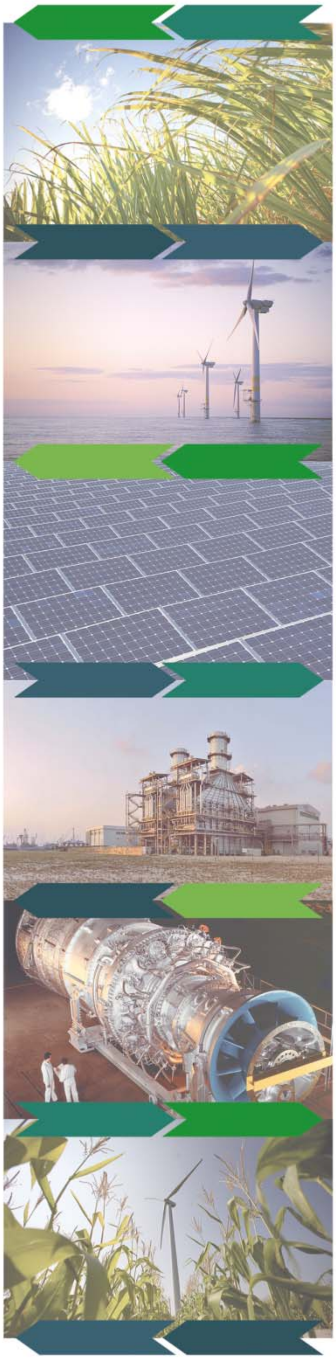
Navigating the Roadmap for Clean, Secure and Efficient Energy Innovation



D9.5 Summary report "SET-Nav – Integrative policy recommendations"

Decarbonising the EU's Energy System

Authors: Pedro Crespo del Granado (NTNU),
Marijke Welisch, Michael Hartner, Gustav Resch (TU Wien),
Sara Lumbreras, Luis Olmos, Andrés Ramos (Universidad Pontificia Comillas),
Frank Sensfuss, Christiane Bernath, Andrea Herbst, Tobias Fleiter, Matthias Rehfeldt, Stephanie Heitel (Fraunhofer ISI),
Charlie Wilson, Yeong-Jae Kim (University of East Anglia)
Arnaud Fougeyrollas, Baptiste Boitier (SEURECO)
Peter Kotek, Borbala Toth (REKK)
Franziska Holz, Dawud Ansari (DIW Berlin)

April 2019 (final version)

A report compiled within the H2020 project SET-Nav
(work package 9, deliverable D9.5)

www.set-nav.eu

Project Coordinator: Technische Universität Wien (TU Wien)

Work Package Coordinator: NTNU

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no. 691843 (SET-Nav).

Project coordinator:

Gustav Resch, Marijke Welisch

Technische Universität Wien (TU Wien), Institute of Energy Systems and Electrical Drives, Energy Economics Group (EEG)

Address: Gusshausstrasse 25/370-3, A-1040 Vienna, Austria

Phone: +43 1 58801 370354
Fax: +43 1 58801 370397
Email: resch@eeg.tuwien.ac.at; welisch@eeg.tuwien.ac.at
Web: www.eeg.tuwien.ac.at

Dissemination leader:

Haris Doukas, Charikleia Karakosta (Project Web)

National Technical University of Athens (NTUA-EPU)

Address: 9, Iroon Polytechniou str., 15780, Zografou, Athens, Greece

Phone: +30 210 7722083
Fax: +30 210 7723550
Email: h_doukas@epu.ntua.gr; chkara@epu.ntua.gr
Web: http://www.epu.ntua.gr

Executive Summary

What next steps and priorities for the SET Plan?

In October 2018, the Intergovernmental Panel on Climate Change (IPCC) published its special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways (IPCC, 2018), putting even stronger urgency on climate and energy policies to address this issue.

As Europe's answer to this, the European Commission (EC) published its long-term strategy "A Clean Planet for all" (EC, 2018a) in November 2018. This strategy presents the EC's long-term vision on how "Europe can lead the way to climate neutrality by investing into realistic technological solutions, empowering citizens, and aligning action in key areas such as industrial policy, finance, or research – while ensuring social fairness for a just transition." (EC, 2018b).

In the SET-Nav project, we conducted our own independent analysis of possible pathways for a deep decarbonisation for Europe until 2050, assessing a broad portfolio of options under distinct framework conditions. Following a large-scale modelling effort, we offer a bandwidth of solutions and provide key insights based on the main modelling perspectives of SET-Nav: demand side, energy supply and infrastructure, and the macroeconomic effects.

In this policy brief, we focus on the **specific energy transition questions** addressed by the SET Nav pathways and on the **implications and recommendations for research and innovation**. In this context, the European Strategic Energy Technology Plan (SET Plan) is a central element in Europe's approach to combat climate change. It has aimed at accelerating the development and deployment of low-carbon technologies for the past decade, seeking to improve new energy technologies and bring down costs by coordinating national research efforts and helping to finance projects. Within SET-Nav we conducted a reflection of the related activities and recommend to strengthen the following key priorities in the SET-Plan:

- Directed innovation efforts within the SET Plan portfolio should be more balanced across the full portfolio of priority areas. Currently the portfolio is weighted towards renewable energy, energy efficiency and sustainable transport. Greater consistency is also needed among the different innovation activities supported by the SET Plan to ensure the innovation system works effectively. Currently sustainable transport-related activities strongly emphasise international knowledge flows but only weakly generate and codify knowledge within the EU; the opposite is the case for energy-efficiency related activities.
- Regarding the different sectors, the main priorities for further research and public support on the demand side are decentralised heat supply and heat pumps. Furthermore, to decarbonise industry, extending the ETS with a minimum price as well as expanding public RD&I (research, development and innovation) funding are important measures. A CO_2 tax as the central element of a broader energy tax reform could provide the incentives needed for fuel switching. Policies to overcome barriers to energy efficiency are also crucial, as is pushing sales of electric vehicles and inducing a modal shift from cars to public transport, car-sharing, cycling and walking.
- In terms of energy infrastructure, electricity network development for integrating new renewables generation is a prerequisite, as is preparing grids for the integration of large volumes of distributed energy resources and for new forms of energy storage. From the supply perspective, our analysis shows that direct electrification should be favoured wherever reasonable as it is more efficient and

leads to fewer requirements on energy infrastructures (e.g., power grid upgrades or conventional generation).

- The final takeaway is that efficient decarbonisation via direct or indirect (e.g. via the transformation and use of hydrogen) electrification requires efficient linkages between the energy markets by monitoring close to real-time carbon content of energy carriers and emissions.

The SET-Nav concept:

Navigating critical uncertainties …

Pathways towards a low-carbon future

The EU Energy Roadmap 2050 (EC, 2011) and various stakeholders' discussions with the European Commission have outlined four main decarbonisation routes for the energy sector. These are Energy Efficiency; Renewable Energy Sources (RES); Nuclear; and Carbon Capture & Storage. More recently, in November 2018, the EC published its long-term vision for a decarbonisation in the European context, outlining how "Europe can lead the way to climate neutrality by investing into realistic technological solutions, empowering citizens, and aligning action in key areas such as industrial policy, finance, or research – while ensuring social fairness for a just transition" (EC, 2018b).

The European Strategic Energy Technology Plan (SET Plan) is another central element in Europe's approach to combat climate change. The SET-Plan has been aiming to accelerate the development and deployment of low-carbon technologies for the past decade, seeking to improve new technologies and bring down costs by coordinating national research efforts and helping to finance projects.

Figure 1: SET-Nav Case Studies linked to SET-Plan Key Actions & Priorities

	SET-Plan Key Actions & Priorities *(below)* covered by **SET-Nav Case Studies** *(right)*	Scenarios of the global fossil fuel markets	Energy demand and supply in buildings and the role for RES market integration	The contribution of innovative technologies to decarbonize industrial process heat	Ways to a cleaner and smarter transport sector	Decentralized vs. centralized development of the electricity sector. Impact on the transmission grid	Projects of Common Interest (PCI) and gas producers pricing strategy	Role for Carbon Capture, Transport and Storage in the Future Energy Mix	Diffusion rate of renewable electricity generation	Unlocking unused flexibility and synergy in electric power and gas supply systems	Perspectives for nuclear power – a closer look at cost developments	Macroeconomic consequences of sustainable energy sector innovation in Nordic countries
No.1 in Renewables	(1) Performant renewable technologies integrated in the system	●	●	●		●	●		●	●		
	(2) Reduce costs of technologies	●	●	●		●			●			●
Smart EU Energy System with consumers at the centre	(3) New technologies & services for consumers		●			●						●
	(4) Resilience & security of energy system		●	●		●	●	●	●	●	●	●
Efficient Energy Systems	(5) New materials & technologies for buildings		●						●			●
	(6) Energy efficiency for industry			●					●	●		●
Sustainable Transport	(7) Competitive in global battery sector (e-mobility)				●				●			●
	(8) Renewable fuels				●							●
	(9) Carbon Capture storage / use			●		●		●		●		
	(10) Nuclear safety										●	

Within SET-Nav we aimed to contribute to the above. With our qualitative and quantitative analyses we tackled all originally defined topics as well as the ten key actions of the revised SET-Plan. Our strategic policy analysis encompassed a dual approach, combining detailed bottom-up 'case studies' linked to SET-

Plan Key Actions & Priorities (cf. Figure 1) with holistic 'transformation pathways'.[1] We then conducted our own independent analysis of pathways for a deep decarbonisation of Europe until 2050. We assessed the *drivers* and *scenario dimensions* that affect the broad set of applicable decarbonisation options under distinct framework conditions.

The findings from our project offer a bandwidth of solutions as well as key insights alongside the SET-Nav main modelling perspectives: demand side, energy supply and infrastructure, and the macroeconomic effects. With this, we intend to provide guidance, navigating through critical uncertainties in the efforts to decarbonise our energy system.

Approach and assumptions

This section outlines our approach and assumptions, followed by our modelling results and policy recommendations in general and specifically also targeted towards research and innovation.

SET-Nav devised four hypothetical pathways to a clean, secure and efficient energy system – taking different routes. These **pathways** are **shaped by two key uncertainties**: the level of **cooperation** (i.e. cooperation versus entrenchment) and the level of **decentralisation** (i.e. decentralisation versus path dependency), cf. Figure 1. The modelling assumptions for these pathways were an 85-95% emissions reduction by 2050; 40% as an intermediate reduction target in 2030 and meeting all reduction goals by 2020. The pathways serve two main purposes: first, to determine **main drivers and critical uncertainties** and second, to highlight outcomes and consequences. The former are *modelling parameters*, the latter are *modelling results*. Drivers are policies or intermediate actions, for example. Outcomes consist of costs, the electricity mix or infrastructure developments, among others.

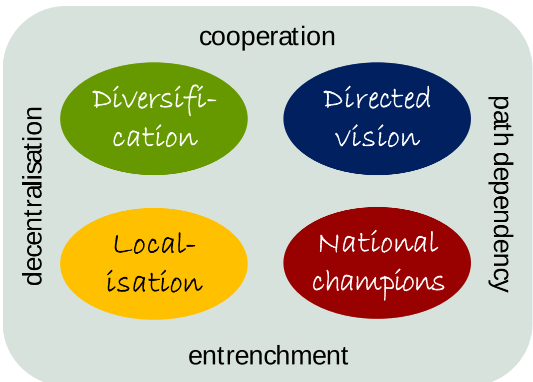


Figure 2: SET-Nav pathway storyline visualisation

The SET-Nav pathways

The **Diversification** pathway depicts a decentralised but cooperative world where many new entrants and heterogeneous actors determine the market. Digitalisation, prosumers and high support for coordination as well as regulatory opening characterise this pathway. The **Directed Vision** pathway goes in a different direction. Although the scenario is still a cooperative one, we see more path dependency and strong EU guidance in determining the shared vision. Large actors are favoured.

The other set of storylines is less cooperative: the **Localisation** pathway focuses on the exploitation of local resources. National strategies differ according to country and public resistance leads to lower investment in big new infrastructure but rather favours the emergence of market niches and digitalisation. Finally, the **National Champions** pathway minimises transition costs which allows a strong role for incumbent firms

[1] At the first stage, eleven bottom-up research 'case studies' were defined in response to critical modelling challenges, in particular model linking requirements. They tackle the full range of SET-Plan themes and subsequently defined key actions. Here a narrow perspective was taken to shed light on a specific topic in focus and to gain further insights in this respect. In the second half of the project comprehensive 'transformation pathways' have been defined and assessed comparatively and comprehensively using the full suite of modelling resources. Detailed characterisation of these pathways have been defined jointly throughout the project, building on lessons learnt from the case studies and an intensive stakeholder dialogue.

and utilities. This transition is highly path dependent and favours large-scale projects. For more details on pathway modelling and analysis, see the SET-Nav Pathways report.

Modelling and analysing SET-Nav pathways

In the following sections, we outline the main findings and insights of the SET-Nav pathways. Addressing the multiple dimensions of energy transition entailed using around 15 different energy system models in the SET-Nav project. This unique and large-scale energy modelling exercise consisted of three main parts: 1) demand perspective, 2) supply and infrastructure assessments, and 3) macroeconomic outlooks. To sum up our analysis in each of these parts, we formulated a common set of research questions and structured the answers, to show which portfolio of measures is necessary to arrive at a low carbon future. Finally, we also examined the role of energy innovation in the SET Plan technology portfolio given future uncertainties.

Policy implications

… a roadmap towards a deep decarbonisation

Policy implications from modelling and analysis of energy ***demand sectors***

How do policies complement each other to achieve the EU's 2030 and 2050 targets?

Buildings: Policies to achieve ambitious CO_2 emission goals would need to target a strong decarbonisation of the building sector of more than 90% until 2050. Support and promotion of thermal efficiency and energy performance of buildings can lead to substantial reductions in consumption, especially space heating demand, which facilitates the deployment of heat pumps and also restricts the increase in biomass use and electricity demand for heating. Lower heat demand in combination with low temperature urban heat distribution systems allows for the **integration of efficient heating technologies**, facilitating the transition to advanced, low-temperature district heating systems and reduces the need for limited biomass resources. To increase the share of connected buildings within district heating areas, information and/or district heating regulatory policies (e.g. zoning) will be needed. In particular, the role of **spatial heating and cooling planning** as an integrative policy approach at the local and regional level needs to be strengthened. Carbon prices on fossil fuels in the heating sector alone are unlikely to provide sufficient incentives to decarbonise the building stock. Further **financial incentives for RES-H/C systems** and renewable support or obligations for renewable heating systems are needed. Very ambitious decarbonisation scenarios in the building sector also go hand in hand with a phase out of fossil fuels including natural gas in the long term. Since the cooling demand is expected to increase significantly, measures to increase the efficiency of cooling systems or the promotion of district cooling gain importance. The affordability of decarbonisation measures, but also of comfortable housing, is a prerequisite to the acceptance and successful implementation of low-carbon policies.

Industry: In industry, the current policy mix needs to be adjusted in order to effectively support RD&I activities directed at the decarbonisation of industrial production. At the current level of certificate prices (EUAs) the ETS is not effective in reducing industrial emissions. Extending the **ETS** with a **minimum price**

path (i.e. a floor price) could provide more long-term clarity and the certainty investors need for low-carbon innovations. In the context of a highly uncertain environment and the needed potential investments, **public RD&I funding** can play an important role in accelerating the market introduction of innovative low-carbon processes. A **CO_2 tax** as the central element of a broader energy tax reform could provide the incentives needed for fuel switching for companies outside the ETS. However, this must avoid any double burden on companies inside the ETS. Boosting **material efficiency and a circular economy** approach along the value chain also requires a broad policy mix (e.g. measures to increase recycling rate, measures to keep CO2 price signals visible along the value chain). In addition, **targeted public procurement** can support the market introduction of low-carbon products by establishing niche markets. Policies to **overcome barriers to energy efficiency** (e.g. energy management schemes, audits, soft loans) are a prerequisite for other (price-based) policies including the provision of RES-based electricity at a competitive price (e.g. compared to biomass).

Transport: In order to decarbonize the transport sector, three main strategies should be combined and supported by policy measures to accelerate the transition: A **modal shift** from trucks and privately-owned cars to the more efficient modes rail, inland waterways, public transport, car and ride sharing, cycling and walking can be achieved by increasing the convenience of these options compared to road transport. This requires investments in the railway, waterway and multimodal freight terminal infrastructure, urban planning measures and the development of common electronic multi-modal information platforms and services to reduce waiting times and to enable seamless electronic ticketing, real-time trip planning and information. The **diffusion of low and zero-emission vehicles** can be pushed by stricter fuel efficiency and CO_2 standards for cars and vans that should be extended also to buses and trucks. These standards put pressure on the automotive industry for shifting their product portfolio to new technologies. In addition, recharging and refueling infrastructure has to be deployed sufficiently and timely to reduce range anxieties. Additional measures should increase the financial attractiveness of new technologies compared to conventional vehicles (e.g. subsidies for electric vehicles in early market phases, vehicle registration taxes steered via bonus-malus systems as well as fuel taxes and road charges related to CO_2 emissions). If low-emission vehicles do not diffuse fast enough regardless of the implemented measures due to soft factors of technology acceptance, phase-out decisions for pure fossil-fuel based cars could be an option to accelerate the transition. The demand for **alternative fuels** will increase to cope with a lack of mature low-emission technologies, in particular for aviation and ships, but also for certain special purpose trucks. Therefore, the production of advanced biofuels should be supported and PtX import solutions should be evaluated. When sustainable supply can be ensured for certain quantities, respective blending quotas of biofuels and PtX fuels should be established.

For each pathway, what are the important elements, drivers and factors of the energy transition and their cost-effective solutions?

	Diversification	Directed Vision	Localisation	National Champions
Buildings	• diverse mix of decentral heat pumps, biomass boilers and solar thermal systems in combination with IT solutions for smart heating, • fossil fuel phase out (natural gas from 2030)	• concerted ambitious thermal renovation and district heating uptake, • decentral renewable heating especially in low heat density areas, • fossil fuel phase out (natural gas from 2030)	• focus on national/local availability of energy sources, • higher diffusion of solar thermal and PV systems, • strong biomass use (as in Diversification and Directed Vision), • also phase-out of fossil fuels	• different strategies per country, settings based on current status, • also assumed that countries with currently high shares of natural gas would not follow phase out and could opt for green gas to avoid decommissioning of gas grids
Industry	• radical changes in industrial processes (e.g. low carbon cement sorts, H2 for direct reduction, H2 as feedstock), • strong fuel switch to power-to-heat, power-to-gas, • increased material efficiency/circular economy	• no radical process improvements take place, as companies invest in CCS for major energy-intensive point sources instead of other radical process improvements, • fuel switch to biomass	• radical changes in industrial processes (e.g. low carbon cement sorts, H2 for direct reduction, H2 as feedstock) • strong fuel switch to power-to-heat, power-to-gas, • increased material efficiency/circular economy	• no radical process improvements take place, as companies invest in CCS for major energy-intensive point sources instead of other radical process improvements and fuel switch to biomass
Transport	• "mobility as a service" system with new business models, shared and increasingly autonomous vehicles for freight and passengers, • range of various technologies and policies adapted across EU countries.	• joint infrastructure and policy decisions across EU countries, • strong electrification of road transport with trolley truck infrastructure, • phase-out of pure fossil-fuel based cars, • biofuels mainly used for non-road modes.	• strong role of car sharing, public transport, walking and cycling for local mobility, • technologies differ between countries. • decentral roof-top PV installation incentivises electric car purchases for households, • biomass as local resource is part of the decarbonisation strategy.	• national development of new technologies and policies, • biofuels adopted on a large scale, also for road transport, • low- and zero-emission technologies diffuse relatively slowly, • low changes in modal split and car ownership.

What are the long-term impacts of alternative mitigation options on the economy, the energy sectors and technology development?

Buildings: The phasing-out of natural gas is one of the main challenges for the decarbonisation of the building sector. This transformation will have significant effects on gas network operators and retailers. Only in scenarios with a high amount of green gas generation would the gas grid structure and business models be sustained. Alternatively, district heating could take over the role of natural gas in densely populated areas. The integration of excess heat, large-scale heat pumps and to a limited extent biomass, deep geothermal and solar thermal energy into district heating networks would substitute imports of natural gas and create a more regional/local heat supply structure than heat supply from fuel oil and natural gas. The pathway analysis shows that the use of heat pumps and solar thermal systems for decentralised heating is a cornerstone of the energy transition in the building sector. Also the use of biomass is crucial in strong decarbonisation scenarios. However it has to be taken into account that biomass potentials are limited and the demand for biomass is also expected to strongly increase in the industry and transport sector. This requires corresponding activities in the building stock regarding the reduction of the energy demand and temperature levels in the heat distribution systems of buildings. The substitution of direct electric heating systems, which are currently widespread in some countries, and the installation of efficient heat pumps combined with heat storage and demand response schemes can substantially reduce electricity demand in scenarios with a high diffusion of electric heat pumps.

Industry: The analysis has shown that for the industry sector todays available technologies are not sufficient for deep decarbonisation. The remaining energy efficiency potentials due to applying BAT (best available technologies) are limited and fuel switching from fossil fuels such as natural gas to renewable sources is often not possible due to the high temperature levels required in industrial furnaces and the competition for biomass with other sectors. In addition, process emissions from chemical reactions within production processes pose a special challenge for the sector as they are difficult or even impossible to mitigate with today's productions processes and products.

Mitigation levels in industry of >80% can only be achieved by either the use of CCS (also for smaller point sources) and/or the implementation of various types of mitigation options including energy-efficient and low-carbon production innovations, renewable-based electricity and hydrogen (also as feedstock for the chemical industry), a comprehensive circular economy and improvements in material efficiency. Although many low-carbon process innovations are currently under development - e.g. low carbon cement sorts using new binders, H_2 or electrolysis based direct reduction in the steel industry, H_2 based feedstock use in the chemical industry - they differ strongly in maturity and distance to market. In order to have new technologies and innovations ready by 2030, substantial research, development and innovation activities need to take place in the coming decade. Pilot and demonstration plants need to be built to prepare for market introduction as it might easily take 10 years for new processes to progress from lab-scale to market. In addition, certification processes such as those needed for new cement sorts can prolong the time taken even more.

Transport: The diffusion of zero-emission vehicles such as battery electric cars, fuel cell electric trucks and hybrid trolley trucks generates increasing electricity demand. By contrast, the consumption of fossil fuels will decrease noticeably over time, while demand for alternative fuels will increase. Europe’s production of vehicles contributes to GDP growth and employment. Both will be influenced by moving to new zero-emission technologies, depending on how the automotive industry manages the transition and ensures competitiveness. If 'Mobility as a Service' solutions prevail, a major shift to more efficient transport modes could lead to declining car ownership rates and, in consequence, a negative development of car sales. Studies on acceptance, economic, social and ecological impacts of substitutions (e.g. land use for the production of biofuels) and secure supply of scarce resources (like rare earths for electromobility) should be considered when narrowing options down to specific technological solutions. In the case of joint approaches across countries, prices for new technologies are expected to decrease faster due to learning effects and economies of scale. As long as the preferred technology mix is not clear, the transition towards zero-emission vehicles should be triggered with technology-independent measures for all road modes.

Policy implications from analyses of ***Supply and Infrastructure*** perspectives

How do policies complement each other to achieve the EU's 2030 and 2050 targets?

The integration of large volumes of RES generation at Transmission level and Distributed Energy Resources (DER) will result in relevant changes to the flows in transmission and distribution grids, potentially leading to the need to undertake relevant upgrades in these grids. Policies to promote the deployment of RES generation should, thus, be complemented with others facilitating the development of the grid infrastructure required to integrate new RES generation developments and DER in general at distribution level. This may also be true for certain storage technologies. Thus, with an appropriate amount of transmission interconnection capacity in place, there may be areas in the European system where large hydro storage capacity could also balance excesses or deficits of electricity in other areas, which may be located far away from these storage sites

The role of carbon capture and storage (CCS) and nuclear is highly dependent on political decisions. Both options have no cost advantage over a decarbonized energy system without them. New nuclear power plants are even more costly than other generation options. Considering current decisions on phase out of coal in important member states and the outcome of our calculations it is very unlikely that the European power sector will be a strong driver for CCS. If EU policy makers want CCS to be part of the electricity generation mix or for reducing industrial emissions, massive further support is needed. First, the R&D to develop the capturing technology and test it in commercial-scale projects would need more financial and regulatory support than in the past. Second, the operations of CCS-power plants will likely require financial support to cover their costs due to their little run time.

For each pathway, what are the important elements, drivers and factors of the energy transition and their cost-effective solutions?

In the Diversification and Directed Vision pathways, significant coordination efforts take place at European level. This might lead to large energy exchanges among areas that may differ substantially from traditional ones. Because of this, significant reinforcements to the electricity transmission grids will be needed.

In the Localisation and National Champions pathways, transmission network development needs are less pronounced. In Localisation, countries rely primarily on local resources to supply their needs. Thus, energy exchanges among European regions are limited. In National Champions, traditional incumbents will be in charge of leading the decarbonisation efforts according to national strategies. Here, conventional technologies may play a key role: nuclear generation will still be in place, while relevant amounts of thermal generation will be used in combination with CCS. This will result in energy exchanges across Europe being limited and similar to the traditional ones, which explains why accommodating these flows does not require building very large amounts of transmission capacity. Given that centralised rather than DER solutions prevail, distribution network development needs should not be great either.

Constructing large new pan-European transmission infrastructure developments, whose number and size would be larger in Diversification and Directed Vision, calls for three main challenges to be addressed: 1) implementing an appropriate institutional framework to govern the development of the cross-border network; 2) allocating the cost of cross-border network investment projects in an efficient way that is perceived as fair by national authorities; and 3) putting in place the appropriate conditions for these projects to attract funds at a reasonable cost.

The further development of distribution networks will be relevant in all the pathways, but these developments should be especially large in those pathways that heavily rely on DER, namely Localisation. In order to achieve the required development of electricity distribution networks, one main need, besides implementing and preserving favourable financing conditions, is to put in place a remuneration scheme for DSOs that takes into account the extra costs that these entities may incur when integrating large amounts of DER, like distributed generation, or new forms of these, like storage. These extra costs not only entail additional network investments, but also the communication infrastructure required to control generation, demand and storage in the DSO grids and allow them to participate in markets, both global (system level) ones and local.

As for the role of CCS, we include it as a technology option at moderate cost in the Directed Vision pathway, as part of the optimisation of electricity supply, and at a higher cost in the National Champions pathway. Our analysis of these pathways shows only a moderate diffusion of CCS, contributing between 8 and 10% of total generation.

In all pathways, renewables play a crucial role in energy supply. The most prominent source in all pathways is wind energy. This prominent role of renewables is a very robust outcome. This result has an important impact on the decarbonisation strategy. In principle, the decarbonised electricity generation can decarbonise other sectors such as heat supply or energy use in the industrial energy supply. The available options are direct use of electricity generation or the utilisation of secondary energy carriers such as hydrogen. Our analysis shows that direct electrification should be favoured wherever reasonable as it is more efficient and leads to fewer requirements on generation infrastructures. The Diversification and Localisation pathways with a very high hydrogen demand end up with a substantial utilisation of the existing renewable generation potential in Europe, which could raise issues of public acceptance. Our analysis shows that the decarbonisation of the energy system via electrification is possible. This will be cheaper if we can strengthen the electricity grid. The Localisation pathway, with a firm restriction on extending electricity grids, shows the highest cost of electricity supply.

What are the long-term impacts of alternative mitigation options on the economy, the energy sectors and technology development?

Not developing transmission networks sufficiently will result in significant increases in the cost of deploying and operating RES generation at European level, since, in this case, electricity generation excesses and deficits within each area would have to be balanced locally. This, among other things, would prevent the deployment of large European RES developments, which could negatively affect the development of the RES generation industry in Europe. In this situation, local generation and storage would have to be deployed on a very large scale, regardless of its cost.

Additionally, if appropriate distribution network infrastructure is not deployed, the motivation of small consumers to increase the efficiency of their energy use and the exploitation of DER in general would be very limited, which would impact the environmental footprint of the energy sector as well as the cost of electricity supply. The development of RES generation technology of a distributed type (like PV) within Europe would be negatively affected. Here, a key takeaway is that efficient decarbonisation via direct or indirect electrification requires efficient linkages between the energy markets reflecting the close to real-time carbon content of energy carriers. In other words, the demand side has to adjust to the short-term nature of the electricity market. This requires flexibility and bivalent generation options in all sectors. A robust example in all pathways is the use of large heat pumps in heat grids with the backing of fuel-based boilers and heat storages as alternative generation options.

Regarding developments in the gas sector, all SET-Nav pathways foresee European natural gas consumption falling greatly by 2050. When considering domestic European production potential, two of the four pathways may result in significantly lower import dependency compared to the current level, due to increased integration of renewable gases. However, the current operation of the gas infrastructure is not sustainable if the consumption and flow patterns are to change. Therefore capacity-based exit tariffs may need to be increased if gas demand keeps falling as suggested by Pathways to allow for the current revenue level of TSOs. We suggest that European PCI support should be directed to electricity infrastructure and energy efficiency, not to create stranded assets. For natural gas to play a role in the long-term future energy supply, its value chain must become (nearly) carbon neutral, e.g., considering negative emissions elsewhere or CCS.

What is the role of innovation in energy transition?

What next steps and priorities for the SET Plan?

The SET Plan comprises portfolios of technologies (the six priority areas) and directed innovation efforts to influence a range of innovation system processes throughout the technology lifecycle from basic research to market deployment. Our analysis of SET Plan activity emphasises the importance of designing, monitoring, and evaluating SET-Plan performance along both these portfolio dimensions. To this end, we developed three normative criteria for tracking progress in the EU's energy research and innovation portfolio: balance, consistency and alignment.

Balance. A balanced SET Plan would place similar relative emphases on different technologies. Our analysis shows that SET Plan activity is currently weighted towards three priority areas: renewable energy, energy efficiency and sustainable transport. Increasing portfolio diversity across the full set of priority areas is an effective means of addressing technology risk and maintaining option value. This is particularly important given the stringency of decarbonisation goals that leave little room for innovation or deployment failure. Portfolio managers could use a range of approaches for redressing imbalance in these areas including: introducing tied conditions to research funding (e.g., on requirements for scientific publication); strengthening basic research with higher propensity to generate influential intellectual property (e.g., through ERC programmes); targeting research funding to support single actor research projects with fewer constraints on intellectual property protection (e.g., through Horizon 2020 programmes); or support for public-private research consortia with higher propensity to engage in open knowledge exchange (e.g., through informal stakeholder networks and formal research frameworks such as the European Industrial Initiatives).

Consistency. A consistent SET Plan would place similar relative emphases on different innovation system processes. This is particularly important for less mature technology fields (like industrial low-carbon process innovations, CCS or sustainable transport) which benefit from a diversity of processes throughout the innovation system and so are more sensitive to inconsistencies. Our analysis shows that SET Plan activity is least consistent in the generation, codification, spillover, and international flows of knowledge in the sustainable transport and energy efficiency areas. SET Plan portfolio managers should be alert to these areas of possible tension or weakness where specific innovation efforts could be strengthened to act in concert, for example by using tied conditions in exchange for RD&I support. This is particularly important given the need for accelerated energy-system transformation in line with the EU's 2030 and 2050 strategic goals. There a range of approaches available for stimulating knowledge codification, flows and spillovers including those suggested above in relation to imbalance, as well as stronger incentives for active stakeholder participation in roadmap development.

Alignment. An aligned SET Plan would place similar relative emphases on late-state innovation processes associated with widespread market deployment in line with the EU's strategic goals, particularly decarbonisation. Our analysis finds evidence of misalignment in the smart grid area for which market activity (resulting from regulated smart metre rollouts) has outpaced innovation system activity, with the converse in evidence in the sustainable transport area for which market activity is still limited. Ensuring the alignment of SET Plan activity with medium- to long-term targets and goals is an essential feature of policy learning and adaptive management, and a basis for tracking and improving on innovation system performance. This is particularly important for the SET Plan to deliver on EU policy goals on innovation and energy-system transformation. Low market share for sustainable transport is the result of relatively slow change at the margins (new vehicle sales) being absorbed into a large stock (all vehicles), reinforcing the importance of strong market-pull incentives in the form of purchase subsidies, differential tax regimes (e.g. feebates to discourage fossil-fuelled vehicles and encourage non-polluting alternatives), and charging or alternative-fuel vehicle charging or refuelling infrastructures (McCollum et al., 2018). Low learning for smart grids is the likely result of regulated smart meter rollout programmes failing to provide dynamic incentives for technology improvement. As with imbalance and inconsistency, these areas of potential misalignment invite redress by SET Plan portfolio managers.

Policies and important elements, drivers and factors of the energy transition

A clear finding from our analysis of energy innovation in the SET-Nav pathways is that a diverse mix of policy instruments can help foster collaboration among innovators in the EU's energy innovation system (measured by multi-country patent co-inventions) and this collaborative activity is positively associated with successful innovation outcomes. Policy diversity implies portfolios of regulatory, market-based, innovation, and strategic instruments in line with SET Plan goals. This is consistent with literature that finds that combinations of consistent and stable policy instruments towards long-term targets are important for innovation (Reichardt & Rogge, 2016).

Policy diversity can also better respond to the needs and niches of heterogeneous actors, should innovation activity become more localised and barriers to entry fall, thereby allowing for easier market access for new entrants (including via digital platforms). This is particularly important in the Diversification and Localisation pathways, which see a decentralisation of innovation activity in the EU, and pose greater coordination challenges for effective actor interaction and knowledge exchange.

An implication for the future SET Plan is therefore to continue emphasising a strong collaborative approach by engaging industry, small and medium-sized enterprises, research institutes, policymakers, and other innovation actors in between-country activities. It is hard to isolate robust effects of future uncertainty in each pathway on energy innovation outcomes due to the complex causal functioning of the innovation system. This means the potential effect of one uncertainty (e.g. the strengthening of RD&I expenditure) may be offset by another uncertainty (e.g. the weakening of policy stability).

The one exception is that in the Diversification and Localisation pathways, the positive and statistically significant relationship between policy diversity and collaborative activity (measured by pan-EU patent co-inventions) signals the importance of policy portfolios tailored to the specific needs of increasingly heterogeneous and localised innovation actors.

...and future destinations

Summary of key findings for the different pathways

We identified a variety of actions to achieve a decarbonised future taking different pathways. The different pathways are based on storylines of different, largely political decisions regarding the future of the European Union. Depending on political realities, different key research questions will come into focus. Below, a few examples show how they might play out.

Diversification	Directed Vision
• innovation research with strong RD&I activity • developing a variety of new technologies • strong use of local renewable resources combined with very high hydrogen demand	• top-down decision-making favours conservative approach with known technologies and processes (e.g. fossil power generation) • more likely to call for ideas on how to expand the grid • cost-efficient use and management of cross-border flows of electricity
Localisation	**National Champions**
• innovative solutions for decentralised energy and the distribution grid • radical changes in industrial processes, strong switch to biomass, power-to-heat, power-to-gas • wide-spread use of local renewable resources combined with very high hydrogen demand	• hard to find cost-efficient decarbonisation solutions for an incumbent energy sector focussed on national solutions • lack of pan-European R&D efforts and, hence, little cost decreases in new technologies • little interconnection with neighbouring countries, so peak load must be covered at higher costs domestically • prominent role for (green) gas solutions • no radical changes in industrial processes and continued use of the internal combustion engine

References

Crespo del Granado et. al. (2019). Comprehensive report "SET-Nav – Comparative assessment and analysis of pathways", SET-Nav project, http://www.set-nav.eu/content/pages/library

European Commission for Energy, 2011. Energy roadmap 2050. https://eur-lex.europa.eu/legal-content/EN/ALL/;ELX_SESSIONID=pXNYJKSFbLwdq5JBWQ9CvYWyJxD9RF4mnS3ctywT2xXmFYhlnlW1!868768807?uri=CELEX:52011DC0885

European Commission, 2017. The strategic energy technology (SET) plan (2017 edition), https://publications.europa.eu/en/publication-detail/-/publication/064a025d-0703-11e8-b8f5-01aa75ed71a1

European Commission, 2018a. A Clean Planet for all - A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy. COM(2018) 773 final.

European Commission, 2018b. Press release: The Commission calls for a climate neutral Europe by 2050, http://europa.eu/rapid/press-release_IP-18-6543_en.htm

Fougeyrollas, Boitier et al. (2019). Work package Report on Macro-economic aspects, documenting work package activities and the methodological approaches and interlinkages for all macro models, SET-Nav project, Deliverable D8.3, http://www.set-nav.eu/content/pages/library

Hartner, Heitel, Herbst et. al. (2019). Summary Report "Energy Systems: Demand Perspective" documenting work package activities and the methodological approaches and interlinkages for all demand models, SET-Nav project, Deliverable D5.8, http://www.set-nav.eu/content/pages/library

International Panel for Climate Change (IPCC), 2018. SPECIAL REPORT: Global Warming of 1.5º, accessible at https://www.ipcc.ch/sr15/

Lumbreras, Olmos, Ramos et al. (2019). Summary Report on Energy Systems: Infrastructure, documenting work package activities and the methodological approaches and interlinkages for all infrastructure models, SET-Nav project, Deliverable D6.7, http://www.set-nav.eu/content/pages/library

McCollum, D. L., Wilson, C., Bevione, M., Carrara, S., Edelenbosch, O. Y., Emmerling, J., ... van Vuuren, D. P. (2018). Interaction of consumer preferences and climate policies in the global transition to low-carbon vehicles. Nature Energy, 3(8), 664–673. https://doi.org/10.1038/s41560-018-0195-z

Reichardt, K., & Rogge, K. (2016). How the policy mix impacts innovation: Findings from company case studies on offshore wind in Germany. Environmental Innovation and Societal Transitions, 18, 62–81. https://doi.org/10.1016/J.EIST.2015.08.001

Sensfuss, Bernath et al. (2019). Summary Report on Energy Systems: Supply Perspective, documenting work package activities and the methodological approaches and interlinkages for all supply models, SET-Nav project, Deliverable D7.8, http://www.set-nav.eu/content/pages/library

Wilson, Kim (2019). Section on SET-Plan pathways assessment report (D9.3), using an innovation systems perspective to interpret modelling analysis SET-Nav project, Deliverable D3.3, http://www.set-nav.eu/content/pages/library

SET-Nav
Strategic Energy Roadmap

Project duration:	April 2016 – March 2019
Funding programme:	European Commission, Innovation and Networks Executive Agency (INEA), Horizon 2020 research and innovation programme, grant agreement no. 691843 (SET-Nav).
Web:	www.set-nav.eu
General contact:	contact@set-nav.eu

About the project

SET-Nav aims to support strategic decision-making in Europe's energy sector, enhancing innovation towards a clean, secure and efficient energy system. Our research will enable the European Commission, national governments and regulators to facilitate the development of optimal technology portfolios by market actors. We will comprehensively address critical uncertainties facing technology developers and investors, and derive appropriate policy and market responses. Our findings will support the further development of the SET-Plan and its implementation by continuous stakeholder engagement.

These contributions of the SET-Nav project rest on three pillars: modelling, policy and pathway analysis, and dissemination. The call for proposals sets out a wide range of objectives and analytical challenges that can only be met by developing a broad and technically advanced modelling portfolio. Advancing this portfolio is our first pillar. The EU's energy, innovation and climate challenges define the direction of a future EU energy system, but the specific technology pathways are policy sensitive and need careful comparative evaluation. This is our second pillar. Ensuring that our research is policy-relevant while meeting the needs of diverse actors with their particular perspectives requires continuous engagement with the stakeholder community. This is our third pillar.

Who are we?

The project is coordinated by Technische Universität Wien (TU Wien) and being implemented by a multinational consortium of European organisations, with partners from Austria, Germany, Norway, Greece, France, Switzerland, the United Kingdom, France, Hungary, Spain and Belgium.

The project partners come from both the research and the industrial sectors. They represent the wide range of expertise necessary for the implementation of the project: policy research, energy technology, systems modelling, and simulation.