewable sources can decarbonise fossil-fuel intensive industries, such as chemicals and iron and steel. However, the wide adoption of hydrogen-based technologies, combined with a limited uptake of energy efficiency and electrification, will make the transition costlier and will induce energy losses.
- EE improvements and the RE transition is pivotal in increasing security of supply and reducing natural gas dependency.
- Future integrated energy system modelling needs to consider the industry sector in greater detail – opening the "black box" of the industry sector.

CLICK HERE for Policy Brief

CLICK HERE for Reports on Industry (WP3)

CLICK HERE for Webinar on Industry

CLICK HERE for sEEnergies Publication on EE Potentials in Industry

CLICK HERE for sEEnergies Publication on Industrial Excess Heat for DH

V. ENERGY GRIDS

ASSESSMENT OF THE ROLE AND COSTS OF ENERGY GRIDS

- Background
- Methods
  - Electricity Grids
  - Thermal Grids
  - Gas Grids
- Results
  - Electricity Grids
  - Thermal Grids
  - Gas Grids
- Conclusions

V. Energy Grids – Background

Assessment of the Role and Costs of Energy Grids

Current energy grids are designed to integrate centralised carbon-intensive generation sources and there is a lack of interaction between the different energy grids (electrical, thermal and gas grids).

How to modify energy grids in order to integrate a higher share of low-carbon technologies at the lowest cost?

Electrical Grids – High transmission and distribution losses.
Cost of reinforcing distribution grids for allowing low-carbon technologies (LCT) integration?

Thermal Grids – Unexploited potential of heating networks.
Potential for district heating and associated infrastructure cost?

Gas Grids – Low transmission of biogas, hydrogen, syngas through current gas grids.
Potential for power-to-gas and the transmission of new energy vectors (e.g. hydrogen) and associated infrastructure cost?

OBJECTIVES

To analyse the behaviour and costs of different energy grids (electricity, thermal and gas grids) as well as energy storage solutions.

- Assessment of the feasibility and technological constraints of the scenarios (current and future for 2030 and 2050) towards full decarbonisation.
- Combine findings into an indicator showing potential issues and opportunities to implement scenarios in the EU regions.

V. Energy Grids – Methods

Electrical Grids

Assessment and simulation of EU electricity distribution grids

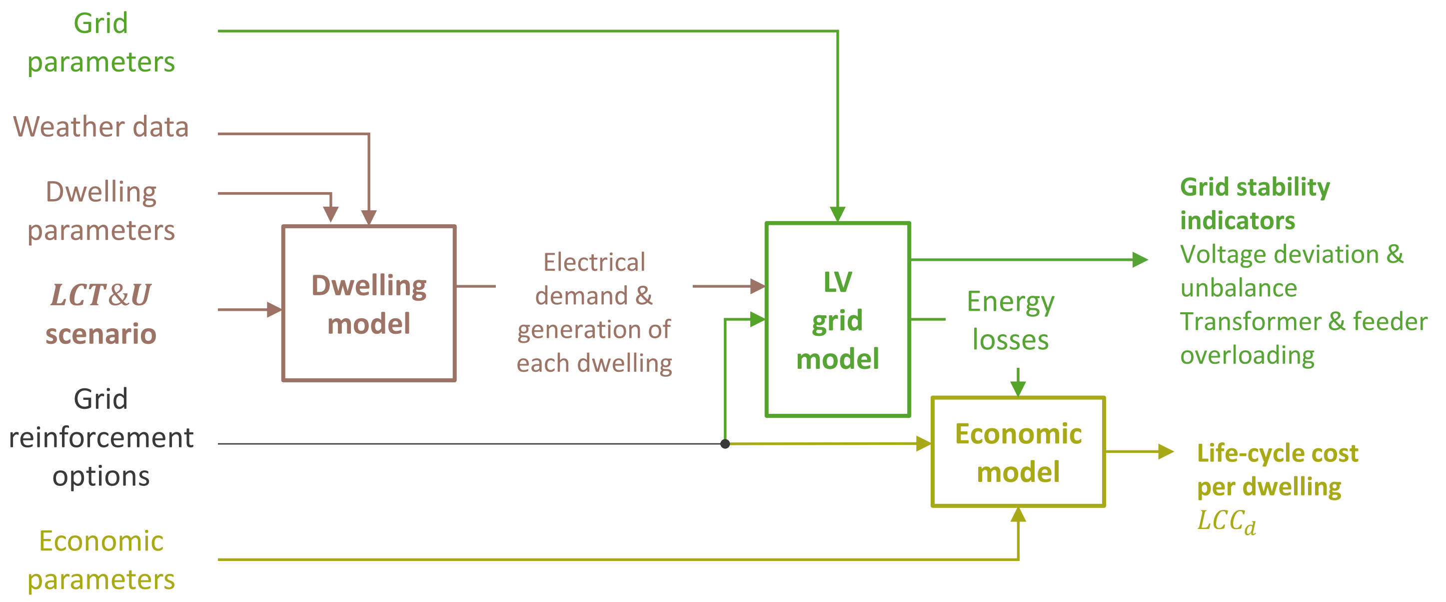
$$LCC^*(country, LCT\&U) = D_r(country) \cdot LCC^*_{d,r}(country, LCT\&U) + D_u(country) \cdot LCC^*_{d,u}(country, LCT\&U)$$

where:

$LCC^*(country, LCT\&U)$ is the life-cycle cost of reinforcing the grid for a given low-carbon technology integration and building insulation scenario $LCT\&U$ in a given country; $D_r(country)$ is the number of dwellings in rural areas of the country; $LCC^*_{d,r}(country, LCT\&U)$ is the grid reinforcement cost per dwelling for representative rural grids for the considered scenario; $D_u(country)$ is the number of dwellings in urban areas of the country; and $LCC^*_{d,u}(country, LCT\&U)$ is the grid reinforcement cost per dwelling for representative urban grids for the considered scenario.

Computing the reinforcement cos per dwelling for representative grids

- For a given LCT integration rate and dwelling insulation level (e.g. 20% HP, 40% PV&U decreased by 50%), the grid stability is evaluated, and the cost is computed for all reinforcement options.
- We select the cheapest technically viable reinforcement option and deduced the reinforcement cost per dwelling LCC^*_d.



Dwelling model

- based on occupant behaviour & dwelling parameters.
- 10 minutes thermo-electric simulations.
- **Weather data** from Meteonorm.
- **Dwelling parameters** from WP1.

Low-Voltage grid model

- Unbalanced power flow.
- Defined grid stability indicators specific to EU standards.
- Representative **grid parameters** for EU countries. obtained from 24 open access grids & 23 articles.

Economic model

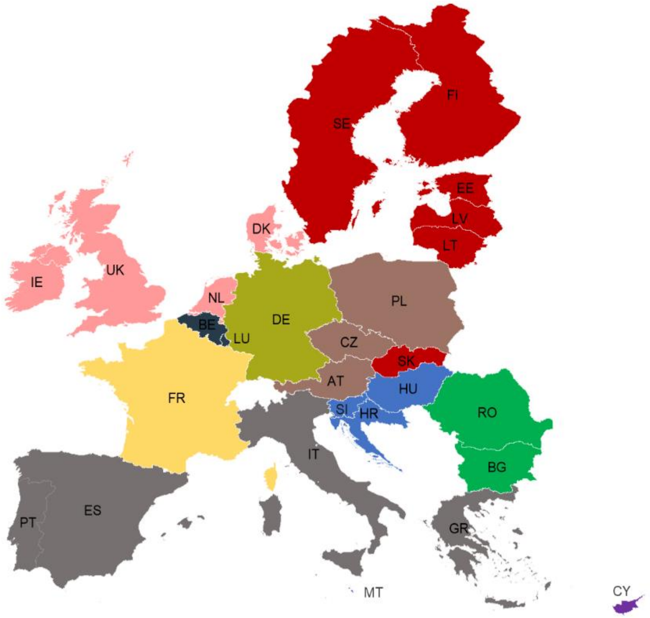
- Investments in reinforcements.
- Operating costs related to energy losses.
- Representative economic parameters for EU countries obtained from 23 articles.

V. Energy Grids – Methods

Electrical Grids

Application to all EU countries: Country Grouping

- Hierarchical clustering method
- Grouping criteria
  - Average extreme summer temperature (°C)
  - Average extreme summer irradiance (kWh/m²)
  - Average extreme winter temperature (°C)
  - Average UA-value (W/K)
  - Average roof area (m²)
  - Share of electric heating
  - Share of electric cooling



- Group 1: CY, MT
- Group 2: FR
- Group 3: PT, IT, ES, GR
- Group 4: HU, SI, HR
- Group 5: IE, NL, UK, DK
- Group 6: RO, BG
- Group 7: SE, FI, SK, LT, LV, EE
- Group 8: PL, CZ, AT
- Group 9: BE, LU
- Group 10: DE

Developing Cost Functions

- Average grid reinforcement cost per dwelling in rural area as a function of %HP, %PV, avg. U-value

$$LCC^{*}_{d,r}(country, \%HP \;\&\; \%PV \;\&\; U) = \sum_{m,n,o} k_{m,n,o} \times (\%HP)^{m} \times (U)^{o}$$ (3rd order polynomial)

- Similar approach for urban area
- This allows for the computation of the cost per country as an input for WP6:

$$LCC^{*}(country, \%HP \;\&\; \%PV \;\&\; U) = D_{r}(country) \cdot LCC^{*}_{d,r}(country, \%HP \;\&\; \%PV \;\&\; U) + D_{u}(country) \cdot LCC^{*}_{d,u}(country, \%HP \;\&\; \%PV \;\&\; U)$$

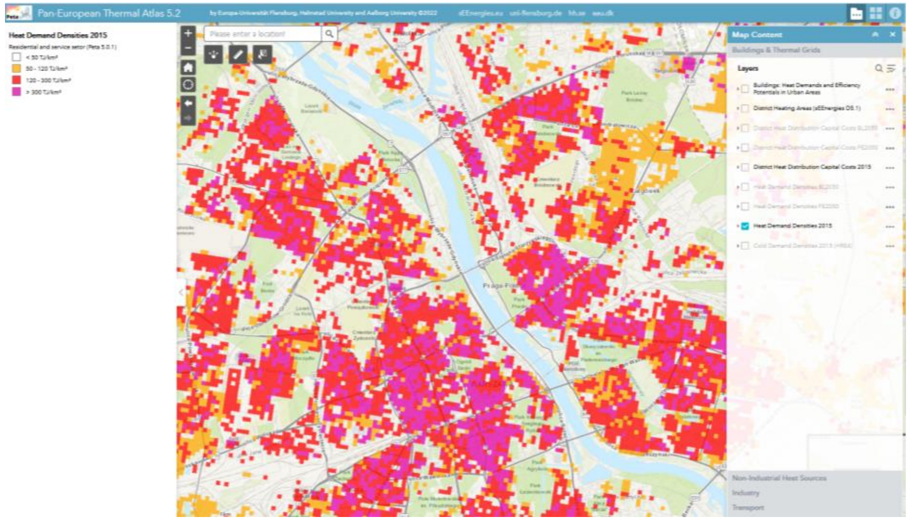
V. Energy Grids – Methods

Thermal Grids

Spatial modelling and assessment of thermal grids for the EU28.

Mapping of the heat sector 2015 →

- Heat Roadmap Europe (HRE4) methodology extended to EU28 and adjusted sEEnergies scenarios.
- Current extent of DH systems.
- Potential D zoning → Prospective Supply Districts (PSD).
- Investment costs in distribution grids.
- Allocation of RE and excess heat.



New version of Pan-European Thermal Atlas

Future Heat Demand Mapping

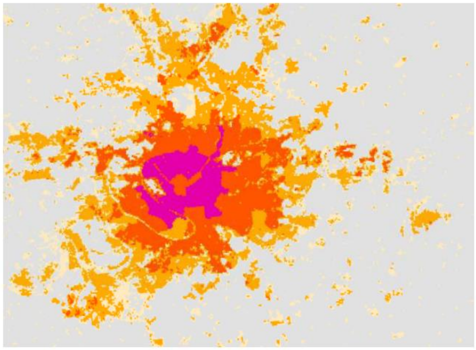
A new 100m population grid for 2030 and 2050

- Based on past urban development (JRC GHS, 1990 – 2015)
- Aligned with national population scenarios (PRIMES)
- Includes moderate expansion of urban areas

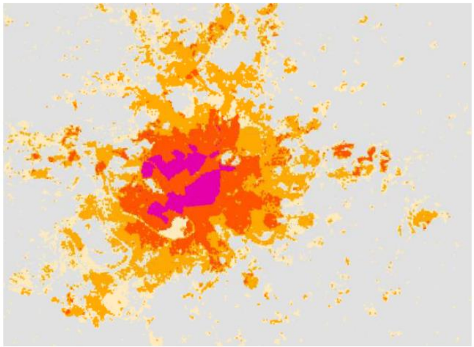
First of its kind attempt to model future population at this resolution and scale.

Future heat demand (WP1) on national level is distributed to 100m level by population, adjusted to heating index (HRE).

Simple model that disregards sectoral distribution, age of buildings and urban spatial development and policy constraints.



Heat demand: Paris 2030



Heat demand: Paris, 2050

V. Energy Grids – Methods

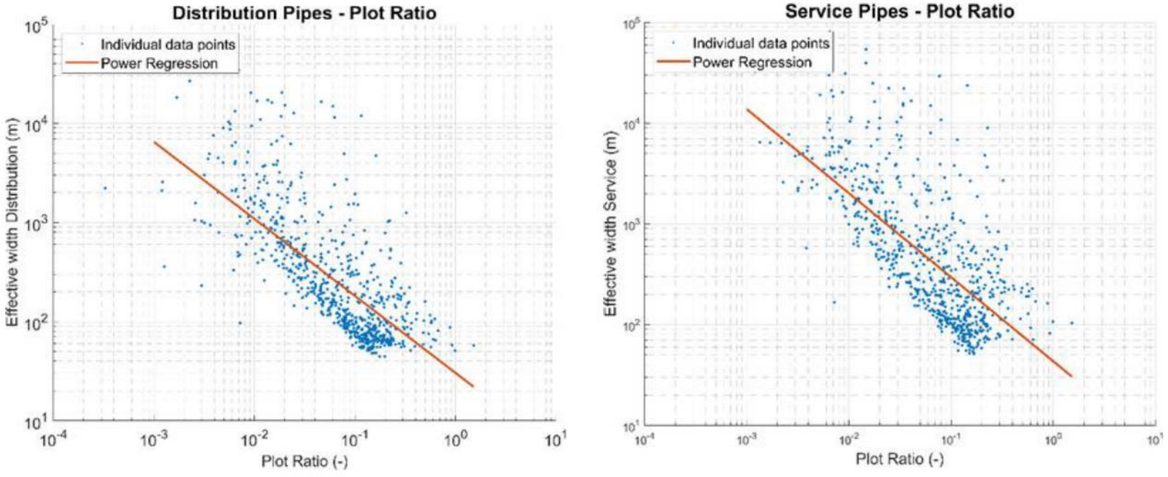
Thermal Grids

Representative thermal grids and their costs

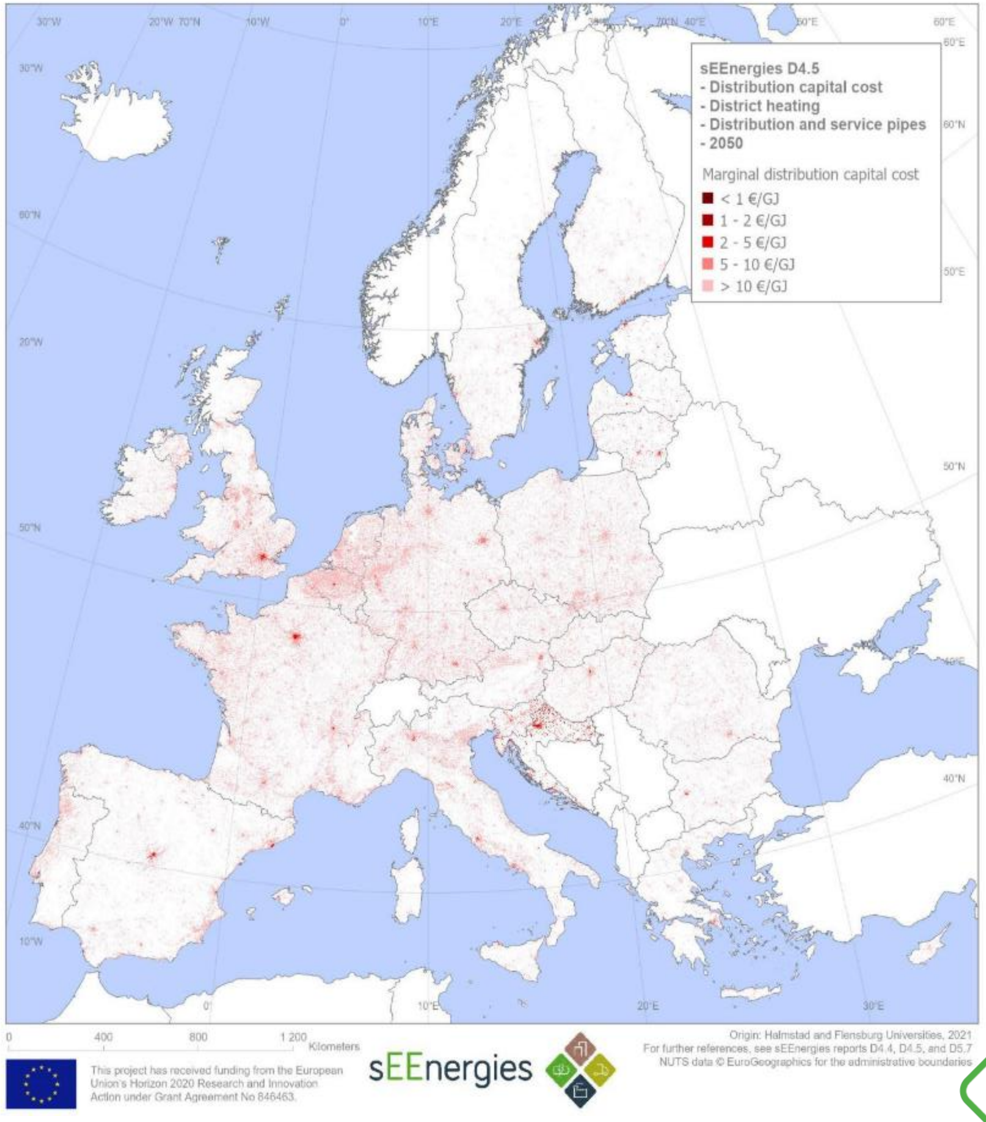
- Studies of existing district heating grids to arrive at country-specific DH grid costs

Thermal grids have been characterised by their physical suitability (representative heat demands) as well as their economic suitability (representative cost curves)

Example for the DH system of Odense

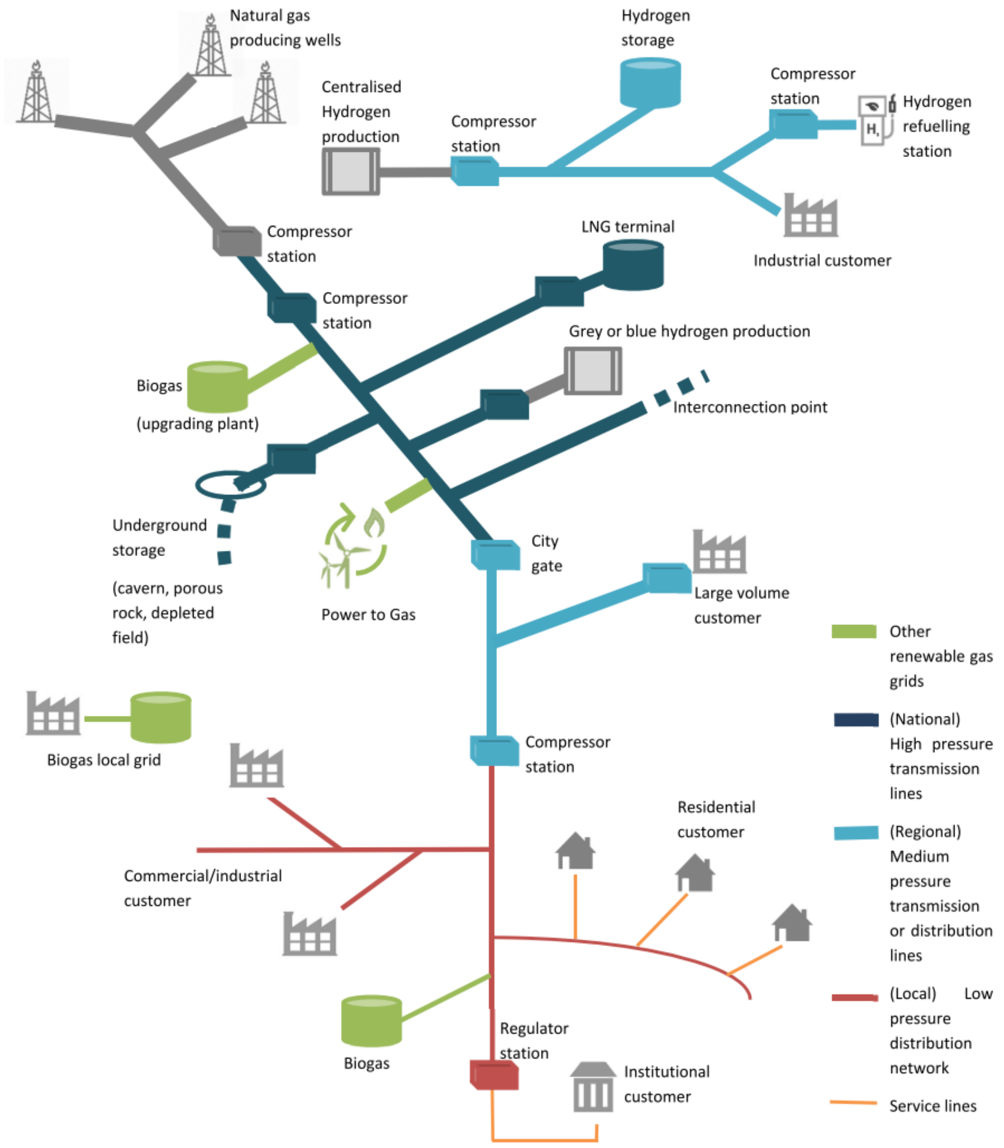


Correlation between effective width and plot ratios for distribution (left) and service (right) pipes



V. Energy Grids – Methods

Gas Grids



Assessment of the role and costs of existing gas grids:

- Data collection on state-of-play of existing natural gas grids, from the European Network of Transmission System Operators for Gas (ENTSOG), Gas Infrastructure Europe (GIE) and Marcogaz (Technical Association of the European Natural Gas Industry).
- Investment costs are derived for all EU countries by adjusting the share of the costs associated with the installation of the technology according to the country labour costs.

$$C_x = C_{ref} * r_{labour} * I_{country,labour} + C_{ref} * (1 - r_{labour})$$

  - C_x is the total cost of the unit in question in country “X”
  - C_{ref} is the (total) cost of the unit in question from the identified reference
  - r_{labour} is the ratio between the share of the total costs related to labour costs and the total cost of the unit (i.e. between 0 and 1)
  - $I_{country,labour}$ is an index number representing the ratio between the labour costs of country “X” and the labour costs in the country representing the reference cost (i.e. between 0 and 1)
- Outputs review:
  - European survey: few answers.
  - Supplemented by literature review.

Future role of gas grids and types of gases:

- Literature review

V. Energy Grids – Results

Energy efficiency matters! Grid related results strongly depend on the chosen scenarios

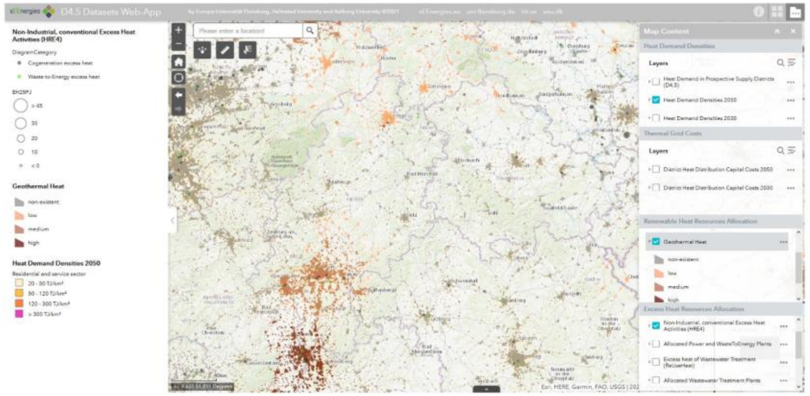
sEEnergies

Electrical Grids

- Developed a **techno-economic methodology** to estimate the low-voltage **grids reinforcement cost** as a function of the residential **low-carbon technologies** integration and **dwelling insulation level scenario.**
- Grid reinforcement cost is generally lower in urban versus rural areas.
- Grid reinforcement cost for urban grids is up to 360 €/dwelling, for rural grids up to 450 €/dwelling,
- Grid reinforcement cost is generally higher in badly insulated dwellings.
- Grid reinforcement cost is higher when increasing the %HP.
- Grid reinforcement cost is generally higher when increasing the %PV.
- At worst insulation levels, the increase in grid reinforcement cost is higher for %HP than for %PV.
- At best insulation levels, %PV tends to trigger more grid reinforcement cost than %HP.

Thermal Grids

- Applied and extended mapping of current and future **heat demands** and potentials of **district heating** to EU28.
- Studied representative thermal grids and included **country-specific costs** to identify DH suitability across Europe.
- Mapped potential DH by extent and cost and allocated **excess heat** and **RE potentials** using **online mapping**.
- Allocation results and resulting district heating investment costs presented as operational web map layers at new web-map app, the **sEEnergies D4.5 Datasets Web-App**.



Gas Grids

- Overview of the current status of European gas grids, interconnections and storages
  - **Natural gas** infrastructure is well-developed and interconnected and provides Europe with around 1,500 TWh of cross-seasonal flexibility.
  - Existing **hydrogen** transport infrastructures correspond to industrial clusters. The permitted concentration of hydrogen in the natural gas grid varies significantly between countries.
  - So far, the **greening of the gas system**, based on biogas and biomethane, has proceeded to a share of about 4%.
- Data sheet (cost database) with more than 800 cost estimates
  - Investment costs for **natural gas** transmission, distribution and service lines
  - Investment costs for dedicated **hydrogen** grid or retrofitting of natural gas grids
  - for hydrogen transportation
  - **Biogas** upgrading investment costs

V. Energy Grids – Conclusions

Assessment of the Role and Costs of Energy Grids

sEEnergies

- Energy efficiency matters, and grid-related results strongly depend on the chosen energy efficiency scenarios in the European Union.
- Regarding the **electricity grid**, low-voltage distribution networks have to be reinforced to integrate residential low-carbon technologies such as heat pumps (HP) and photovoltaic systems (PV).
  - The increase of HP integration rates always tends to increase the grid reinforcement cost, whereas this is not the case with PV.
  - The grid reinforcement cost due to the low carbon technologies integration tends to decrease with the improvements of dwelling insulation levels.
  - The grid reinforcement cost per dwelling ranges from 60 to 450 € for the EU grids.
- When it comes to **thermal grids**, the development of district heating, a technology that incorporates energy efficiency and resource synergy principles, can trigger important greenhouse gas emissions reduction.
  - The total marginal capital cost levels, thus representing investments both in distribution and service pipes, increase from a test reference case resembling the current year (2015) by approximately 40% by 2030 (from some 11.1 to 15.5 €/GJ) and by roughly 73% by 2050 (from 11.1 to 19.2 €/GJ).
- The well-developed **natural gas grid infrastructure** can be used to distribute renewable gas (e.g. biogas, biomethane and hydrogen) and offer storage capacity.
  - The natural gas infrastructure is well developed and interconnected and provides Europe with around 1,500 TWh of cross-seasonal flexibility.
- The relevant cost maps for different types of grids in the EU can be accessed through the web map.

CLICK HERE for Policy Brief

CLICK HERE for Reports on Energy Grids (WP4)

CLICK HERE for Webinar on Energy Grids

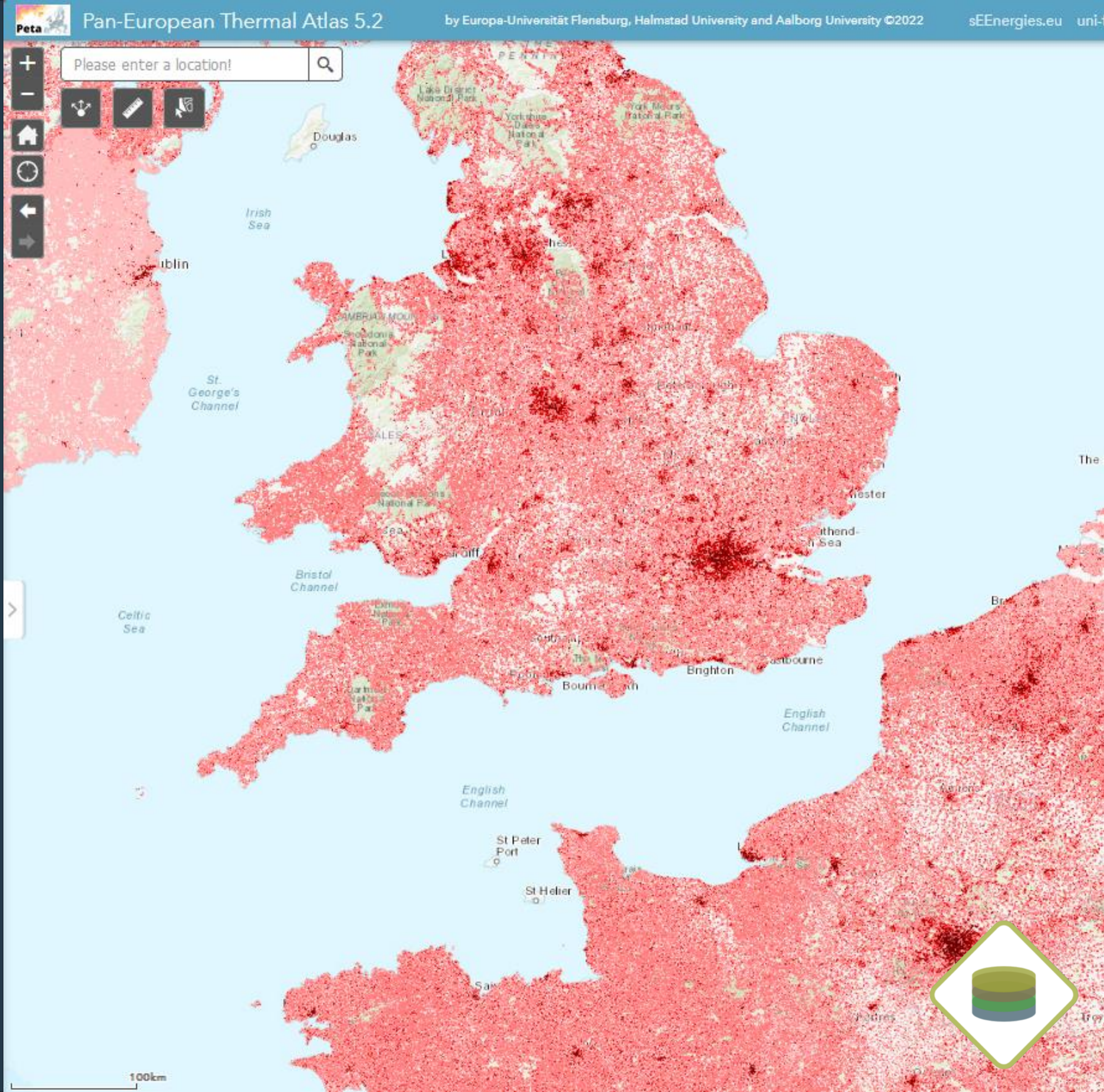
CLICK HERE for the sEENergies Web Map

CLICK HERE for sEEnergies Publication on LV Grid Reinforcements

VI. SPATIAL ANALYSIS

ENERGY EFFICIENCY POTENTIALS AND DEVELOPMENT OF GIS VISUALISATION PLATFORM

- Background
- Methods
  - Model Background – Quantities and Structure
  - Model Development
- Results
  - EU Cost Curves
  - Spatial Analytics and the sEEnergies Index
- Conclusions



VI. Spatial Analysis – Background

Spatial Analyses of Energy Efficiency Potentials and Development of GIS Visualisation Platform

sEEnergies

EE potentials cannot be fully determined by means of national, sectoral, and energy carrier volumes and magnitudes only.

- While energy statistics yield information on volumes and magnitudes on national and sectoral levels and by energy carrier, the local potentials for energy efficiency and their feasibility depend on their spatial context.
- EE measures are subject to geographically determined parameters such as e.g. distribution (density, intensity), relation (e.g. distance between phenomena), and location.
- In the building sector, future heat demands on national scales are being distributed using the age class of built-up areas and innovative models of future population distribution.
- District heat distribution capital costs combined with heat demand densities allow for the assessment of economic potentials of future district heating.
- Efficiency potentials in the transport and industrial sectors are associated to locations, and transmission infrastructures have been mapped.

Combining all these aspects, spatial analytics help understanding the opportunities and constraints that arise from the geography of energy systems.

OBJECTIVES

Spatial analytics and the sEEnergies Index

- General GIS platform for mapping and evaluation of underlying phenomena that influence the viability of EE measures, such as demographics, socio-economics, the built environment, economic activity, and existing infrastructures.
- Web-based GIS interface for the visualisation and presentation of data and results.

VI. Spatial Analysis – Methods

Model Background – Quantities and Structure

District Heating Distribution Capital Cost (DHDCC) model

Distribution system

- Network pipes circulating a media fluid

Main output:

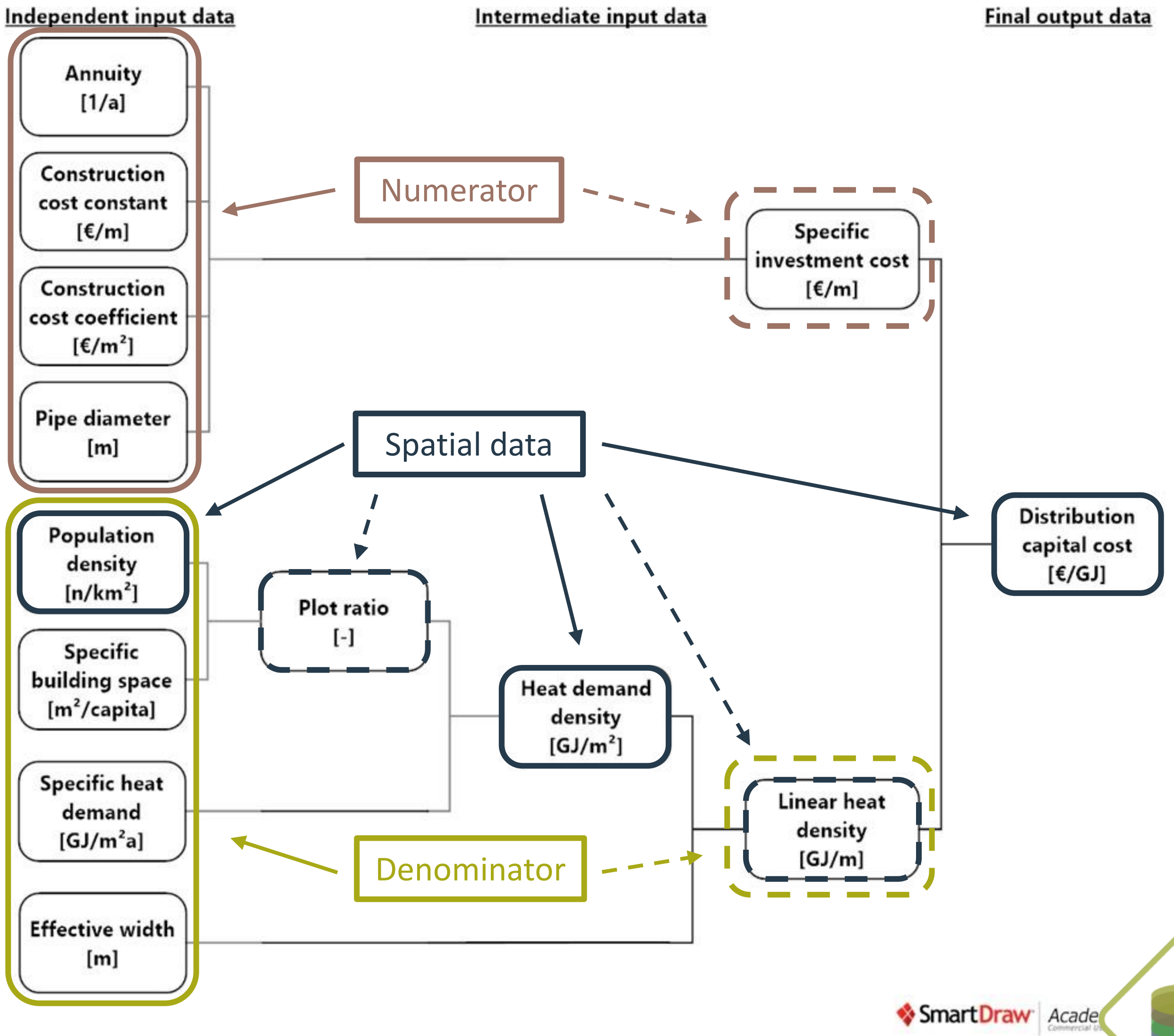
- The specific distribution capital cost

$$The\ specific\ distribution\ capital\ cost\ (C_d)$$
$$= a \cdot \frac{I}{Q_S} = Annuity \cdot \frac{Total\ network\ investment\ cost\ [€]}{Annually\ sold\ district\ heat\ [\frac{GJ}{a}]}\ [\frac{€}{GJ}]$$

Basic equation, introducing trench length (L):

$$C_d = a \cdot \frac{I}{Q_s} = a \cdot \frac{\left(\frac{I}{L}\right)}{\left(\frac{Q_s}{L}\right)} \left[\frac{€}{GJ}\right]$$

$$C_d = a \cdot \frac{(C_1 + C_2 \cdot d_a)}{\rho \cdot \alpha \cdot q \cdot w} \left[\frac{€}{GJ}\right]$$



A distribution capital cost model. Source: Persson U. District heating in future Europe: Modelling expansion potentials and mapping heat synergy regions. Dissertation Thesis. Series Nr: 3769. Göteborg: Energy and Environment, Chalmers University of Technology, 2015.

VI. Spatial Analysis – Methods

Model Development

sEEnergies

Physical suitability

Future population model: Forecasting and mapping of floor areas and heat demand densities

Future heat demands, efficiency and supply depend on:

The energetic development of the existing building mass

The intensity at which buildings are used

The replacement of existing building stock

The expansion of urban areas with new building stock

An assessment of future population distribution may help describing:

Where to expect new-build areas, at which density

Where to anticipate a further decline in population

Where to foresee urban economic development: "booming areas"

Economic suitability

Effective width and plot ratio

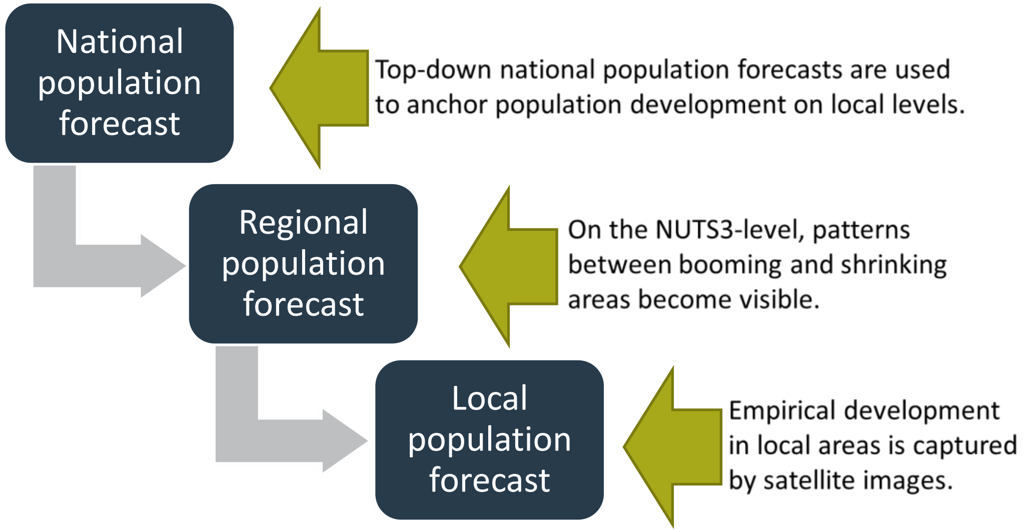
- Effective width: w, the relative demand for district heating pipe lengths (quota of land area and pipe length)
- Plot ratio: e, a city planning parameter describing the fraction between building space area and land area (product of p and α)

- Distribution and service pipes
- Construction costs by Member States

An attempt to model the future distribution of population on the hectare level

Basic hypothesis: past population development in places drives future development in their neighbourhood

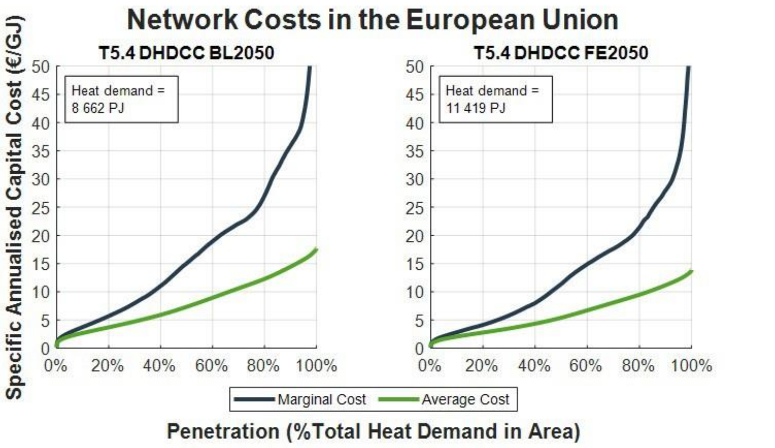
- Places that have experienced significant growth or decline influence locations nearby, which expose a similar trend
- If areas near existing growth areas are suitable, then the attractiveness of growth areas rubs off on these
- The past population increment within a defined neighbourhood can be used to calculate future population in each location

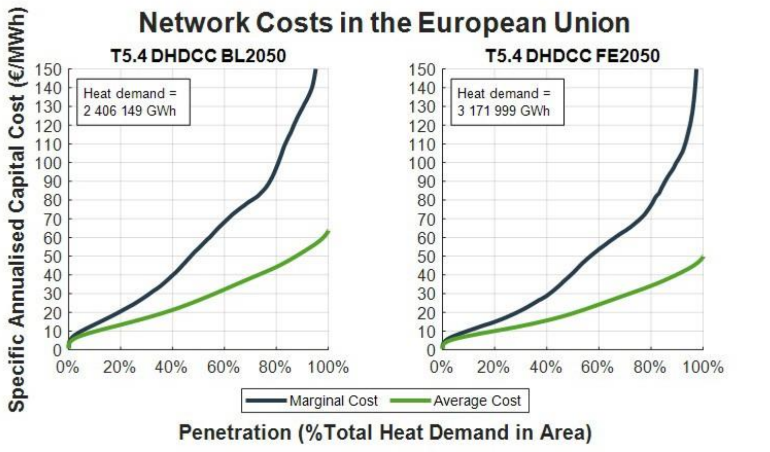


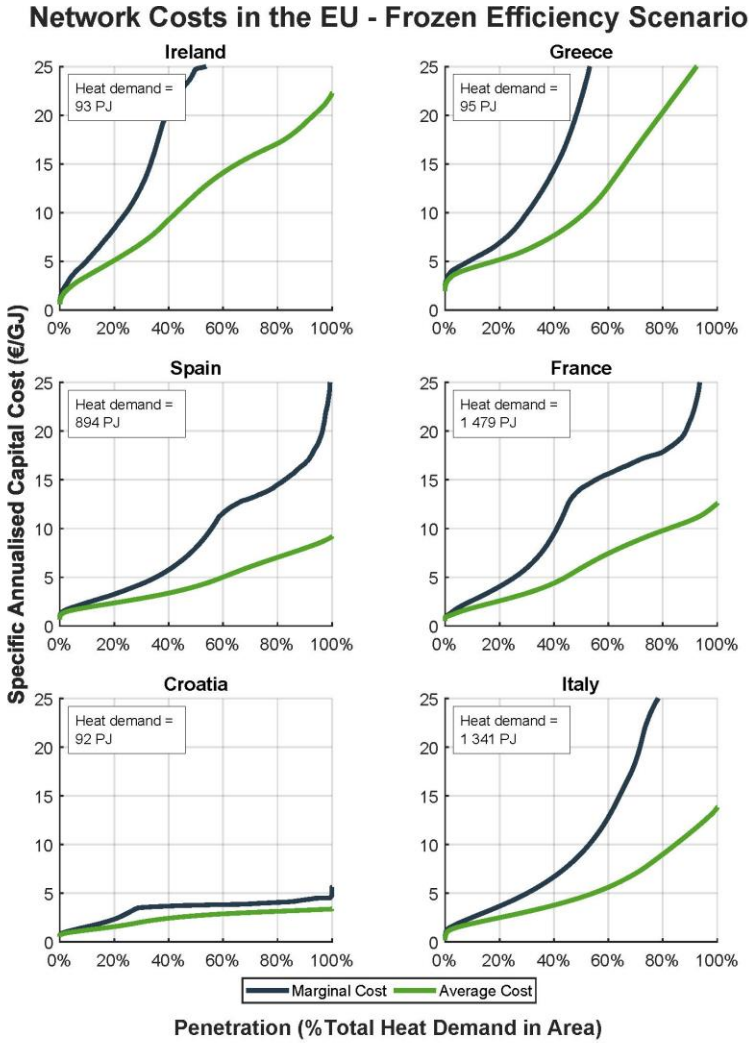
VI. Spatial Analysis – Results

EU Cost Curves

sEEnergies







District heating network investment costs for EU27+UK under the sEEnergies 2050 scenarios (Baseline and frozen efficiency) at anticipated 25% national heat market shares for district heating

MS	Marginal cost [€/GJ]		Average cost [€/GJ]		Acc. heat demand [PJ/a]		Total investment [M€]	
Scenario	BL2050	FE2050	BL2050	FE2050	BL2050	FE2050	BL2050	FE2050
AT	6.96	5.44	4.05	3.17	44.2	56.3	3,513	3,502
BE	7.3	5.06	4.44	3.13	64.9	86.5	5,649	5,303
BG	4.72	4.04	3.59	3.09	23.7	27.0	1,669	1,633
CY	46.13	34.97	32.05	24.59	1.3	1.9	835	898
CZ	6.29	4.65	4.36	3.30	47.3	61.0	4,043	3,941
DE	8.48	5.56	5.56	3.72	407.2	569.1	44,343	41,520
DK	7.56	6.66	4.61	4.05	47.5	55.6	4,287	4,416
EE	2.25	1.82	1.42	1.20	9.0	12.1	249	283
EL	8.79	8.12	6.04	5.63	22.8	23.8	2,695	2,619
ES	4.3	3.76	2.94	2.59	194.6	223.5	11,195	11,342
FI	4.06	3.04	2.59	1.91	44.8	52.5	2,275	1,972
FR	6.33	4.89	3.82	2.95	279.4	370.1	20,911	21,399
HR	4.38	2.96	2.95	1.78	9.7	23.0	559	801
HU	7.49	4.62	4.78	3.04	39.9	54.8	3,736	3,267
IE	23.27	10.25	13.26	5.93	14.1	23.3	3,657	2,705
IT	5.34	4.28	3.45	2.78	280.5	335.5	18,961	18,313
LT	4.52	2.61	3.08	1.75	11.5	25.1	693	862
LU	5.96	3.01	3.71	1.96	4.9	10.7	353	409
LV	1.92	1.45	1.23	0.97	14.0	18.7	338	353
MT	5.72	3.81	2.52	1.78	0.9	1.1	47	38
NL	11.88	9.08	8.43	6.51	84.0	106.3	13,877	13,567
PL	5.96	4.52	4.17	3.13	111.3	162.5	9,106	9,983
PT	17.24	15.57	11.77	10.63	15.7	17.8	3,632	3,706
RO	11.78	8.01	7.92	5.68	35.9	47.5	5,571	5,289
SE	6.33	4.74	3.84	2.90	60.4	73.2	4,548	4,162
SI	4.93	2.59	3.03	1.60	7.5	17.4	444	545
SK	13.16	5.4	8.38	3.49	14.3	42.3	2,354	2,899
UK	9.12	6.12	5.73	3.84	275.1	358.2	30,904	[illegible]
Max. value	**46.13**	**34.97**	**32.05**	**24.59**	**407.2**	**569.1**	**44,343**	[illegible]
Min. value	**1.92**	**1.45**	**1.23**	**0.97**	**0.9**	**1.1**	[illegible]	[illegible]
Avg. value	**9.01**	**6.32**	**5.85**	**4.18**	**77.4**	**102.0**	[illegible]	[illegible]

VI. Spatial Analysis – Results

EU Cost Curves

sEEnergies

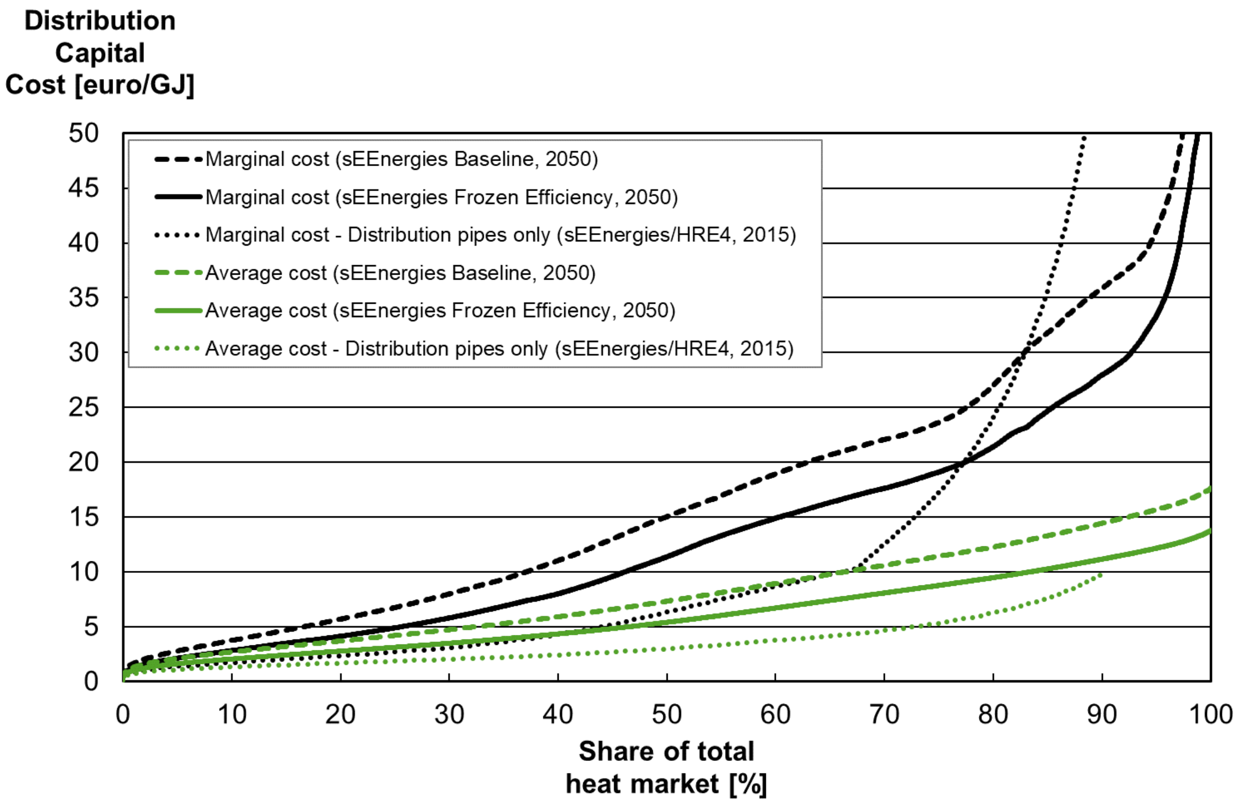
HRE4 2015 anticipated the total market value for a 50% EU28 MS heat market share saturation at **318 G€** (distribution pipes only)

Given a 65% share for the distribution pipe cost investment, the 50% level in the FE2050 scenario, would correspond to **~394 G€**

Noteworthy, the relative accumulated share of distribution pipe costs decreases with higher levels of heat market shares.

Table 4. District heating network investment costs on average for EU27+UK (modelled as one single entity) under the two sEEnergies 2050 scenarios (Baseline (BL2050) and frozen efficiency (FE2050)), by four anticipated levels of total heat market shares for district heating

DH heat market share [%]	Marginal cost [€/GJ]		Average cost [€/GJ]		Acc. heat demand [PJ/a]		Total investment [M€]		Acc. share distribution vs. service pipes [%]	
Scenario	BL2050	FE2050	BL2050	FE2050	BL2050	FE2050	BL2050	FE2050	BL2050	FE2050
25%	6.76	4.91	4.21	3.13	2166	2854	178,899	175,235	70%	72%
50%	15.04	11.39	7.34	5.41	4331	5711	622,950	605,677	64%	65%
75%	23.65	19.12	11.43	8.77	6497	8566	1,455,450	1,473,280	57%	59%
100%	377.58	305.28	17.67	13.83	8662	11419	3,000,203	3,095,727	54%	55%



VI. Spatial Analysis – Results

Spatial Analytics and the sEEnergies Index

The Pan-European Thermal Atlas version 5.2

Key features

- Mapping of localised energy system data for the EU27+UK
- Highly detailed information down to the 1-hectare level
- Integration of building, industrial and transport sectors

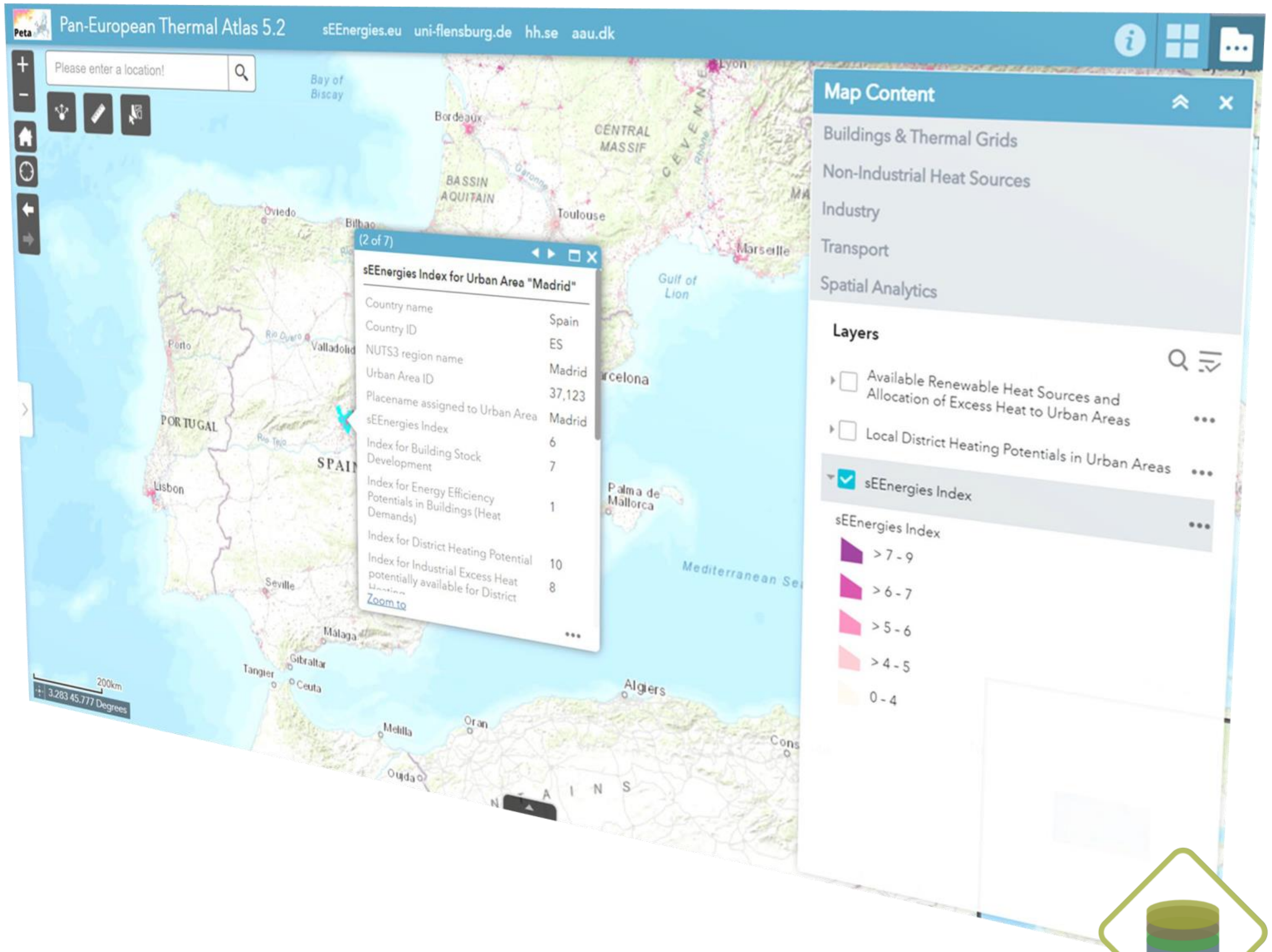
Value added

- Cross-sectoral mapping of energy efficiency
- Easier access of attributes, better selection and map sharing
- Open Data hub for data sharing
- Illustrative Story Maps

Combining spatially distributed information on energy efficiency to identify local synergies

Cases

- Energy efficient buildings and future district heating
- Sustainable heat sources for local heat supply strategies
- Urban development, socio-economics and EE
- Combining multisectoral efficiency potentials to a local sEEnergies Index



VI. Spatial Analysis – Conclusions

Spatial Analyses of Energy Efficiency Potentials and Development of GIS Visualisation Platform

sEEnergies

- A coherent geospatial representation of energy efficiency potentials on the local level for building, industry, and transport sectors has been developed for the present and future.
- For about 150,000 Urban Areas, key characteristics of energy efficiency have been mapped.
  - High-resolution grids on the 1-hectare level, 150,000 urban areas, and national aggregates may be used to quantify and locate energy efficiency across sectors.
- EU-27 plus UK-wide map layers and output datasets of energy efficiency potentials by scenarios for buildings, transport, and industry sectors.
- Spatially explicit datasets of physical and economic suitability of heat supply solutions for different end-use efficiency scenarios in urban and rural areas, to be used in smart energy systems analysis.
- A geographical allocation of renewable and waste heat sources to local settlements and their potential district heating systems.
- The sEEnergies Index: a simple way to assess, combine, and compare the potential to implement energy efficiency in buildings, transport, industry, and infrastructure for all urban areas.
- An online web-map interface and an Open Data Hub facilitate visualisation and data sharing.
- Energy efficiency potentials determined on the local level are made available for national studies.
- Story Maps improve the dissemination of a magnitude of results.

CLICK HERE for Policy Brief

CLICK HERE for Reports on Spatial Analysis (WP5)

CLICK HERE for Webinar on Spatial Potentials

CLICK HERE for Peta Version 5.2

CLICK HERE for Open Data Hub

CLICK HERE for sEEnergies Publication on Effective Width for DH systems

VII. ENERGY SYSTEMS

MODELLING ENERGY SYSTEM SYNERGIES AND QUANTIFICATION OF EEFP IMPACTS

- Background
- Methods
    - Energy System Analysis for Each Country
    - Technology Data and Costs
    - Modelling Platform Development for New Scenarios based on EEFP
    - EnergyPLAN
    - Investment Roadmap and Policy Gap Analysis
- Results
    - sEE1.5 and sEE2030 System Efficiency Overview
    - Annualised Costs
    - Investment Strategy and Ranking of EE Measures
    - Electricity Demand, Production and Capacities
    - Energy Storages
    - Bioenergy Demand and Potential
    - Non-Energy Impacts
    - Policy Recommendations
- Conclusions

VII. Energy Systems – Background

Modelling Energy Systems Synergies and Quantification of EEFP Impacts

The Energy Efficiency First Principle focuses on energy reduction, which helps, achieve the long-term decarbonisation objectives of the EU towards 2050.

How to demonstrate the impact that energy savings have on the energy system?

How to make the Energy Efficiency First Principle understandable on the end-use, operation, transmission and utilisation of resources?

How to understand the impacts of the balances of energy efficiency with investments in renewable energy, energy storage and grids in renewable energy systems?

This is done by developing cost-effective 100% renewable energy system scenarios to 2050 using different energy efficiency first scenarios for transport, industry and the building sectors. Furthermore, the costs for energy grids and spatial analytics information are considered for the development of the energy system scenarios.

Twenty-eight countries (EU27+UK) are assessed, and one final EU scenario (sEE 1.5) is developed that combines all the country scenarios. It demonstrates how Europe can maximise efficiency and become fully decarbonised and 100% renewable by 2050 by applying the Energy Efficiency First Principle focusing on energy conservation, energy efficiency and energy supply changes, also considering security of supply and resource security.

OBJECTIVES

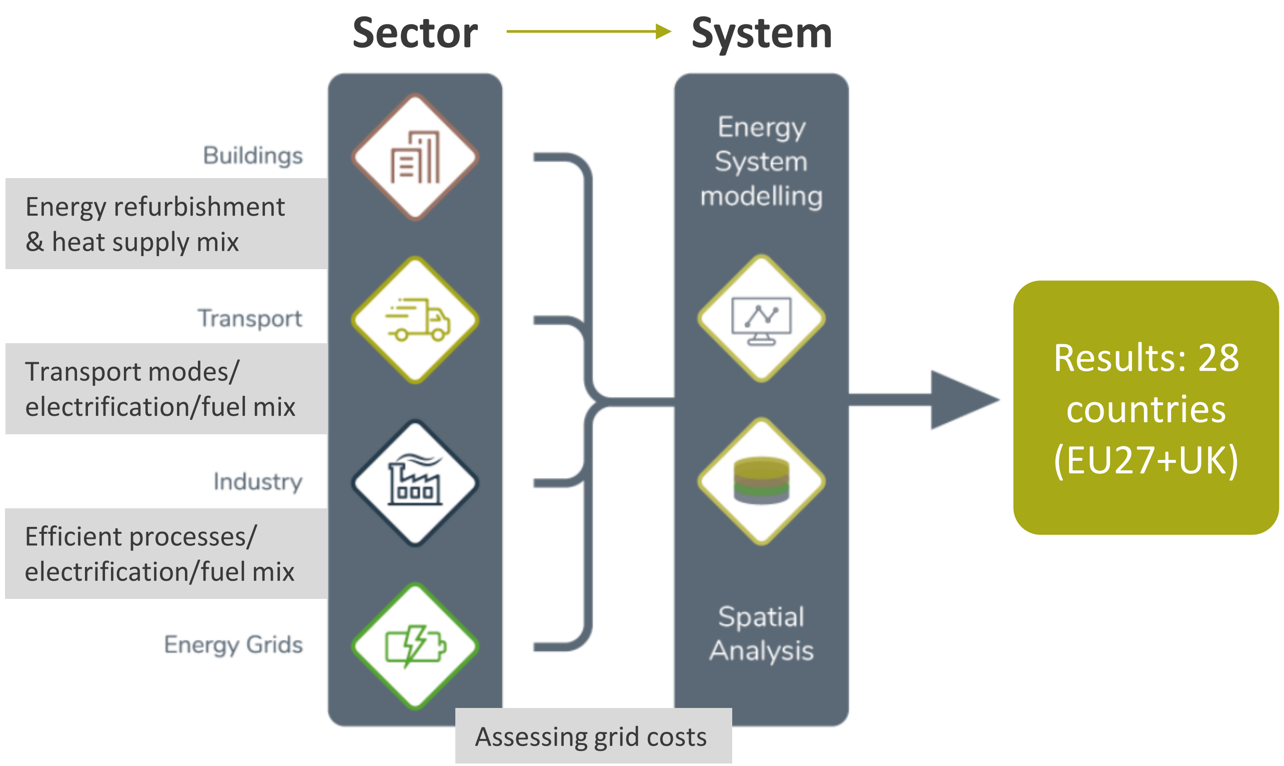
To model and assess all relevant aspects linked to the EEFP impacts

- Assess the impact of EEFP on sectoral and energy system level.
- Quantify the synergies of EE and renewable energy systems.
- Develop and analyse new energy system scenarios aimed at quantifying EEFP.
- Investment roadmap based on most critical EE improvements.
- Science-based policy recommendations.
- Assess non-energy impacts of EE measures.

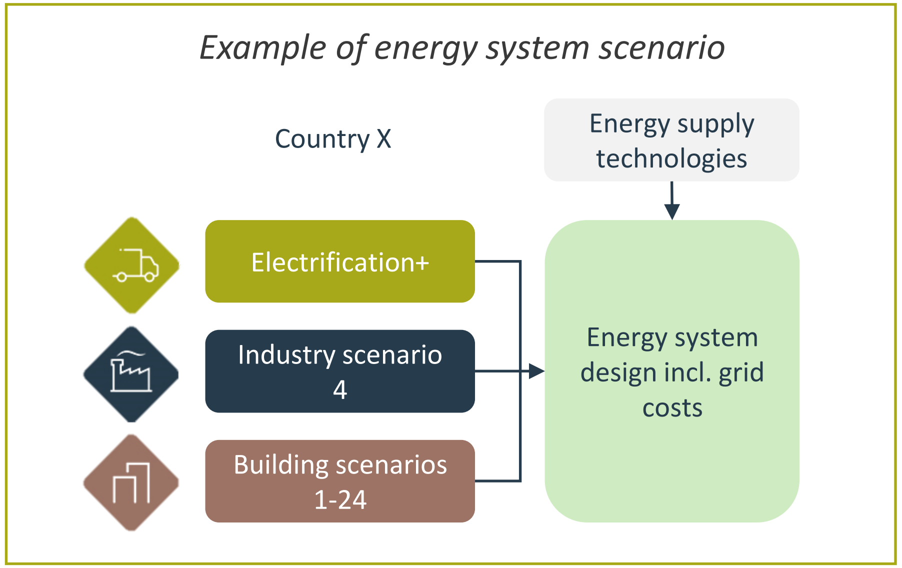
VII. Energy Systems – Methods

Energy System Analysis for Each Country

- Modelling platform combined the energy sector scenarios and grid costs within an energy system analysis for each EU27+UK country.
- An EU27+UK energy system was created from each of the selected countries.



- Sector scenarios and grid costs considered for each country.



- The EnergyPLAN tool was used to analyse the energy system performance of each country hour-by-hour over one year.
- A final energy system configuration for each country was selected based on a performance assessment:
  - Socio-economic cost of the energy system
  - Renewable electricity capacity
  - Level of electricity exchange with surrounding countries
  - Balancing district heat production and demand
  - Biomass consumption

VII. Energy Systems – Methods

Technology Data and Costs

- The choice of technologies and technology pathways is dependent on economic costs.
- To proceed with the energy system modelling, an accurate and up-to-date database based on the current and future cost levels was developed.
- Costs in the future were determined based on technological learning and decomposing the manufacturing and installation costs into raw materials, labor costs, financial costs.
- The database was used in the quantification of total annualised energy system costs for the scenario determination for all 28 EU countries. The database contains raw cost data before manipulation for further use, consisting of seven main datasets:
  1. Energy conversion and storage technologies
  2. Heat conservation
  3. Industrial efficiency (input from IndustryPLAN)
  4. Energy grids
  5. Transport infrastructure (input from TransportPLAN)
  6. Extracted and synthesised fuels/energy
  7. Environmental cost (CO_2 price)
- Coupled with cost data are technology data for numerous energy conversion and storage technologies, including efficiencies, typical capacity, and full load hours where available. This data provides indicative installation size and usage patterns of technologies.
- The same mix of technology capacities are assumed for each country due to lack of data. Although all cost variations are included in the database.
- Formula for converting raw cost data into country specific cost data adjusted for labour costs:

$$C_x = C_{ref} \times r_{labour} \times I_{country,labour} + C_{ref} \times (1 - r_{labour})$$

Where,

- C_x is the total cost of the unit in MS “X”
- C_{ref} is the (total) cost of the unit in question from the identified reference
- r_{labour} is the ratio between the share of the total costs related to labour costs and the total cost of the unit (i.e., between 0 and 1)
- $I_{country,labour}$ is an index number representing the ratio between the labour costs of MS “X” and the labour costs in the country representing the reference cost (i.e., between 0 and 1)

VII. Energy Systems – Methods

Modelling Platform Development for New Scenarios based on EEFP

sEEnergies

System-scenario

- Energy system configuration in 2050 for both the EU and for individual EU countries.
- Combines energy efficiency measures within the energy sectors.

Sector-scenario

- Within each energy sector, sector-scenario variations are developed and with the aid of these sector-scenario variations, a final sector-scenario is determined for applying into the final system-scenario for the EU or for a country.
- Integrated through two different steps:
    1. Integrating transport and industry sector scenarios into the system scenarios in an aggregated EU27+UK,
    2. Integrating the heating sector and energy grid scenarios into the system scenarios of individual countries.

Modelling Platform

- The structure of the modelling platform in sEEnergies follows the backcasting principle.
    - Backcasting makes scenarios in the future and indicates the types of changes required now and in the next years to get to the future scenario.
    - Due to the complexity of the energy system and its many components, it is preferable to do backcasting from a predefined future energy system. Therefore, in sEEnergies the reference scenario is developed based on the PRIMES 2050 Baseline energy system.
    - The PRIMES 2050 Baseline data was collected mainly from the "A clean planet for all" report by the European Commission (European Commission, 2018), where data was extracted to be used in EnergyPLAN
- Key consideration – how energy-system efficiency measures affect other energy system components.
    - A matrix of heat savings and district heat and heat pump supply costs was required for energy system analysis in each country

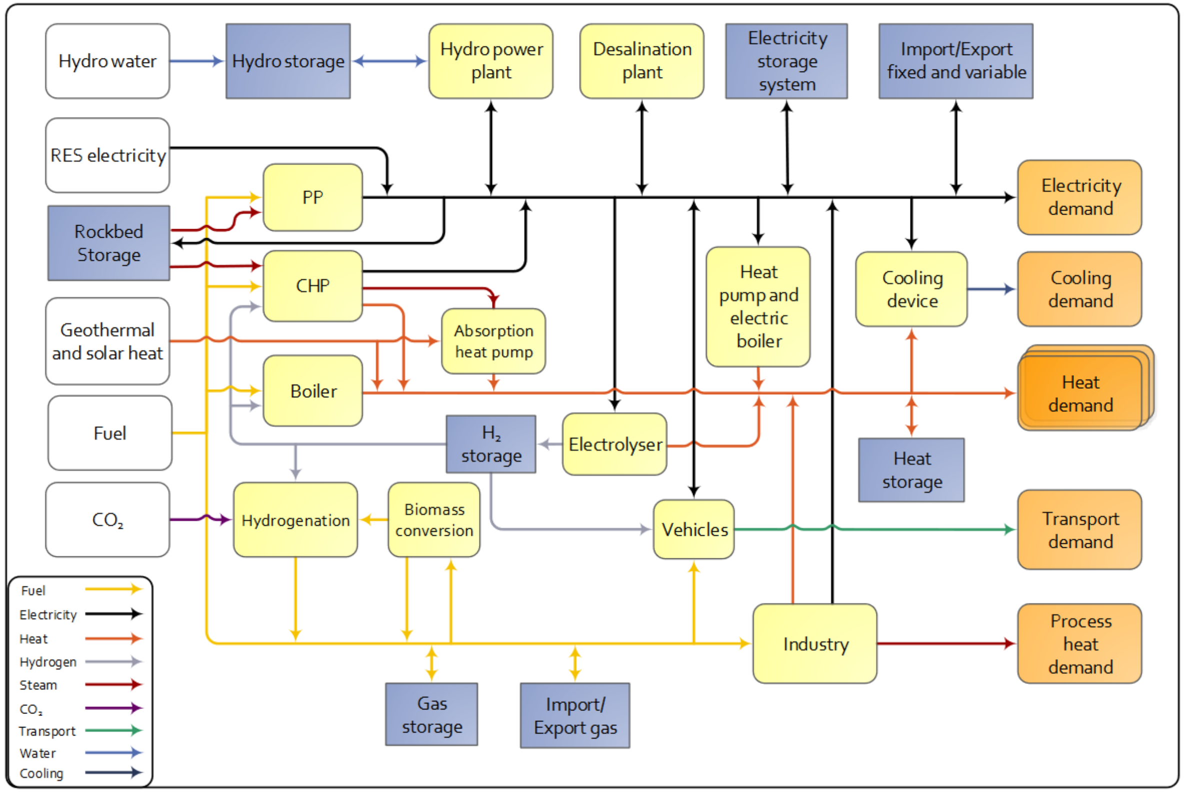
VII. Energy Systems – Methods

EnergyPLAN

sEEnergies

- Deterministic simulation model, simulating hourly balances for all energy sectors of the energy system including the heating, power, gas, transportation, and industry sectors (Lund et al., 2021).
- Updated regularly to maintain relevance with technological advancements.
- The tool does not include spatial allocation of energy demands and supply in the modelled system, but in sEEnergies, several of the data inputs are based on spatial analyses conducted in the individual work packages.
- Main data inputs categories needed in EnergyPLAN used to structure the modelling platform:
  - **Demand**: Electricity (whole energy system), Heating (whole energy system), Cooling (whole energy system), Industry (fuel), Transport (fuel)
  - **Supply**: Combined Heat and Electricity, Central Power Production, Variable Renewable Electricity, Heat Only, Solid Waste Incineration
  - **Balancing and Storage**: Electricity Grid, Storage
  - **Costs**: General, Investments, Fixed Operation and Maintenance, Variable Operation and Maintenance, Fuel Prices

Overview of sectors, technologies and demands in EnergyPLAN



VII. Energy Systems – Methods

Investment Roadmap and Policy Gap Analysis

sEEnergies

To assess the EU energy policies and inform the investment strategy for developing the sEE1.5 2050 energy system, an interim 2030 EU27+UK energy system was required.

Backcasting to 2030

A sEEnergies 2030 model was developed based on sEE1.5 2050, using backcasting.

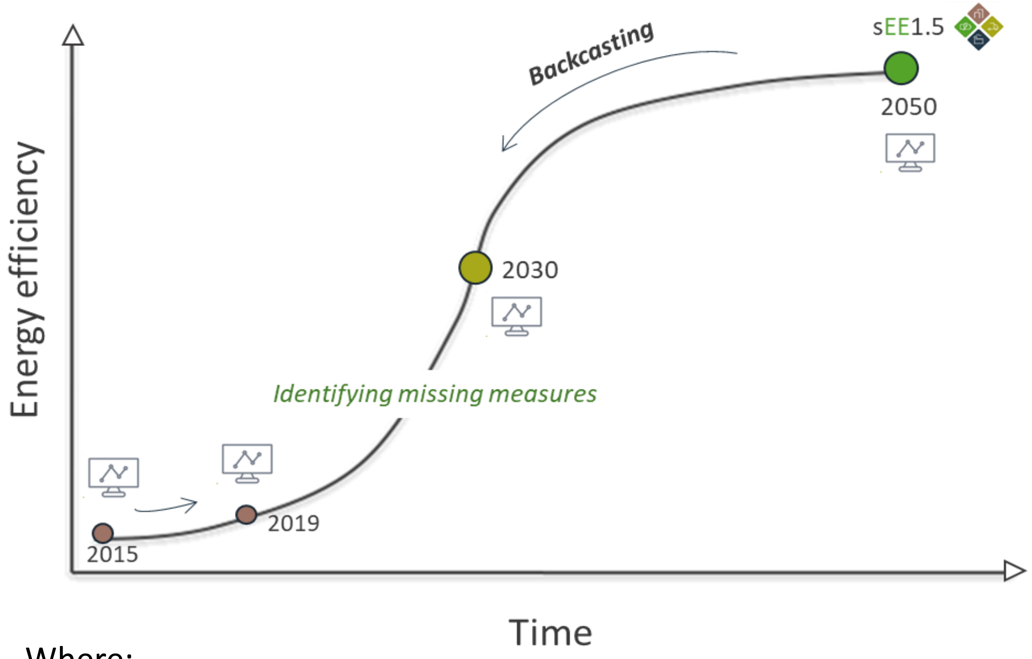
Trend curves from 2015 to 2019 for numerous energy system components.

Transition S-curves to project the timing for the investment and implementation from 2015 to 2050.

Prioritisation and timing of the energy efficiency actions based on their impacts, current development level and role within the reconfiguration of the energy system design to 2050.

To plot the inflection point in the transition curve and determine the values for each year from 2015 to 2050, a logistic regression fit, when not assuming logged X-values, was used following the equation:

$$y = min + \frac{max - min}{1 + \left(\frac{X50}{x}\right)m}$$

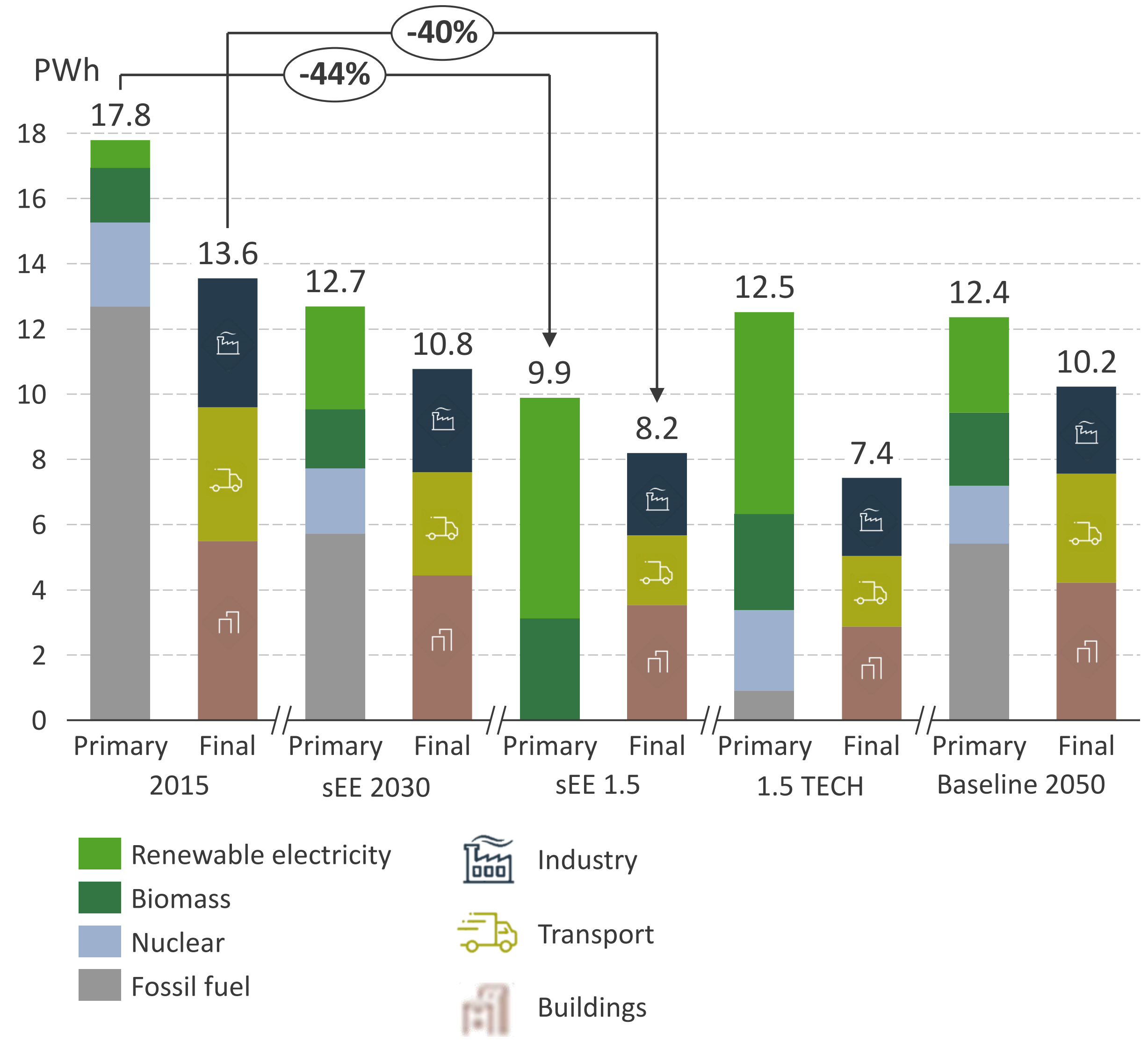


Where:

- *min* and *max* are the lower and upper asymptotes of the curve (these were fitted approximately to the min and max values at 2015 (from the Eurostat database) and sEE1.5 2050, respectively),
- *m* is the slope of the curve at its midpoint (determining the speed of change),
- *X50* is the x-coordinate of the inflection point (x, y) (determining the time period of change).

VII. Energy Systems – Results

sEE1.5 and sEE2030 System Efficiency Overview



sEE1.5 and sEE2030 System Efficiency Overview

The application of the energy efficiency first principle makes it possible to have a highly efficiency decarbonized European energy system by 2050.

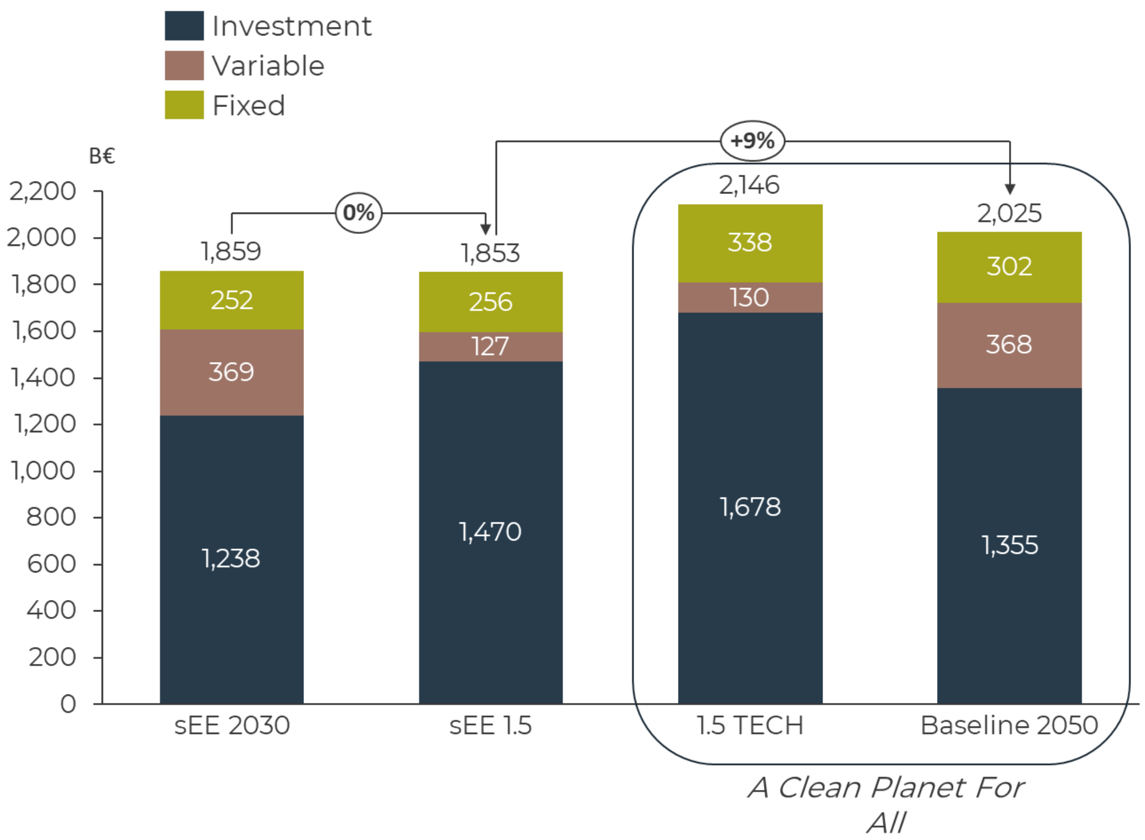
- Primary and final energy demand can be reduced significantly compared to today's energy system (2015 used as the reference), reducing by 45% and 40%, respectively.
- This is possible, among other measures by building renovations, extensive electrification of the transport and the industry sectors both via direct and indirect electrification.

The energy efficiency is greater than the 1.5TECH scenario although the final energy is similar. Demand side energy efficiency improvements allow re-design of the overall supply system.

- This re-design also provides an opportunity to integrate more cost-effective renewable energy such as solar PV and wind → allows us to balance the overall energy system with energy storage and transfer technologies such as thermal storages, power to X etc.
- One key difference is sEE1.5 phases out nuclear power.

VII. Energy Systems – Results

Annualised Costs

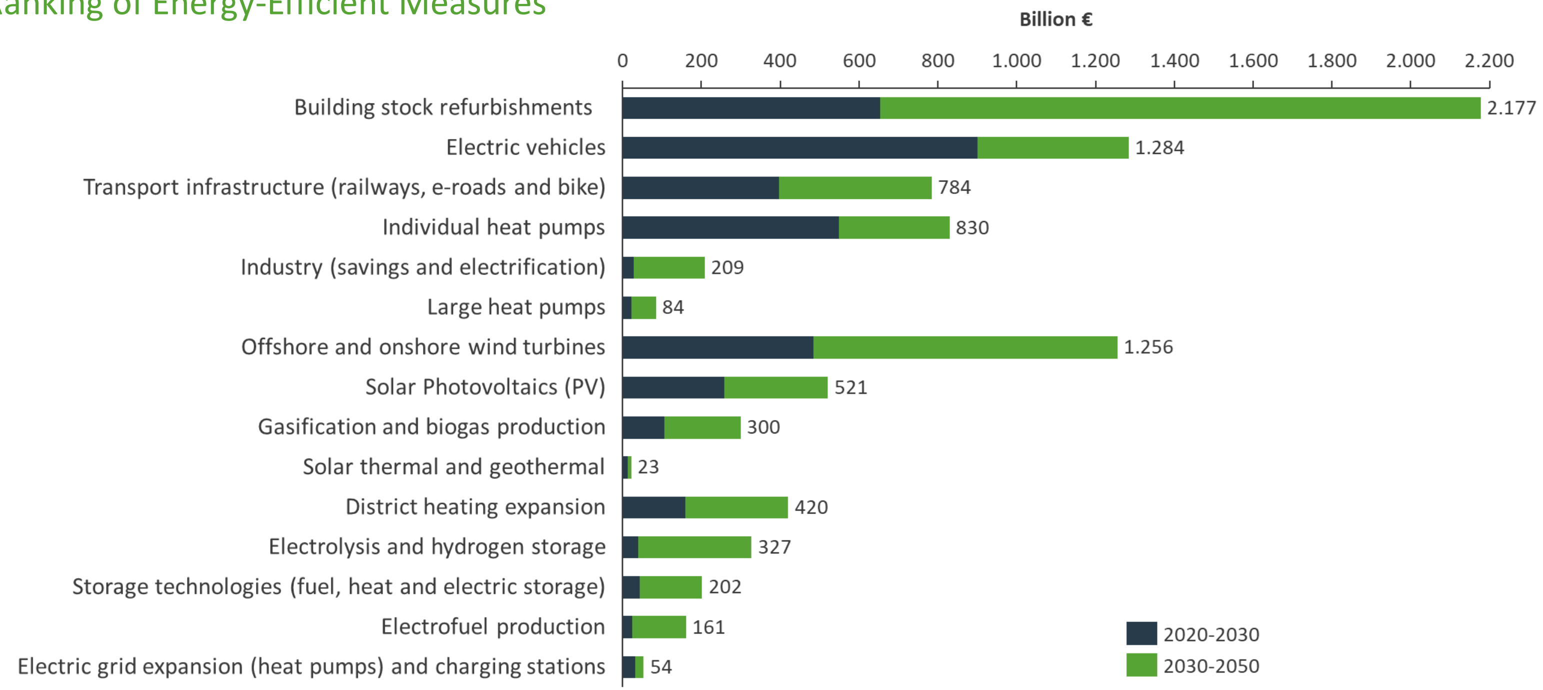


Annualised Costs

- sEE1.5 scenario can be achieved without incurring large additional energy system costs.
- Overall, the annualized costs are lower than 1.5TECH due to:
  - Fewer energy efficiency measures (especially in the building sector)
  - Fewer vehicles on the roads, and the exclusion of nuclear power.
  - In general, most costs in sEE1.5 arise from investments in infrastructure, with fuel costs decreasing when transitioning from the current fossil fuel and nuclear energy system.
- sEE1.5 is more cost effective compared to 1.5TECH.
- In the heating sector sEE1.5 has less energy savings and better synergies due to district heat and use of excess heat.
- The sEE2030 scenario sees an increase in the annualised investment costs compared to 2015, primarily due to the new investments in energy efficiency, conversion technologies and new electric vehicles, but manages to stay below the PRIMES Baseline and 1.5 TECH scenarios.

VII. Energy Systems – Results

Investment Strategy and Ranking of Energy-Efficient Measures



A system redesign based on the energy efficiency first principle and renewable energy entails that the energy system changes from a system with high fuel cost to a system with very high investments. In energy efficient 100% renewable energy systems an increase in investments for these measures is compensated by the decrease in the variable costs such as fuel costs for the system. In total the annualized costs in a smart energy system using synergies across sectors and combining energy efficiency with energy storages with renewable energy the total costs are lower costs than a traditional energy system such as the EU Baseline for 2050 or the 2050 1.5 TECH system proposed by the EU Commission. In sEE1.5 for 2050 we are able to keep the overall cost at a level about 10% of the commission scenarios.

Both energy efficiency (demand side) measures and energy supply measures are critical in re-designing the system to cross-sectorial based smart energy systems.

- The former includes investments in measures that directly reduce the final energy consumption such as heat demand savings, changes toward an EE urban development, electrification of transport and industry sectors, etc.
- The latter includes energy supply measures such as replacing more power plants with existing renewable energy supply technologies such as wind and solar.

The supply system and end demand systems and combined with conversion technologies and energy storages to form a smart energy system. This avoids silo thinking, where optimization is done in each sector or energy vector.

VII. Energy Systems – Results

Investment Strategy and Ranking of Energy-Efficient Measures

sEEnergies

Investment Strategy 2020 – 2030

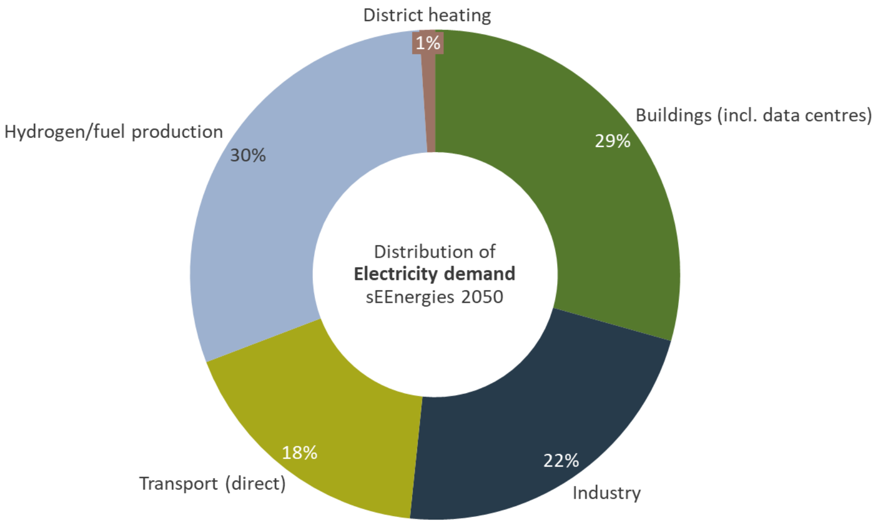
- Energy efficiency in buildings is an extremely important measure, which takes time to implement.
- By 2030 the effects of refurbishments may seem low looking at the investments, but the effects are 10% end demand savings on natural gas and other fuels.
- The main other measure for buildings is heat pumps which can be implemented to a significant level by 2030.
- By 2030 district heating should cover 20% of the demand. 8,500 – 9,000 new district heating systems can ensure further developments of district heating towards 2050.
- Electrification of transport and industry as well as heating serves as the low-hanging fruit in redesigning the energy system in the short term.
    - Replacing inefficient demand-side technologies such as combustion engines with electric motors and technologies increases the overall electricity demand of the system, but at a much lower rate than the fuels replaced.
- By 2030 a ramp up of electrolysers has been initiated to cover hydrogen demands in industry and to start the transition of heavy-duty transport, primarily marine and aviation, using electrofuels.
- The increase in electricity demand requires a ramp-up in investments for renewables, particularly in the short term. Hence, the majority of the investments for the period 2020-2030 are for increasing the electrification of the system, i.e., increasing EV stock, and individual heat pumps and dramatically increasing the renewable electricity production capacities

Investment Strategy 2030 – 2050

- Critical to continue to invest in end demand heat savings in buildings, along with a system re-design based on measures, such as district heating expansion.
- Building renovations and refurbishments rank as the highest in the investment strategy from 2030 – 2050.
- The heat demand for buildings needs to be reduced from 2.700 TWh in 2030 to around 1,900 TWh in 2050. The reduction in heat demand allows the further expansion of waste heat use within district heating networks, as well as having higher efficiencies in heat pumps in 2050.
- An increased expansion of renewable energy capacity for onshore combined with heat demand savings and an increase in district heating allows us to integrate large-scale heat pumps in the overall energy mix, thus, reducing the need for CHP and oil boilers.
- Important to invest in enabling smart energy system components such as electrolysers, hydrogen, and thermal storage units, which become increasingly important after 2030, as the demand for hydrogen both for direct use in industry and production of electrofuels for aviation, and shipping increases.
- A heavy expansion of renewable energy production is needed especially due to further electrification of transport, industry and the use of power-2-X where there are significant losses.
- The system proposed in sEE 1.5 considers a bottom-up approach to the energy efficiency first principle, and even with this deep understanding of the possibilities, large amounts of renewable energy are required.

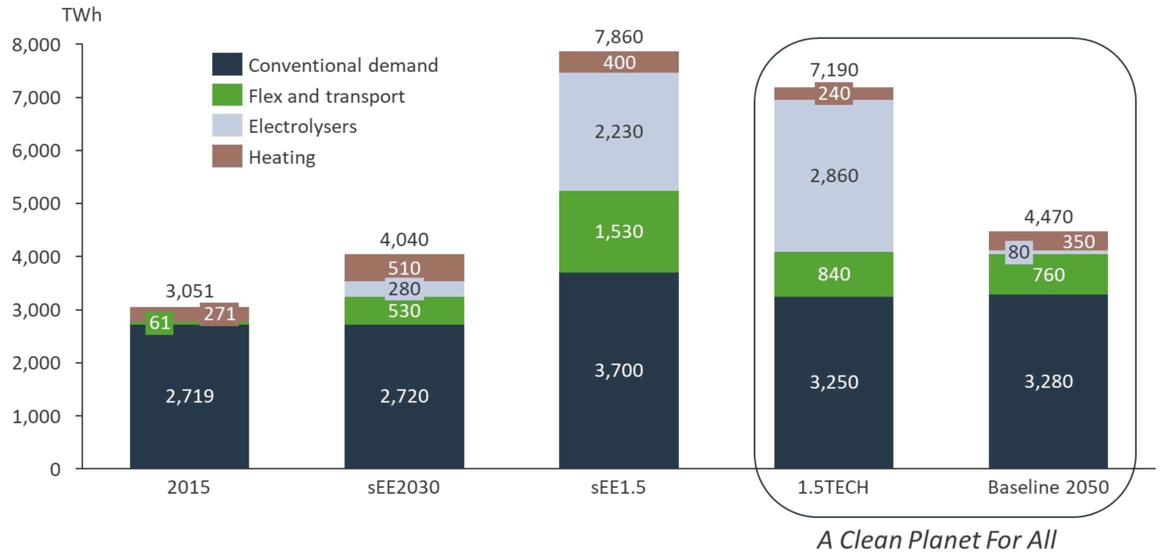
VII. Energy Systems – Results

Electricity Demand



Electricity Demand

- The energy efficiency measures allowed for a system redesign similar to 1.5TECH, but with some key differences.
- The electricity demand in sEE1.5 is higher than 1.5TECH due to the higher electrification of the former.
- The differences are primarily given by the higher number of electric vehicles and heat pumps which positively influence the energy system.
- Final energy demand decreases significantly and primary energy demand is lower than 1.5TECH even with higher electricity demand.
- Higher electricity demand in the flexible and transport demand type means the energy system is more flexible and capable of integrating fluctuating renewable electricity.
- Overall, when comparing to 2015, sEE 1.5 increases the electricity demand by 150%.

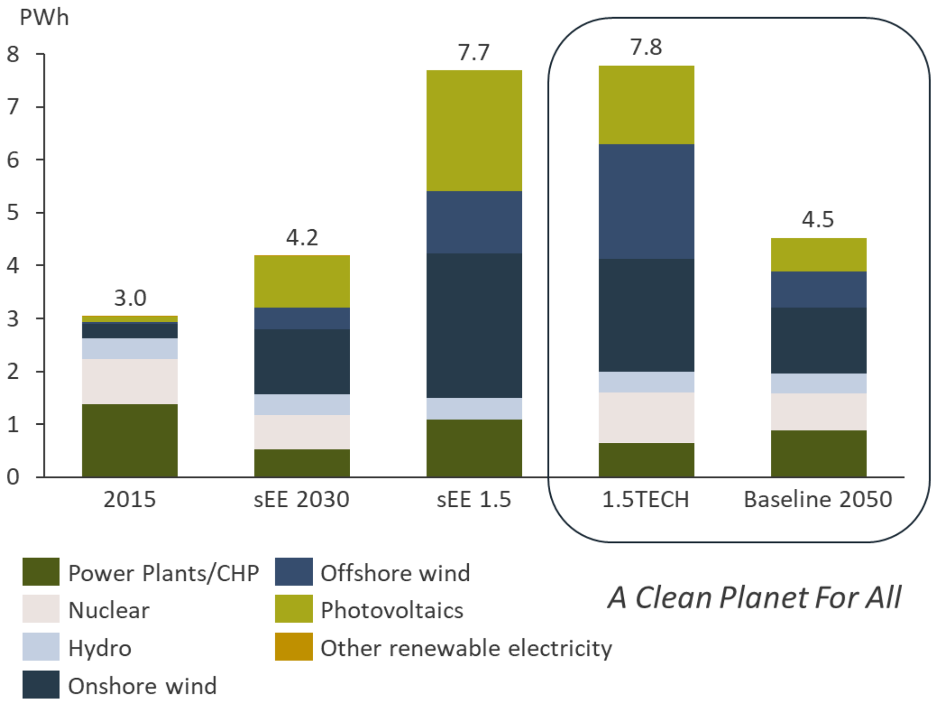


- Hydrogen electricity demand for fuel production are expected to be as high as the total domestic electricity demands, even when considering the very high shares of electrification in transport and heating used in this model.
  - This is a reminder of how the idea of a renewable energy system progresses further if electrification is not maximized and hydrogen is used in applications where it is not necessary.
- The transport sector is still a small share of the electricity demand despite the high direct electrification rate.
- In the industry sector the rate of electrification increases for those types of industry where low heat demands are needed.
  - Heat pumps and direct electricity replace large amounts of fossil fuels.

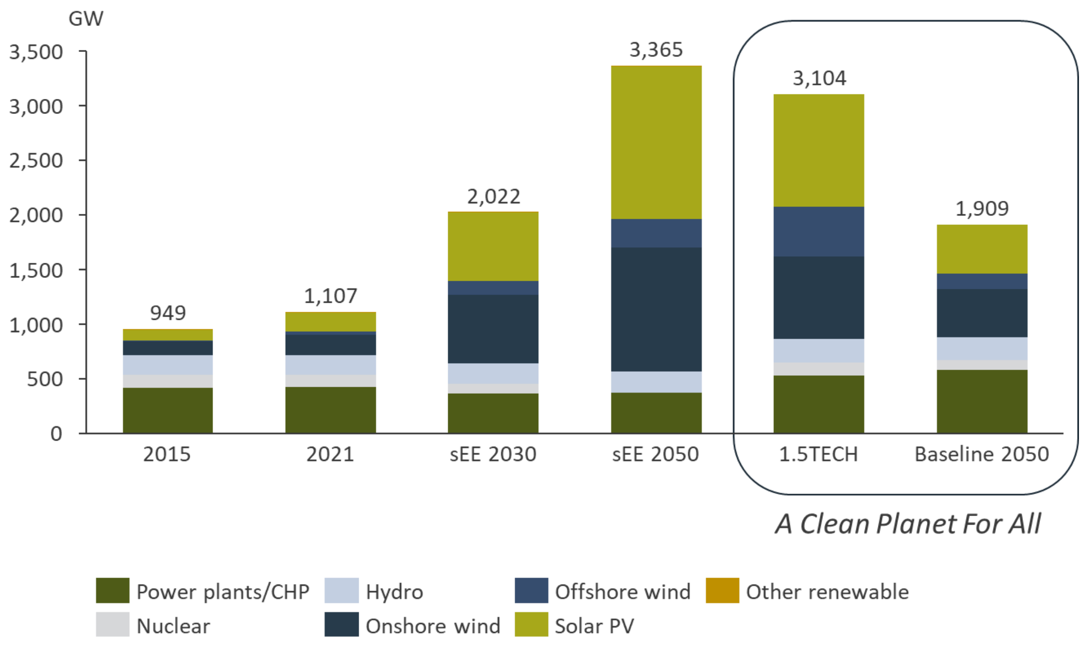
VII. Energy Systems – Results

Electricity Production and Capacities

Electricity Production



Electricity Capacities

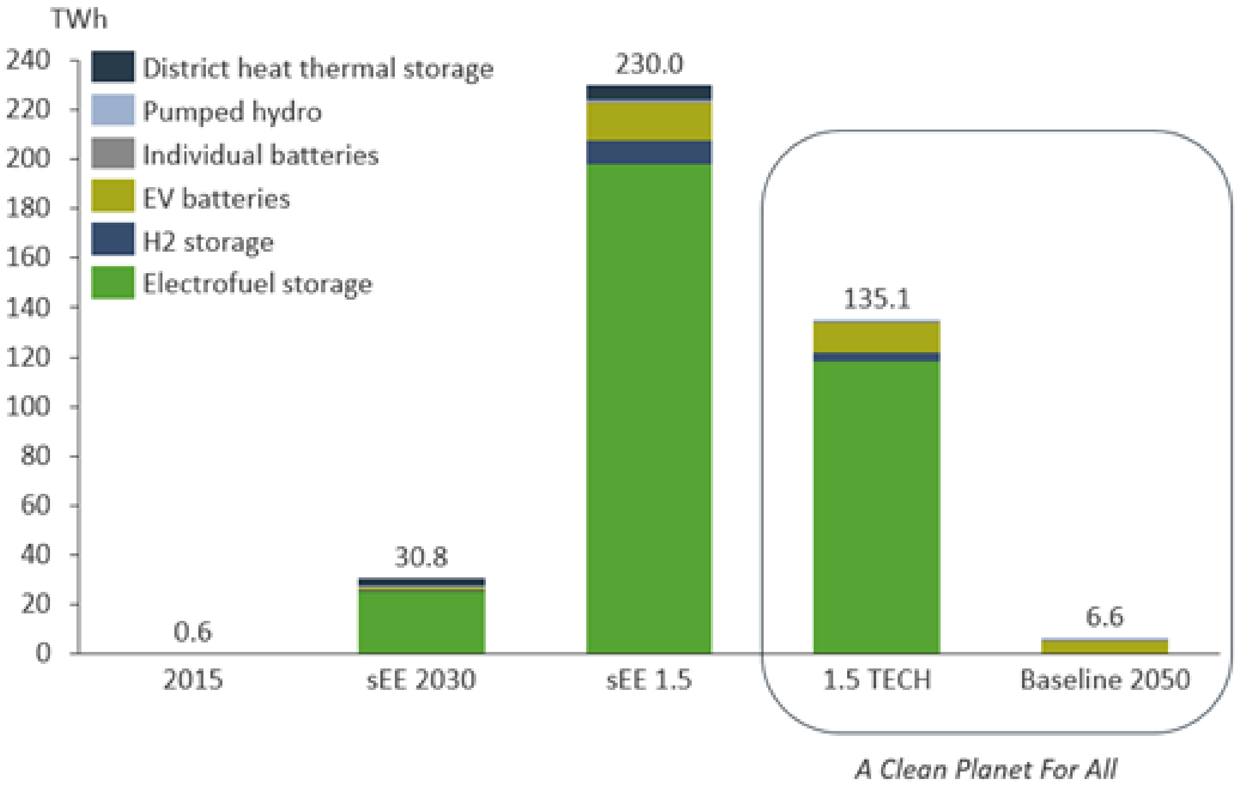


- The redesign of the energy system in both sEE 2030 and sEE 1.5 implies using large amounts of renewable electricity to support the high electrification rates.
- Total electricity production is very similar to 1.5TECH, but includes a much higher share of nuclear energy and offshore wind, whereas for the sEEnergies 1.5 scenario, a complete nuclear phase out is envisioned.
- Due to the phase out of nuclear power the higher capacities of onshore wind and solar PV are required.

- Due to higher costs and lower available potential, onshore wind is preferred over offshore.
- The capacities were determined based on renewable electricity capacity in each country.
- Cheaper energy system due to more onshore wind and PV.

VII. Energy Systems – Results

Energy Storages

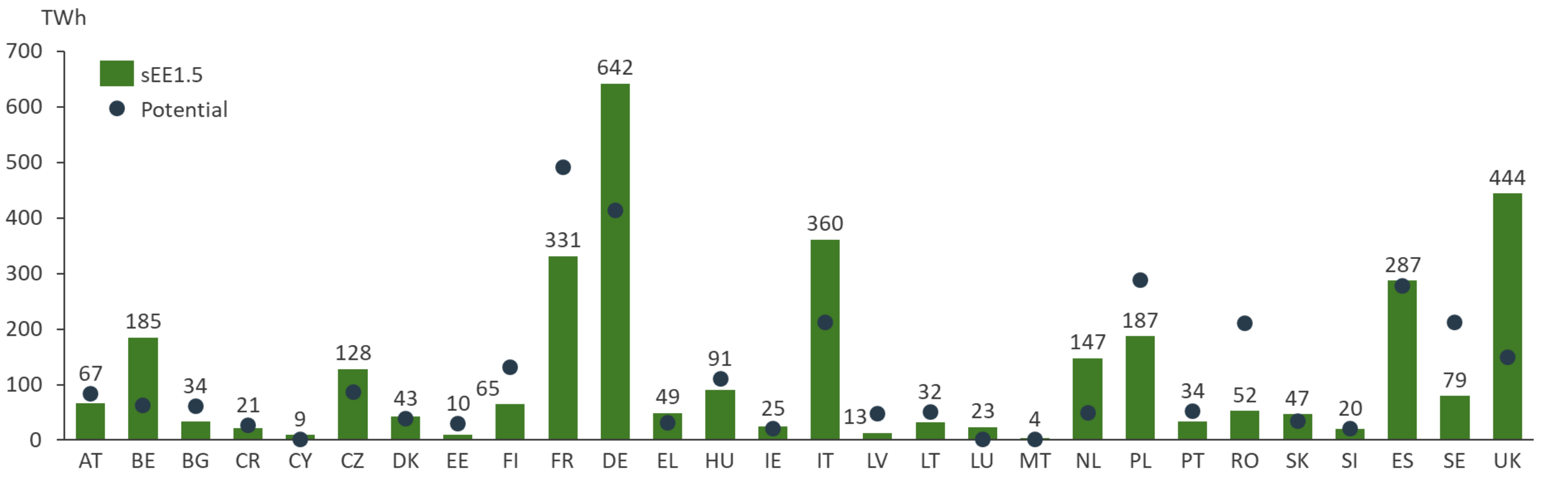


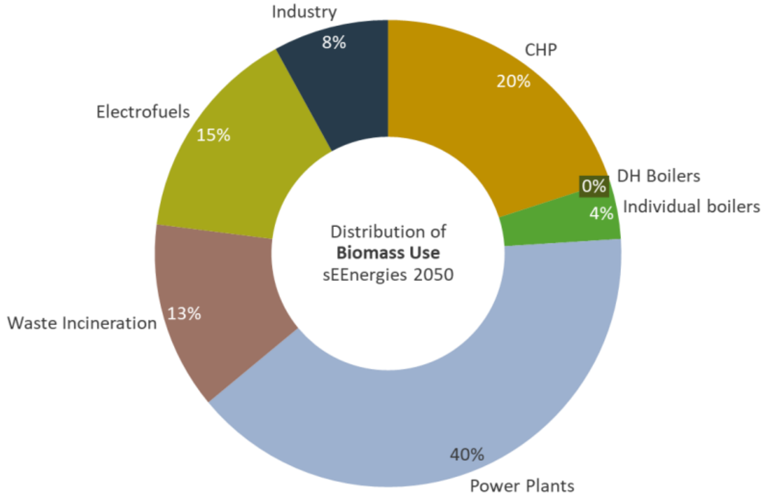
Energy Storages

- Energy storage is an important component in sEE1.5.
  - Supplements the extensive electrification and cross-sectorial integration.
- The renewable energy systems are balanced with new types of energy storage and bridging technologies such as district heating, electric vehicles, electrolysis or fuel syntheses.
- Excluding gaseous and liquid fuel storage, thermal storage is the largest energy storage in sEE 2030 and the second largest in sEE 1.5.
  - Thermal storage for district heating systems is required and should be expanded in every country at a larger scale since it can offer that system flexibility that few other storages can offer at this cost level.
- Direct electricity storage in electric vehicle batteries and individual batteries is a small proportion of the total storage capacity.
- Hydrogen storage should be prioritized as well as thermal storage for district heating systems.
  - In the sEE scenarios, hydrogen has the role of bridging the electrolysis and fuel syntheses and does not operate as a long-term storage.
  - This appears to have another role in 1.5 TECH, where hydrogen is used directly in boilers or industry.

VII. Energy Systems – Results

Bioenergy Demand and Potential

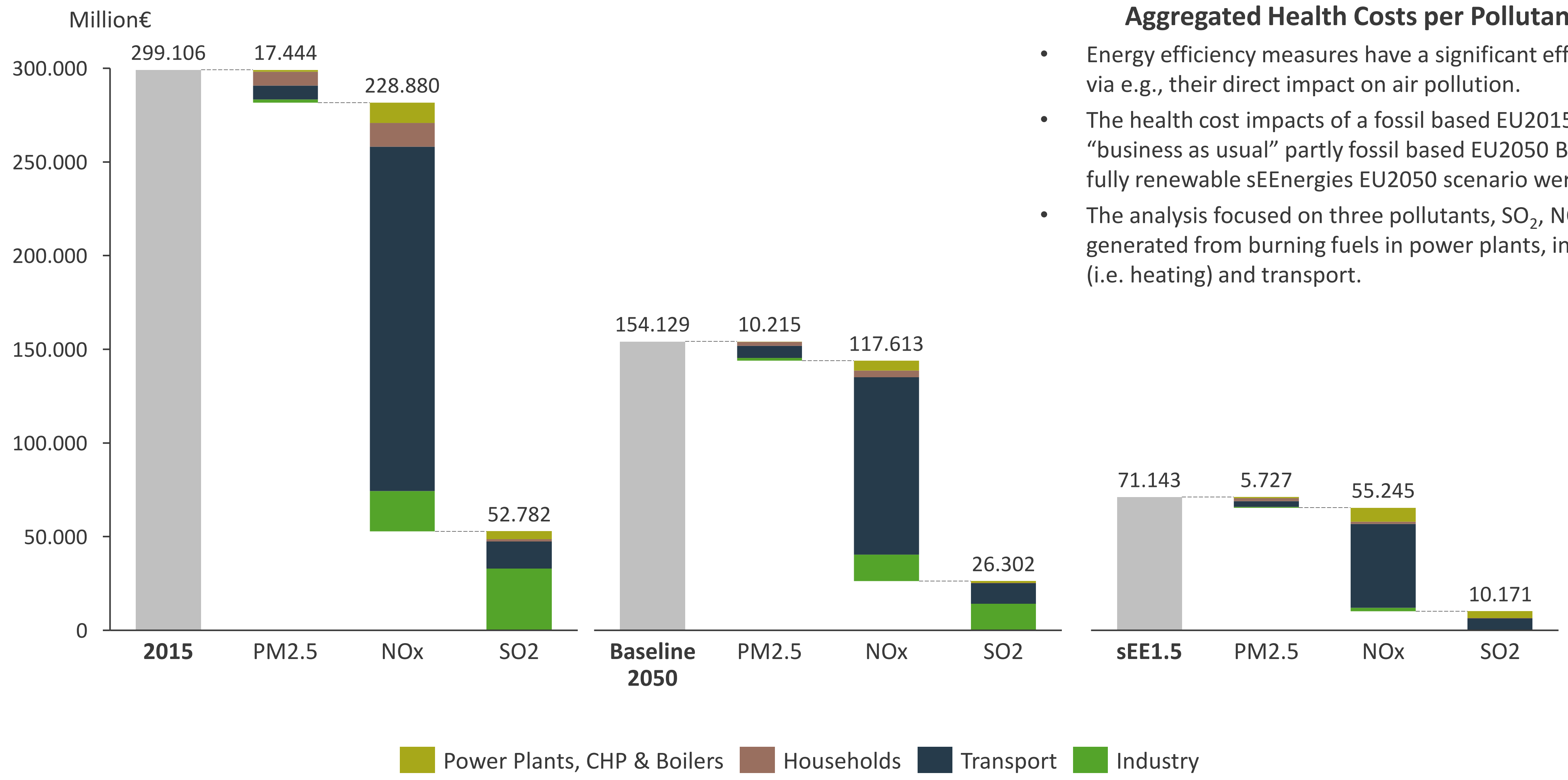




- Resource security especially regarding bioenergy is critical.
- In sEE1.5 the biomass consumption is restricted to 3130 TWh per year, which is in line with the reference scenario from the JRC ENSPRESO project (2019) of 3200 TWh (EU27+UK) or 21.8 GJ/capita (based on 2050 population forecast).
- Although the overall bioenergy demand is within sustainable levels, there is an imbalance between bioenergy potential and demand in five major countries – Belgium, Germany, Italy, Netherlands and United Kingdom.
    - This means that bioenergy trade will become more important for the future energy system or countries with abundant bioenergy will develop bioenergy demanding energy sectors.
- Bioenergy is consumed in three main forms, biogas and solid biomass and waste (municipal).
    - Both CHP and power plants consume 60% of bioenergy which is mostly biogas (75%) supplemented with solid biomass.
    - Transport consumes 15% of the bioenergy for electrofuel production however there is also indirect consumption within the electricity for direct electrification.
    - Industry consumes 8% of the bioenergy directly and also indirectly consumes bioenergy via electrification.

VII. Energy Systems – Results

Non-Energy Impacts – Impact of Air Pollution on Health Costs



Aggregated Health Costs per Pollutant and Sector

- Energy efficiency measures have a significant effect on human health via e.g., their direct impact on air pollution.
- The health cost impacts of a fossil based EU2015 energy system, a "business as usual" partly fossil based EU2050 Baseline scenario, and a fully renewable sEEnergies EU2050 scenario were compared.
- The analysis focused on three pollutants, SO_2, NO_x and $PM_{2.5}$, that are generated from burning fuels in power plants, industries, households (i.e. heating) and transport.

VII. Energy Systems – Results

Policy Gap Analysis

EU Policies, Directives, Regulations, Strategies Reviewed

- Energy System
  - REPowerEU
  - European Green Deal
    - Energy System Integration Strategy
    - Offshore Renewable Energy Strategy
    - Hydrogen Strategy
  - Energy Efficiency Directive
  - Renewable Energy Directive
  - Energy Union Strategy
  - National Energy and Climate Plans
  - Trans-European Networks in Energy
- Buildings
  - Energy Efficiency Directive
  - European Green Deal
    - Renovation Wave Strategy
  - Energy Performance of Buildings Directive
  - Eco-Design Directive
  - Energy Labelling Directive
  - Heating and Cooling Strategy
- Transport
  - European Green Deal
    - Sustainable and Smart Mobility Strategy
    - ReFuelEU Aviation Initiative
    - FuelEU Maritime Initiative
  - CO_2 emissions regulations of new vehicles and new heavy-duty vehicles
  - Fuel Quality Directive
  - Renewable Energy Directive
  - Alternative Fuel Infrastructure Regulation
  - Clean and Energy Efficient Road Transport Vehicles
  - Directive on the Interoperability of the Rail System
- Industry
  - European Green Deal
    - Hydrogen Strategy
  - Industrial Emissions Directive
  - Eco-Design and Energy Labelling Directives
  - Heating and Cooling Strategy
  - Fuel Quality Directive
  - EU Emissions Trading Scheme

Policy Recommendations Topics

- Primary and final energy consumption
- Renewable energy generation
- Greenhouse gas emissions
- Natural gas consumption
- Individual heat pumps
- Hydrogen
- Sustainable bioenergy
- District heating
- Energy consumption in buildings
- Renovation rate
- Renewable energy, biofuels and biogas in transport
- Energy efficient urban spatial development and infrastructure development
- Electrification of transport and industry
- Waste heat recovery

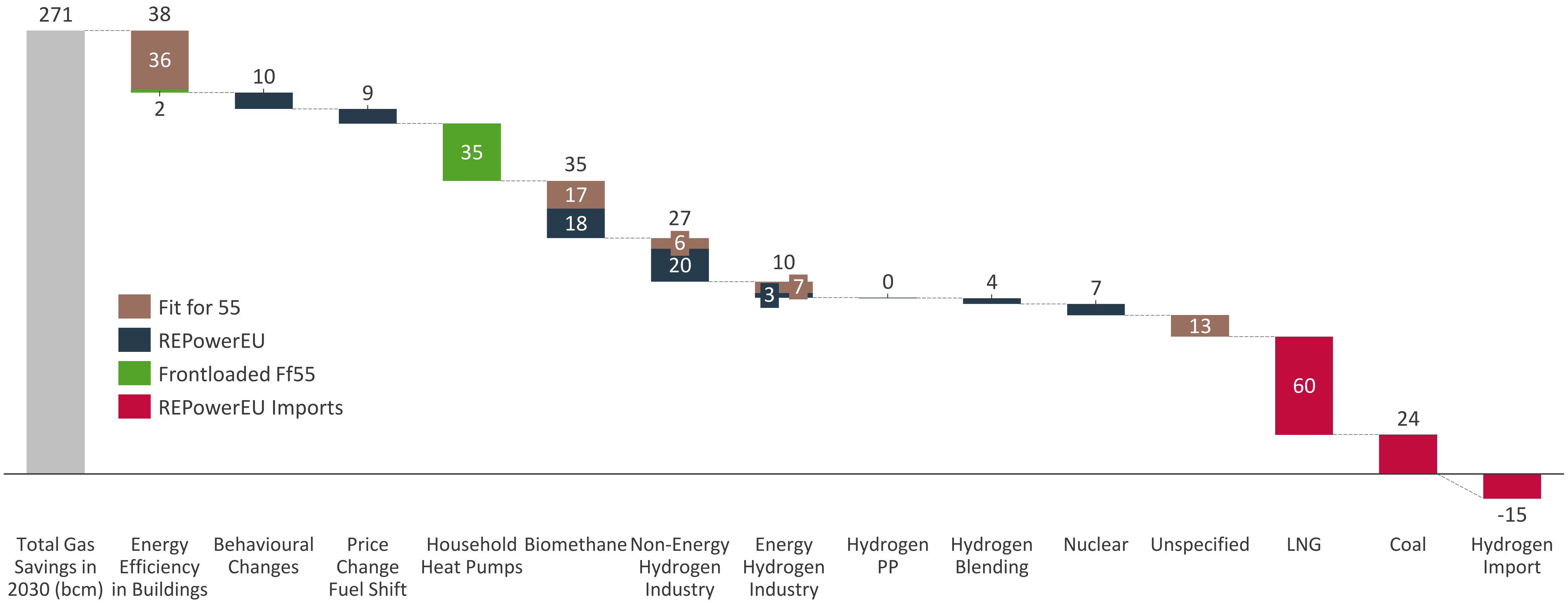
VII. Energy Systems – Results

Policy Gap Analysis – Fit-for-55 and REPowerEU on Europe's Natural Gas Consumption

sEEnergies

Fit-for-55 and REPowerEU

- The role of fossil fuel exports in supporting Russia's aggressions has turned the EU's attention on taking decisive action to cut Europe's dependence on Russian gas.
- Some of the REPowerEU measures proposed by the Commission are to frontload Fit for 55 measures → these savings have been categorically separated ('frontloaded Ff55') to avoid double counting.
- The amount of gas displaced by hydrogen was interpreted from the data available in Table 8 in SWD(2022) 230 that shows the hydrogen use by sector in 2030, of which 15 bcm of gas savings are achieved through imported hydrogen, which is highlighted in the chart.

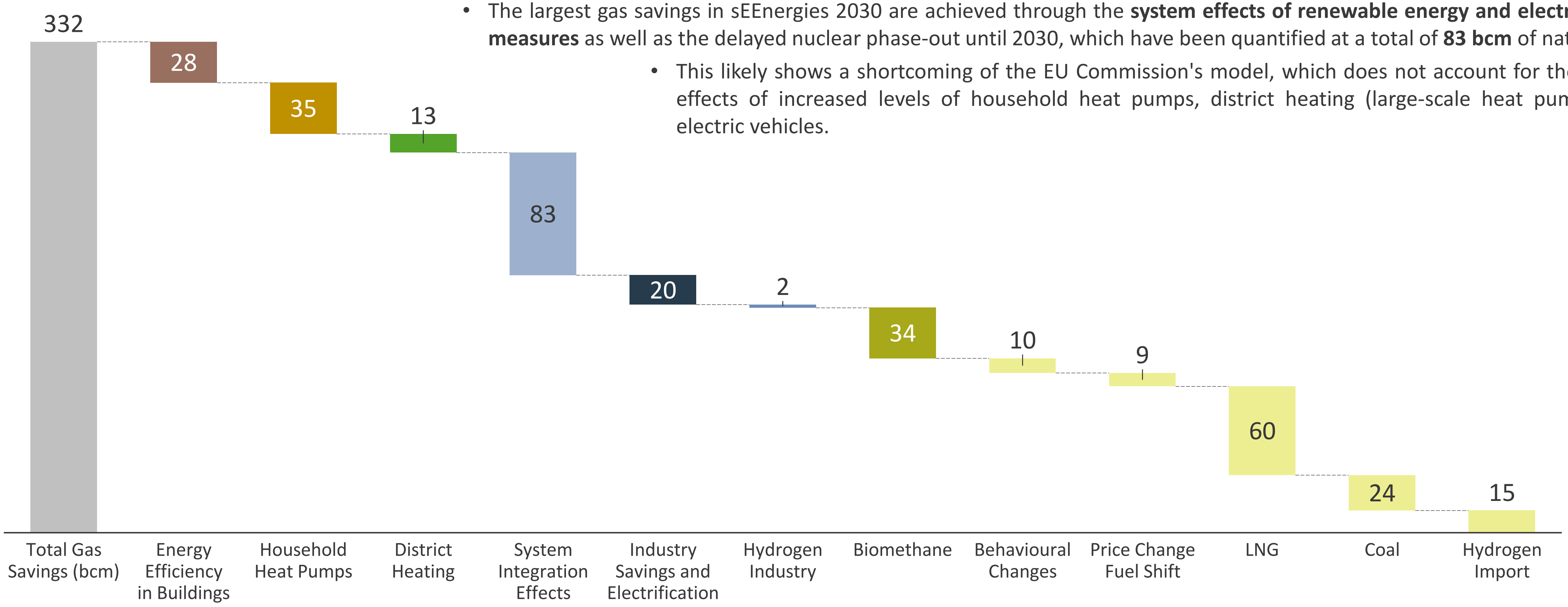


VII. Energy Systems – Results

Policy Gap Analysis – sEEnergies 2030 on Europe's Natural Gas Consumption

sEEnergies 2030 vs. Ff55 and REPowerEU

- sEEnergies 2030 **shows 14 – 22% greater potential gas savings** compared to the total savings set out by Fit-for-55 and REPowerEU measures. To show the full potential for gas savings beyond the energy efficiency and renewable energy measures achieved by sEEnergies 2030, the natural gas savings achieved through fuel shift measures (60 bcm LNG, 24 bcm coal) as well as behavioural (10 bcm) and price changes (9 bcm) are added to the sEEnergies 2030 savings, which comes to **a total of 332 bcm of gas that can be saved in 2030, 22% greater than the saving potential set out by the European Commission's Fit for 55 and REPowerEU measures.**
  - Compared to sEEnergies, the Commission places much greater, and likely overly optimistic, emphasis on hydrogen, which they estimate to displace a total of 27 bcm of natural gas (with 8 Mt of hydrogen).
  - The largest gas savings in sEEnergies 2030 are achieved through the **system effects of renewable energy and electrification measures** as well as the delayed nuclear phase-out until 2030, which have been quantified at a total of **83 bcm** of natural gas.
    - This likely shows a shortcoming of the EU Commission's model, which does not account for the system effects of increased levels of household heat pumps, district heating (large-scale heat pumps) and electric vehicles.



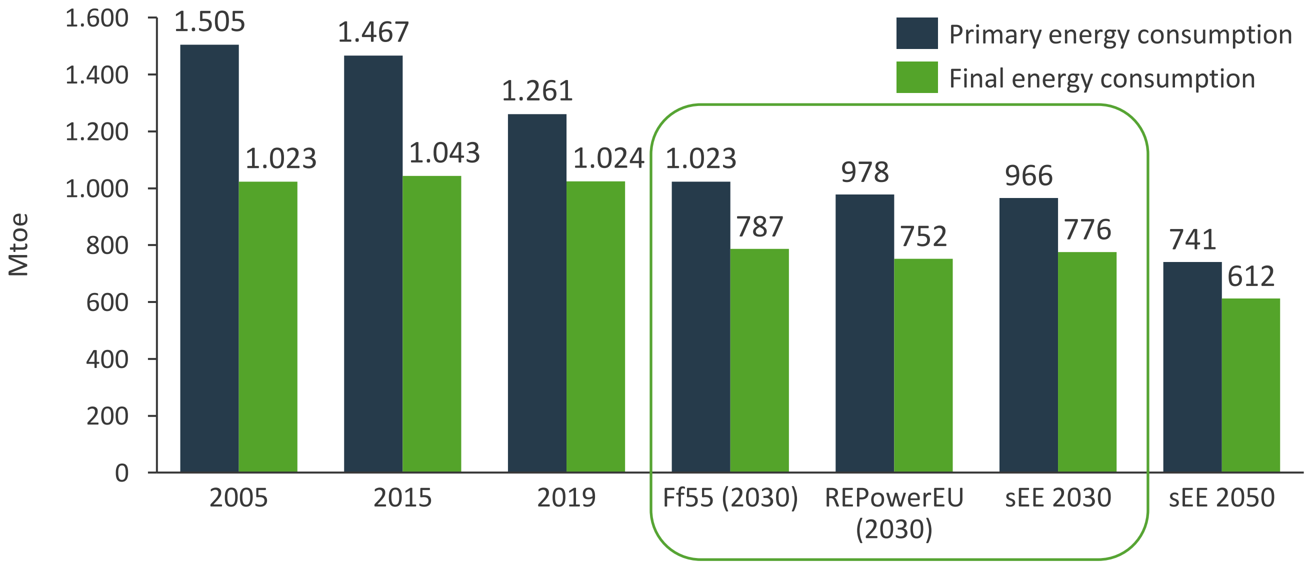
VII. Energy Systems – Results

Policy Gap Analysis – Energy System

Overall, EU policies have an explicit focus on energy demands and not enough emphasis on energy system redesign and conversion. In addition to the specific recommendations listed above, a systemic approach to sector integration is suggested in order to avoid suboptimal system design.

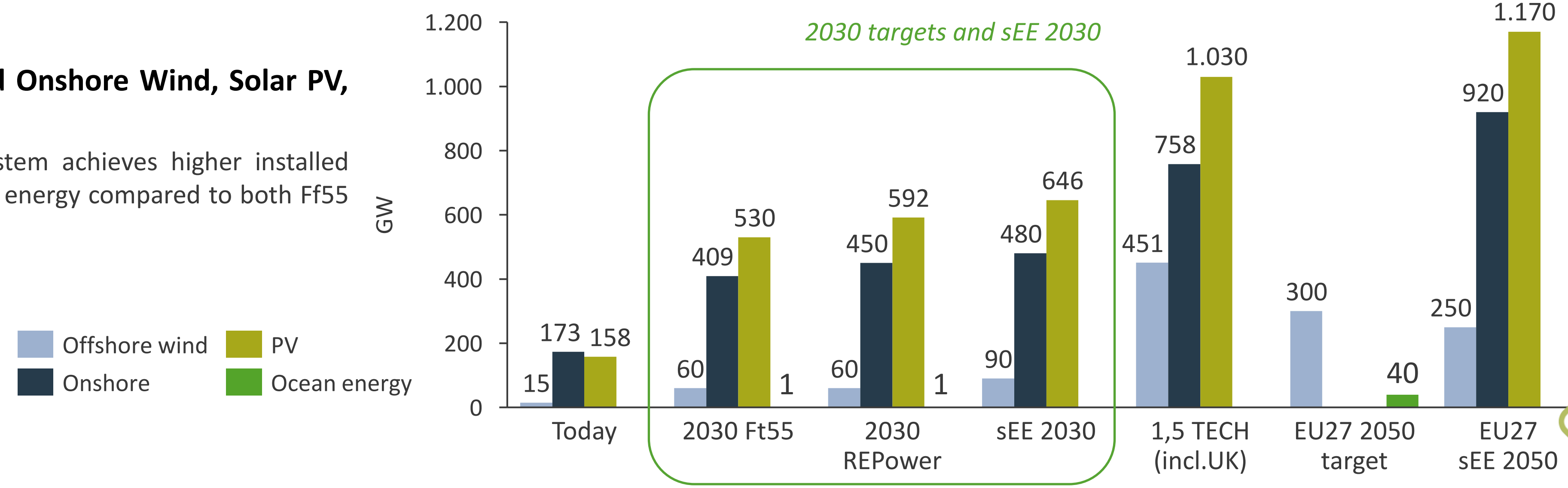
Primary and Final Energy Consumption

- sEEnergies re-design provides a more efficient 2030 and 2050 energy system.
- More emphasis on efficient supply systems for heating such as district heating compared to sole focus on very ambitious targets for end demand reductions in existing buildings and more focus on targeted policies to electrify transport and industry.



Renewables: Offshore and Onshore Wind, Solar PV, and Ocean Energy

- sEEnergies 2030 energy system achieves higher installed capacities of wind and solar energy compared to both Ff55 and REPowerEU measures.



VII. Energy Systems – Results

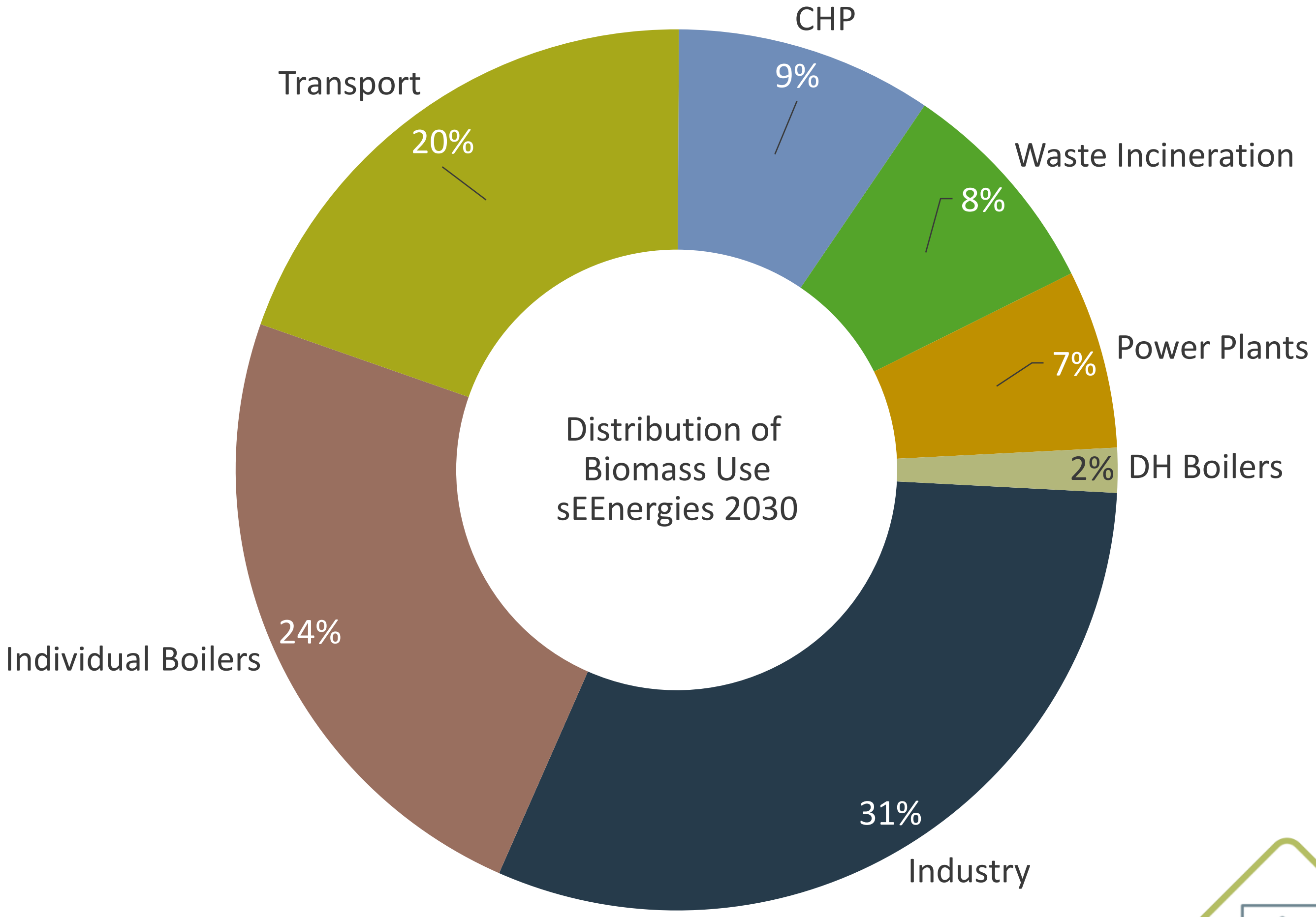
Policy Gap Analysis – Energy System

Hydrogen

- Strongly suggest energy efficiency improvements and extensive electrification over the replacement of one gaseous fuel with another.
- Avoid additional hydrogen production and all new direct and indirect gas consumption.
- A target of 5 Mt of hydrogen in 2030 is considered sufficient, the heightened ambitions of REPowerEU are not recommended.
- Hydrogen for heating buildings is not recommended, instead emphasis should be placed on district heating and heat pumps.

Sustainable Bioenergy

- Current target on sustainable biomethane production, as set by the REPowerEU plan of 35 bcm, by 2030 is considered appropriate.
- Measures should limit the use of biomass to the extent possible, given long-term concerns related to resource scarcity and land use.
- Measures should emphasise the development and roll-out of Power-to-X technologies and electrification, as well as the replacement of coal in industry with biomass.



VII. Energy Systems – Results

Policy Suggestions – Energy System

Energy Efficiency and Renewables

- Overall, EU policies have an explicit focus on energy demands and not enough emphasis on **energy system re-design** and conversion. In addition to the specific recommendations listed above, a systemic approach to **sector integration** is suggested in order to avoid suboptimal system design.
- The overall energy efficiency targets set by the EU's REPowerEU Plan for 2030 are in line with the sEEnergies sEE2030 scenario and subsequently the transition to the sEEnergies sEE1.5 2050 climate neutral system target.
- sEE 2030 achieves a **58% cut in CO_2 emissions from 1990 levels**, which is in line with the heightened ambitions set out by the European Green Deal.
- sEEnergies achieves a more efficient system using less biomass and hydrogen compared to the REPowerEU ambitions and achieves a slightly higher **RE share of 47% in the EU's gross final consumption**, recommending greater levels of fluctuating renewables for 2030 and 2050.
    - 2030 targets: **640 GW of solar PV, 490 GW of onshore wind**, and **95 GW of offshore wind energy.**
    - 2050 targets: **1170 GW of solar PV, 920 GW of onshore wind**, and **250 GW of offshore wind energy**.
- sEEnergies recommends geothermal and solar targets for 2050 **of 0.04 PWh/year geothermal** and **0.03 PWh/year solar thermal energy**.

Hydrogen

- A target of **5 Mt of hydrogen in 2030** is considered sufficient, as set by Fit for 55.
- A target of **50 GW of electrolyser capacity** is considered sufficient for 2030.
- Strongly suggest energy efficiency improvements and **extensive electrification** over the replacement of one gaseous fuel with another.
- Avoid additional hydrogen production and all new direct and indirect gas consumption.

Sustainable Bioenergy

- Current target on **sustainable biomethane production of 35 bcm** by 2030, as set by the REPowerEU plan, is considered appropriate.
- Measures should **limit the use of biomass** to the extent possible, given long-term concerns related to **resource scarcity** and **land use**, with sEE2030 capping **biomass use at 1790 TWh**.
- Measures should emphasise the development and roll-out of **Power-to-X technologies** and **electrification**, as well as the replacement of coal in industry with biomass.

VII. Energy Systems – Results

Policy Suggestions – Buildings

Energy Performance of Buildings Directive

- Better **balance** between **end savings and supply** is recommended, with more realistic and ambitious targets for end consumption.
  - A **reduction in heat demand of 40%** for existing residential and service buildings is needed from 2020 to 2050, which is equivalent to **1.3-1.4% absolute heat reduction per year**.
  - A heightened ambition is suggested for the **RES share in buildings in 2030 of at least 60%**.
- Rather than having a higher target, the directive should focus on **implementation** of existing targets and measures.
- Stronger **monitoring** and **knowledge-sharing** between Member States on **best practices**.
- A move away from the focus on NZEB and on-site renewable energy production toward stronger targets on the **building envelope** is suggested, as the NZEB concept dilutes the demands linked to building envelope improvements.

New Heat Planning Directive

- Focus on **heating as a part of the energy system** and zoning mechanisms for different types of heat supply.
  - Support the systematic identification of spatial potentials for district heating in the Member States to prioritise between district heating and individual heating solutions.
  - A heightened ambition for individual heat pumps, from the current Fit-for-55 package of 30 million units, is recommended to **45 million newly installed individual heat pumps by 2030**.
- Support framework for **district heating** with mandatory demand to have **local ownership** and **governance models** and to use of state-of-the-art technology for EE and DH.

District Heating and Individual Heat Pumps

- A higher ambition to decarbonize the building stock by 2030 is recommended by **increasing district heating from 13% (2019) to 20%** and **increasing heat pumps share from 5% (2019) to 26%**, instead of a sole focus on end demand reductions in existing buildings and individual heat pumps.
- A **financial infrastructure support mechanism** for establishment of new district heating systems is recommended as well as ensuring that access **to low interest rate public loans** if ownership is local and that no profit is taken out of the system.
- Mandatory planning procedures and private economic conditions are recommended that favour long-term investments in EE and DH.
- **Demand assessments** should be **based on socio-economic cost** and a subsidy (national or EU) should be based on **local valuation** (a kind of CBA system).
- The establishment of a **democratic infrastructure** is also suggested that demands full disclosure of financial elements in tariff structure.

VII. Energy Systems – Results

Policy Suggestions – Transport

sEEnergies

Electrification and Emissions

- Measures promoting the **acceleration of electrification**. sEEnergies model finding at least **93 million electric vehicles** necessary on the roads by 2030, an increase by more than 150% than the European Green Deal target of 30 million zero-emission cars.
- Only allow the registration of **zero-emission vehicles** (cars, vans, motorbikes, mopeds, etc.) by 2030.
- Separate targeted policies for **all modes of transport** are recommended, including light-duty vehicles and heavy-duty transport.
    - For example, the Sustainable and Smart Mobility Strategy target on the number of zero-emission vehicles should **cover other forms of transport**, in addition to cars.
- **Financial support mechanism** for the **electrification** of trucks, navigation, and aviation by battery-electric propulsion systems, e-road systems, and charging stations.
- A heightened ambition is suggested for the **RES share in transport in 2030 of at least 24%**.

Alternative Fuels

- Eliminate targets that allow for biofuels, biogas and LNG in transport.
- Clear targets to support **alternative fuel infrastructure** developments, e.g., methanol for trucks and ammonia and methanol for navigation. sEE 2030 gives the possibility to have blend-in demands for aviation and navigation of 10% (measured in terms of the energy content), which is not directly comparable to EU volumetric blend-in demands, nevertheless, sEEnergies targets are higher than EU targets.
- Electrofuels should be prioritized for **aviation** and **navigation**.
- The focus on CO_2 emissions of heavy-duty vehicles should be reduced, since this promotes the use of biofuels and biogas.

Urban Spatial and Infrastructure Development

- Targeted policies to promote **urban densification and efficient demand growth**, whereby Member States are encouraged to develop local planning mechanisms for limiting continued urban sprawl and sharing platforms for energy efficiency urban development knowledge and best practices are established.
- A **Sustainable Transport Infrastructure Directive** is recommended that frames long-term structural changes in transport, primarily energy efficient infrastructures across Europe, supporting rail and e-road system developments (not only charging points).
- Refocus **TEN-E** to stop the support of road infrastructure (motorways), and instead support the development of **local public transport** infrastructure (e.g., metro, tram) as well as **trans-European high-speed rail.**

VII. Energy Systems – Results

Policy Suggestions – Industry

New directive targeting improved EE in industry

- Shift focus from measures that promote the use of hydrogen, toward measures that support the **electrification of industries** by use of large-scale **heat pumps** and **direct electricity use**.
- Hydrogen and bioenergy should be reserved for hard to abate processes.
- Reward the use of **excess heat for district heating**.
- Push **industrial symbiosis**.
- Phase out low efficiency combustion technologies (Eco-design).
- Promote **onsite use of concentrated solar** and **PV** on large roofs, **geothermal heating**.
- Measures **for flexible demand, operation,** and **consumption**.
  - Flexible consumption can be incentivised through **adjusted fuel and electricity cost structures** based on **peak load and connected capacity** in addition to a volumetric measure of energy.

Electrification and Renewables

- A heightened ambition is suggested for the **RES share in industry in 2030 of at least 50%**.
- Clear **electrification** of industry targets are also recommended of at least **38% in 2030** and **65.5% in 2050**.
- EU wide financial support mechanism for **large-scale electrification** of industry targeted at vulnerable sectors.
- Electrification of **low-temperature processes** can be further prioritised as a short-term means of reducing natural gas consumption.

Align socio-economic potentials with business economic payback times

- Set targets that ensure **high costs on greenhouse gas emissions**.
- Set **lower boundary targets** for **levies on combustion** (a levy to promote electricity and halt increased bioenergy use).

VII. Energy Systems – Conclusions

Modelling Energy Systems Synergies and Quantification of EEFP Impacts

sEEnergies

- The impact of energy efficiency measures at sector and system level show similar results but deeper understanding of the supply-side is gained through system analysis. Compared with 1.5TECH, the sEE 2050 energy system has better energy and cost efficiency with similar biomass demands.
- To achieve a 100 % renewable energy system, the following the key recommendations should be considered:
  - In traditional energy systems, fuels represent the highest share of costs. In future renewable smart energy systems, **technology investments** are prioritised over variable costs. Our analysis shows that there is a need for over 5 trillion € investments in EE measures in buildings, transport and industry, out of a total of approximately 9 trillion €. More than 2 trillion € should be dedicated to renewable energy and over 1 trillion € spent on system redesign measures. While investments are higher in energy efficiency compared to supply and system redesign measures, it is important to note that all investments should be initiated and implemented simultaneously.
  - **40% reduction of final energy demand** can be achieved by saving about 2 PWh in both buildings and transport sectors, and 1.5 PWh within industry, out of a total final demand of 13.6 PWh.
  - **Building stock refurbishment** costs represent the largest investment related to energy savings, followed by investments in **the electrification of the transport and industry sectors** as well as in renewable capacities, primarily wind and solar.
  - **Health costs** from air pollution can be reduced to approximately 71 billion EUR/year in sEE 1.5 towards 2050, down from approximately 299 billion EUR/year in 2015 and 154 billion EUR/year in the PRIMES 2050 Baseline.

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VII. Energy Systems – Conclusions

Modelling Energy Systems Synergies and Quantification of EEFP Impacts

sEEnergies

- An investment of 2.2 trillion € is required to reach the final target of **40% heat savings in the building stock by 2050**. Such savings enable synergies with our system redesign as it increases the energy efficiency of the supply system and increases the possibilities to **integrate renewable heat and low-temperature heat sources**.

- One of the system redesign components is **district heating**, which requires an investment of 420 billion €, and can unlock the potential of using cheaper heat sources. About 1 PWh or half of the energy savings achieved in the buildings sector is a result of end demand savings due to building stock refurbishments and the other half is a result of system redesign measures and changes in the heat supply.

- Half of the **heat demand** (47%) is supplied by district heating in 2050, the remaining half is covered by individual heat pumps. Excess heat and low-temperature heat sources such as industrial waste heat, geothermal, solar thermal, large-scale heat pumps and electrolysis, can supply 60% of district heating, while the remaining 40% is produced with CHP, waste incineration and boilers.

- **Individual heat pumps** are an important energy efficiency measure, representing the fourth largest investment of 830 billion € to install more the 100 million units. However, as with unlocking excess heat and low temperature heat in district heating systems, where expansions are in the district heating grids, individual heat pumps also require new infrastructure investments in **electricity grids**.

- The **transport sector** can deliver the same magnitude of energy savings (2 PWh) as the building sector or about a 50% reduction. This requires an energy efficient urban development as well as high levels of electrification and includes energy inefficiency in the use of hydrogen-based fuels for heavy-duty transport in aviation and navigation. This will reduce the primary energy demand for the transport sector in Europe by around 50% compared to the baseline in 2050.

- **Energy-efficient urban development** will reduce the passenger kilometres driven by a car by 16% compared to traditional urban development. In order to achieve this, new investments need to be made predominantly in more efficient modes of transport and such that higher transport demands are not induced in in-efficient modes of transport. This entails a dedicated investment of 784 billion € in predominantly railroad infrastructure as well as e-roads and cycling infrastructure.

VII. Energy Systems – Conclusions

Modelling Energy Systems Synergies and Quantification of EEFP Impacts

sEEnergies

- **Electrification of the transport sector** is done through direct and indirect electrification, where direct electrification wherever possible should be prioritised. 95% of passenger cars and vans are shifted to battery electric vehicles in 2050. In 2030, the number of electric vehicles are estimated to be 95 million and 254 million in 2050. This requires 1.3 trillion €, b eing the second largest investment. Electrification of heavy-duty trucks is prioritised with the implementation of e-road systems.

- The use of **hydrogen and electrofuels** should be reserved only for the difficult to electrify modes such as aviation and shipping. Major investments in electrolysis capacities and hydrogen storage of 327 billion € need to be made to provide hydrogen and e-fuels for transport and industrial demands. An additional 161 billion € are needed for e-fuel production. Almost 456 GW of electrolyser capacity is needed in 2050 to cater to this demand. By 2030, the electrolyser capacities are low, since focus is on implementing energy efficiency measures.

- The implementation of innovative energy efficiency measures and electrification in **industry** enables reductions in final energy by 36% from today to 2050, and which requires 209 billion €. This includes an assumption of increasing production in line with the past trends. Emphasis on EE improvements and electrification are of high importance in order to avoid extensive biomass consumption when pursuing 100% renewable energy.

- Careful considerations must be taken in the implementation levels of **electrification** and **hydrogen-based technologies** paired with **energy efficiency** to minimize the costs and energy losses.

- By 2050 electrification increases to 66% of the total final energy demand up from 25% in 2015. This is largely in the "others" category for lower temperature sub-sectors such as engineering and the food industry. District heat demand in industry falls from 5% to 1.5% of the energy mix from 2015 to 2050.

VII. Energy Systems – Conclusions

Modelling Energy Systems Synergies and Quantification of EEFP Impacts

- It is expected that by 2030 the **electricity demand** will increase by around 32% from 3.051 TWh due to the electrification of transport, industry, and heating in buildings, and 158% by 2050 to 7.860 TWh, as a result of high hydrogen production in Europe.

- Targeted energy efficiency and the **smart energy system**, with **flexible storage** options can enable that the primary energy demands are kept within sustainable biomass levels and limit the GW wind power and PV to the levels described here. With another system design, with no considerations of more energy efficient infrastructure investments in transport and with lower utilisation of best practise in industry, the **renewable energy** need will be higher.

- The smart energy system requires abandoning silo thinking in each sector and to consider energy storages between energy vectors and between the demand and supply. The main three energy storage options are electrofuels (>2.000 TWh), large scale thermal storages (~6 TWh) and storage of electricity in vehicles (~3 TWh) until the end demands are present. Rounds trip losses should be avoided (electricity to battery to electricity) and a flexible storage should be enabled e.g. 40-60% operation time of electrolysers and large scale heat pumps.

- System redesign in high electrification levels requires large investments in establishing **renewable energy capacities**. **Wind power** represents the third largest investment toward 2050 of 1.3 trillion €, which amounts to 1.135 GW onshore capacity and 265 GW offshore capacity. In addition, 521 billion € are required to be invested in **photovoltaics**, amounting to a capacity of 1.400 GW. Investments in **gasification and biogas production** as well as solar thermal and geothermal are also required.

- The **bioenergy consumption** is in line with the reference scenario from the JRC ENSPRESO project (2019) of 3.200 TWh (EU27+UK). Both sEE 2030 and sEE 1.5 are within the sustainable bioenergy levels. Countries with large amounts of bioenergy and renewable electricity could become the main producers of electrofuels for transport due to shortfall in some countries. Furthermore, due to the inefficiency of biofuels, biofuel quotas should be phased out with increased focus on PtX fuels for sectors not able to electrify.

- Redesign of the energy system based on **Energy Efficiency First Principle** allows a phase-out of **nuclear** by 2050. Replacing nuclear at the end of life with renewable electricity gives lower cost. By 2030, nuclear capacities only decrease marginally to support the quick phase out of Russian natural gas.