WHEN TRUST MATTERS

LITHUANIA ENERGY SYSTEM TRANSFORMATION TO 2050

EPSO-G energy system transformation strategy

REPORT

FOREWORD

Lithuania 2050 is too far away to predict the future and what lies ahead. Along the way, we will face new challenges and new technologies will open up more opportunities. However, Lithuania's ambition to move towards sustainable energy and economic independence, adaptability, flexibility to seize opportunities, openness to strategic partnerships and cross-sectoral integration, which allows for strengthening the capital base and exploiting synergies, will remain a key factor. And people's willingness and expertise are and will remain the fuel for a new energy system.

Renewable energy - Lithuania's strategic focus - allows us to push the accelerator even harder in the inevitable Net-zero race. Often in a race against ourselves, which also gives us a fresh start in the world's energy system and economy which historically have been largely dependent on fossil fuels - oil, coal and natural gas. Inevitably, for countries without these fossil energy resources, the only option is to import the scarce resources. In the past decade, Lithuania was not an exception, with the majority of its energy resources being imported.

The great news is that the world is undergoing changes that are transforming the energy ecosystem. With wind and solar deployment on supply side and electrification on demand, the energy usage mix is changing upside down making electricity the core commodity of the energy mix. Lithuania has high potential for renewable energy. The six-fold increase in solar and two-fold increase in wind capacity over the past few years has enabled domestic generation to meet 40% of the final demand this year so far.
It is therefore crucial for us to continue to increase our domestic electricity generation, especially in view of the trend towards rapid growth in electricity demand.

For countries that do not have what used to be considered conventional - fossil - energy resources in their territories, energy independence is becoming a reality through the use of renewable energies. At the same time, another very important goal is being met: for Europe to become a climate-neutral continent by 2050.

While the Net-zero race has been driven by the urgent need to tackle climate change, it has already become a driver of long-term economic potential. Over the next few decades, we can achieve sustainability targets and even climate-neutral energy systems. The results are energy independence and competitive energy prices for consumers.

Lithuania is already making significant progress towards a sustainable energy future. Solar and wind farms are being developed onshore, preparations are underway for wind farms in the Baltic Sea, and green hydrogen and other strategic energy projects are on the horizon. By 2030, Lithuania is not only expected to produce electricity for domestic needs, but also to become an electricity exporter.

The development of renewable energy opens the door for Lithuania to become a hub for the development of a new generation of industry, where the high demand for green energy for sustainable industry combines to attract investment in new solutions for the production and flexibility of renewable energy sources. A hub for exporting not only energy, but also carbon-free products and e-fuels across Europe.

The Lithuanian Energy Vision presents possible development scenarios to guide the planning and implementation of strategic energy projects, to find opportunities for cooperation, sectoral integration, strategic partnerships, and to create conditions for sustainable growth of the entire ecosystem. This vision will also be an important starting point for reviewing Lithuania's energy independence strategy.

Mindaugas Keizeris

CEO of EPSO-G

EPSOG

About EPSO-G

EPSO-G is a state-owned group of energy transmission and exchange companies. The shareholder rights and obligations of EPSO-G holding are implemented by the Ministry of Energy of the Republic of Lithuania. The group consists of a holding company, the transmission system operators managing the infrastructure of electricity and natural gas transmission, the market operators managing natural gas, biofuels and wood exchanges, as well as the company providing the infrastructure maintenance services.

The EPSO-G goal is to be a transparent, innovative, efficiently managed and future oriented group of companies that ensures safe and secure energy transmission and provides fair energy exchange option to market participants.

CONTENTS

ABBREVIATIONS

BESS	Battery Energy Storage System
CAPEX	Capital Expenditure
CBAM	Cross Border Adjustment Mechanism
CCGT/GT	Combined Cycle Gas Turbine/Gas Turbine
CCUS/CCS	Carbon Capture Use and Storage/ Carbon Capture and Storage
CHP	Combined Heat Powerplant
CO_2	Carbon dioxide
CRM	Capacity Remuneration Mechanism
DE	Distributed Energy scenario
DH	District Heating
DNV ETO	DNV Energy Transition Outlook
DSO	Distribution System Operator
EEZ	Exclusive Economic Zone
EH	Energy Hub
EL	Electricity
ENS	Energy Not Served
EU	European Union
EU ETS	European Emission Trading Scheme
EV	Electric Vehicle
FTE	Full Time Employee
GDP	Gross Domestic Product
GHG	Green-House Gas
H2	Hydrogen
HFO	Heavy Fuel Oil
HP	Heat Pump
HR	Hydrogen for the Region scenario
HV	High Voltage
HVDC	High Voltage Direct Currrent
IC	Interconnector
LCOE	Levelized Cost of Energy

LCOH	Levelized Cost of Hydrogen
LH2	Liquid Hydrogen
LHV	Lower Heating Value
LNG	Liquified Natural Gas
LPG	Liquified Petroleum Gas
LV/MV	Low Voltage/Medium Voltage
M&A	Mergers and Acquisitions
MGO	Marked Gas Oil
MoE	Ministry of Energy
MoEnv	Ministry of Environment
MoT	Ministry of Transport
NCEP	National Climate and Energy Plan
NEIS	National Energy Independence Strategy
NRA	National Regulatory Authority
O&M	Operation and Maintenance
OPEX	Operational Expenditure
P2G	Power to Gas
P2H	Power to Heat
PHP	Pumped Hydro Powerplant
PHS	Pumped Hydro Storage
(Solar) PV	Photo Voltaic
RES	Renewable Energy Sources
RM	Roadmap scenario
SMR	Small Modular nuclear Reactor
TRL	Technology Readiness Level
TSO	Transmission System Operator
V2G	Vehicle to Grid
VLSFO	Very Low Sulphur Fuel Oil
VPP	Virtual Power Plant
vRES	Variable Renewable Energy Sources
WACC	Weighted Average Cost of Capital
ZCP	Zero Carbon Products scenario

1. OUTLOOK 2050

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Lithuania will have an energy system based on **zero-carbon electricity and fuels**. It will have a **secure supply** through own production, adequate network development and operation, and strong connections to the rest of the European and global markets.

Affordability of supply for consumers and **economic viability** of investments for investors, owners and operators will be ensured through the organic growth of supply and demand, and will be monitored closely and controlled through adequate market design and regulatory framework adaptations when needed.

This outlook, and the development roadmap towards 2050, are based on the results of analyses of four different scenarios and their performance against Lithuania's strategic objectives.

Lithuanian final energetic and non-energetic energy demand is expected to reach 75 TWh per year in 2050 with almost half of it being covered by electricity[1].

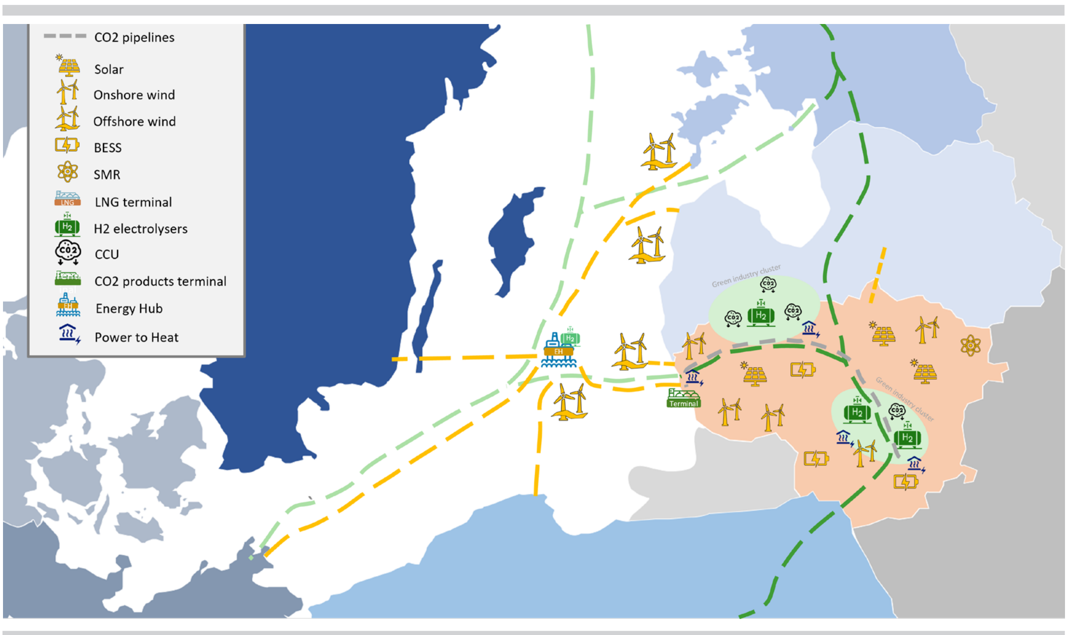
Another dominant energy carrier is hydrogen which will serve three primary purposes:

1) feedstock for fertiliser, chemical and synthetic fuel industries
2) heat production for industry
3) transportation fuel

The remaining energy carriers will include biomass (including biofuels and waste), methane and oil, the latter two having negligible roles. In terms of sectoral split, the industrial sector will emerge as the largest energy offtaker accounting for more than half of the final energetic and non-energetic demand. Availability of electricity and hydrogen at stable prices will enable significant industry growth lead by e-fuels and carbon-free products production in Lithuania. Other demand sectors, such as households, transport and buildings will be responsible for smaller shares of the final demand mainly due to increased energy efficiency and fuel switching. In this report "methane" and "natural gas" are used interchangeably.

FIGURE 1-1

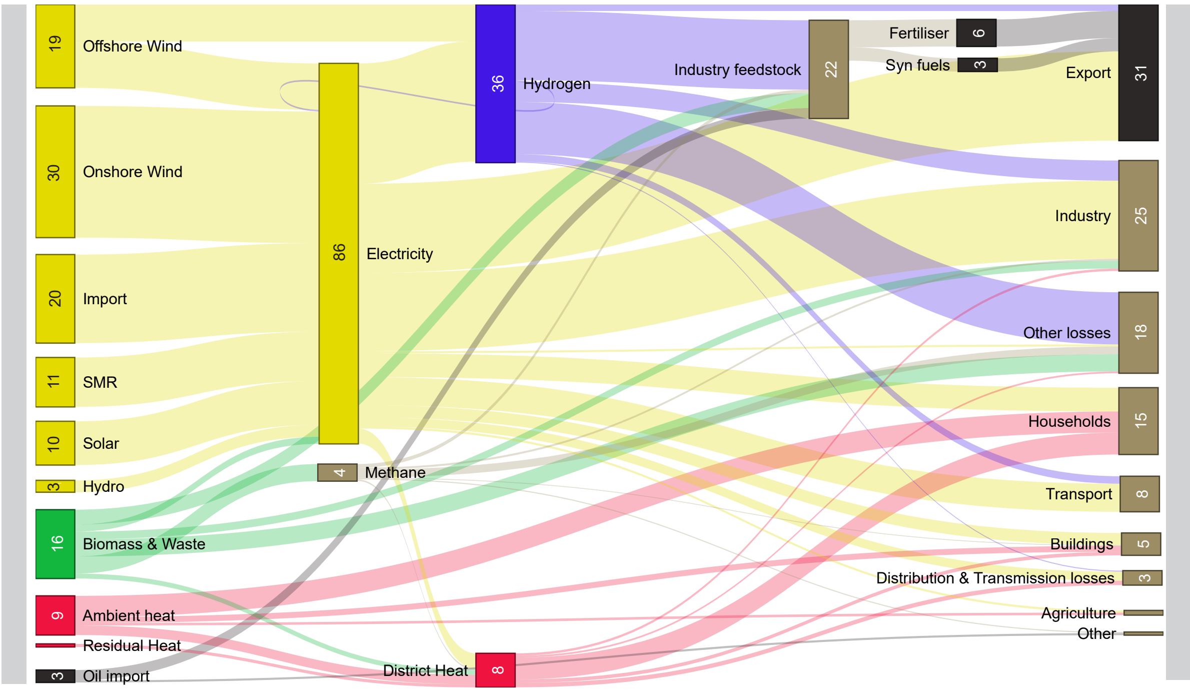
Illustrative map of Lithuania and its energy infrastructure to offshore production assets and neighboring countries by 2050 according to the Roadmap *(Sources: EPSO-G and DNV, 2023)*



[1] Primary energy - energy in the form that it is first accounted for in a statistical energy balance, before any transformation to secondary or tertiary forms of energy. Final demand - the energy delivered to consumers for end consumption (petrol at the pump, electricity in the household, etc.). Energetic final demand – final energy that is used to do work or diffuse heat. Non-energetic final demand – final energy used other than as a source of power or heat, commonly as a feedstock.

FIGURE 1-2

Sankey diagram of final energetic and non-energetic demand (excluding CO_2 and feedstock demand in refineries) in 2050, according to the roadmap *(Source: DNV, based on modelling with the Energy Transition Model (ETM)[2])*



1.1 How to get there?

To give a first high-level view on the key steps and implications of this strategic development of the Lithuanian energy sector, the main building blocks of demand, production, infrastructure, digitalisation, the costs and benefits, innovations, and potential market evolution are described further.

Demand developments

Energy demand will undergo drastic changes between now and 2050. Important trends are the changes in consumption that will move consumers away from the use of fossil fuels to more sustainable alternatives and electricity. Electrification of transport and heat supply are two of the main 'electrification trends' that are driven by falling technology costs, high CO_2 prices, reducing electricity prices, and potentially additional incentives. Furthermore, the (additional) consumption of sustainable ('green') hydrogen and e-fuels will be driven by its availability and affordability (from low-priced electricity in situations with excess generation) and CO_2 from Carbon Capture, Use and Storage (CCUS).

An important development on the consumer-side is the increasing capacity of distributed generation, mainly rooftop solar-PV at households, but also wind turbines and solar parks among traditional business and industrial consumers. These generation resources – if not immediately consumed on-site – are fed back into the power grid, which thereby serves as a source of free storage for these so-called prosumers, under the current net-metering scheme.
The ongoing roll-out of smart meters among Lithuanian consumers and prosumers, will help to facilitate a better integration and system operation, in the face of these increasingly large shares of production coming from former traditional consumers.

[2] Sankey diagram visualisation performed with Acquire Procurement Services tool. http://sankey-diagram-generator.acquireprocure.com/

Generation and fuel production
Currently, Lithuania relies heavily on net imports of natural gas, oil and electricity for its supply. However, the situation will substantially shift by 2050, with a gradual phase out of the use of natural gas in favour of renewable electricity generation, biogas and hydrogen. The intention is to completely stop importing natural gas, requiring a shift to more sustainable and renewable domestically available energy sources.

Net imports of electricity on an annual basis are anticipated to diminish and onshore wind, offshore wind, small modular reactors (SMR), solar power, and dedicated hydrogen-offshore wind plants, are foreseen to provide the majority of the electrical supply. The mix of the electrical supply will continue to include hydro- and bioenergy, including waste combined heat and power (CHP).

Peaks in electricity generation, that will often lead to low hourly market prices, will help to facilitate the production of affordable green hydrogen and e-fuels via electrolysis. Lithuania currently has no installed capability for producing hydrogen. But in the upcoming years, there are significant ambitions to build hydrogen production facilities. According to current outlooks, Lithuania will have 1.3 GW built in power-to-gas hydrogen facilities by 2030. The total installed capacity for producing hydrogen is anticipated to reach 8.5 GW by 2050 with a mix of onshore and offshore assets.

Development of CCUS technology creates opportunities for Lithuania to develop synthetic fuel production even before 2040, depending on the availability of domestic hydrogen surplus. By 2040, as much as 1.5 TWh of synthetic methanol and 0.5 TWh of synthetic kerosene can be produced.
By 2050, these figures are projected to increase to a total synthetic fuel generation of 3 TWh.

TABLE 1-1

Energy demand, generation and production assumptions used for the roadmap 2050 *(Source: DNV)*

KEY PARAMETER	UNIT	ROADMAP
Electricity generation	TWh	74
Onshore wind	GW	10
Offshore wind (radial, energy hub connected)	GW	4.5 (2, 2.5)
Solar (large scale, rooftop)	GW	9 (5, 4)
SMR	GW	1.5
Combined cycle gas turbine (CCGT) or gas turbine (GT) gas / H2	GW	0 / 0.5
BESS	GW	4
H2 Power to Gas (P2G) (grid-connected, energy hub connected)	GW	8.5 (6.5, 2)
Industry size (chemical, fertiliser)	% vs 2022	150%
Interconnectors	GW	5
DH / Heat pump (households)	%	40 / 60
El / H2 in transport	%	80 / 20
CO_2 CCUS	-	Yes

Transmission and supply
Table 1-1 includes inputs regarding infrastructure developments. More specifically on power-to-gas (P2G) production capacity, hydrogen transport infrastructure and additional electricity interconnections (see also Figure 1-1). These infrastructure developments are required, as it stands now, to enable the exchange of power and gasses with regional markets and to optimize the availability and efficient use of zero-carbon energy in Lithuania and the surrounding countries. Given the foreseen high rate of electrification of particularly transport and industry, gas distribution grids are expected to be phased out at some point in the period by 2050.

Besides these major transport infrastructure developments, it will be important to (further) develop the electrical distribution infrastructure, especially to accommodate demand increases from electrification, but also to better enable and deal with the power fed into the grid by prosumers.

Overall, infrastructure developments over the coming three decades need to be 'Hard and Smart':

- 'Hard' because 1) a lot of hardware needs to be added to Lithuania's infrastructure, and 2) because developments need to go rather fast at a large scale
- 'Smart', because 3) 'smart' applications (technologies and software) need to be integrated to enable further digitalization and better monitoring and control of grids, and 4) because the huge investments in infrastructure need to be traded off against alternatives wisely.

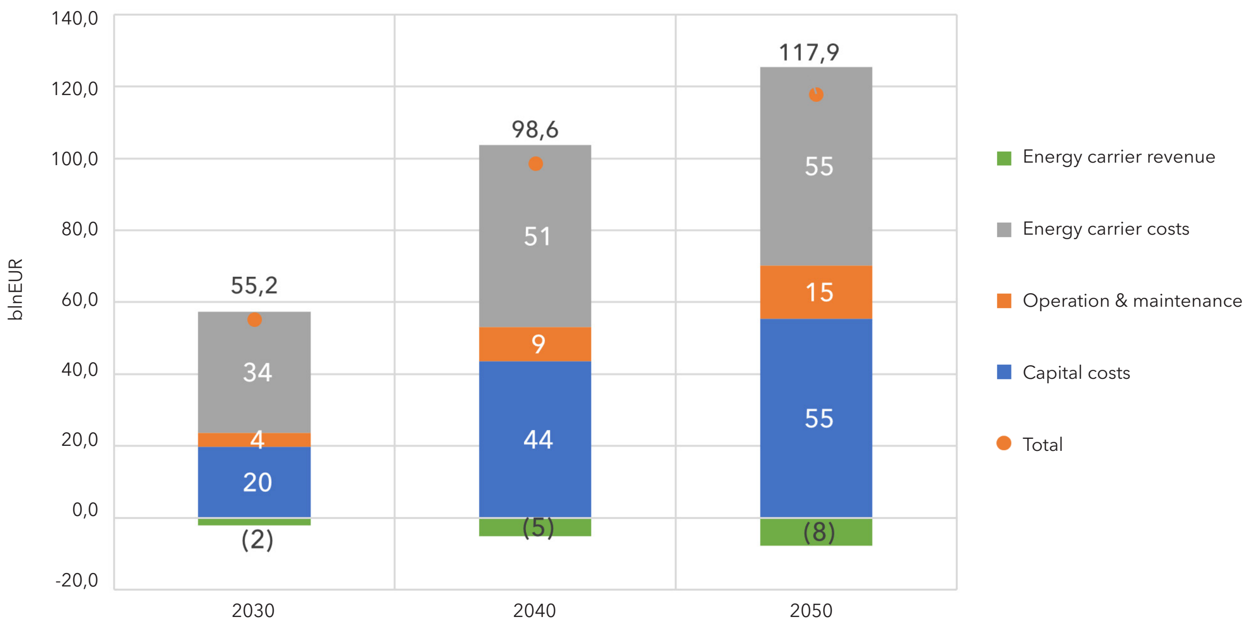
System costs and benefits
Cumulative system costs and benefits over time (energy carrier revenues) are shown in Figure 1-3. The revenues from energy carriers are based on the exported volumes and selling prices. Since the largest share of energy is produced, transported and consumed within Lithuania's borders, the graph predominantly shows costs.*

Figure 1-3 shows that the energy system costs increase is highest from 2030 to 2040, due to high capital costs and still significant energy carrier costs in this period. Annual energy carrier costs significantly decline (shown by minor increase in the net present value from 2040 to 2050), which is typical for net-zero energy systems, and increasing Operation and Maintenance (O&M) costs due to a much larger installed base indicate job creation throughout the energy transition.

Innovations
Development of the Lithuanian energy system and supply until 2050, will (need to) be impacted by innovations and pro-active sector developments on all fronts: technologies (such as P2G, SMR, CCUS, e-fuels, smart meters, electric vehicles (EVs) and smart charging), business models and market participation for all resources (such as prosumer aggregation to unlock and offer more low-cost flexibility, capacity mechanisms to help ensure adequacy, and possible support scheme initiatives for e.g. CCUS and hydrogen value chain developments to provide development support for new industry sectors), and regulations (such as sector coupling facilitation to increase equity base and borrowing capabilities as well as changes to the network charges and electricity tariffs for network operators to ensure economic efficiency, cost recovery and fairness among end customers in the future system).

FIGURE 1-3

Evolution of the net present value of system costs and revenues* accumulated by 2030, 2040 and 2050 *(Source: DNV based on ETM, 2023)*



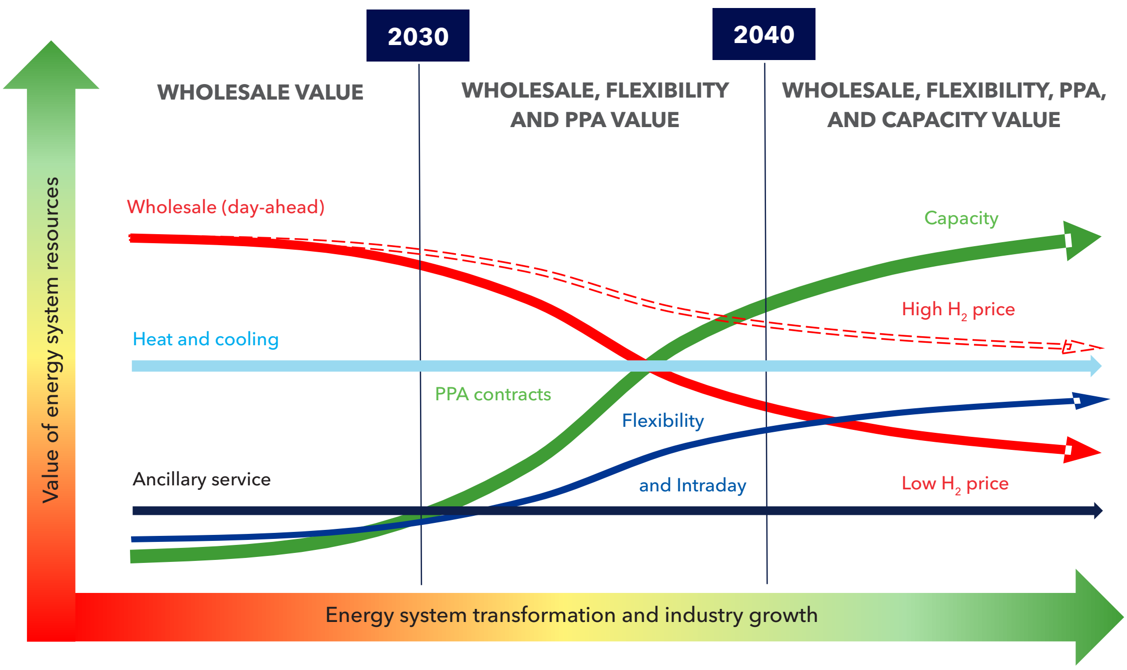
Market and regulatory development
Markets and regulations need to be continuously monitored in line with their role in reaching the strategic goals of the sector, including security of (sustainable) supply, affordability for consumers and viable business cases for investors and market players. An example is the current net-metering scheme for prosumers, which strongly stimulates the development of renewable generation, but, at the same time, results in low regulated income for system operators, which might impede their ability to develop and maintain the grid in line with (long-term) requirements. A second important example is the expected required evolution of electricity markets, moving from largely wholesale trade income to heavier reliance on Power Purchase Agreements (PPAs) and ultimately capacity remunerations, while marginal cost-based pricing for the wholesale market continues.

1.2 Introduction to this report

This document will highlight further details of DNV's approach in the development of this Roadmap for strategic guidance. It sets the Lithuanian context and background and describes the exploration of potential future pathways in various scenarios. This is then translated into the advised Roadmap for development, bringing all the relevant insights together and linking them to the strategic goals for the sector. Ultimately, this is concluded with various sectoral actions to be taken in the next years, to realise strategic development along the lines of the Roadmap.

FIGURE 1-4

Illustrative example of potential market evolution in terms of most relevant revenue streams over time



2. BACKGROUND AND OBJECTIVES

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EPSO-G has commissioned DNV to deliver the energy transformation study, titled "Study on Lithuanian Energy System Transformation to 2050". The results of this study will be used to prepare sectoral strategies, set up business plans for companies in the energy sector, formulate strategic projects, and update the Lithuanian Energy Independence Strategy.

The objective of the study is to draft a strategic development plan for the Lithuanian energy sector by 2050 towards a climate-neutral and self-sufficient energy system, by assessing the required fundamental transformations in the sector with the strategic goal to economically reduce and ultimately eliminate the use of fossil fuels, electrify the economy and industry, facilitate industry growth and position Lithuania as a regional green energy hub.

Before 2022 Lithuania had been covering ~80% of its energy and ~70% of its electricity demand by imports. The 2022 Russian invasion of Ukraine significantly impacted gas and power markets in Europe. Reduced gas flows from Russia in 2021 led to record gas prices that were amplified by events following the invasion in early 2022. EU member states took action to ensure sufficient gas storage levels, and the EU published a communication on security of supply and affordable energy prices. The REPowerEU plan was implemented to address the disruption of global energy markets caused by the war. Measures included the establishment or expansion of Liquified Natural Gas (LNG) import capacities, a renewed rise of power generation using hard coal, increased interest in developing nuclear generation, and strategies for an even more rapid deployment of renewable energy in Europe.

Lithuania and its neighbouring states stopped importing energy from Russia after the invasion, triggering policies to accelerate the deployment of renewable energy sources (RES) across Europe. Looking forward, Lithuania wants to establish itself as a net electricity exporter for the region before 2030, but it may experience challenges in securing low-carbon energy beyond that time frame, unless more ambitious plans on RES deployment and the strengthening of power and gas infrastructure, are adopted.

In 2019, Lithuania published the National Energy and Climate Action Plan (NECP)[3] for the period 2021–2030. The document integrates the provisions, objectives, targets and measures implemented and planned in Lithuanian national legislation, international commitments, strategies and other planning documents. The main strategic documents integrated into the National Plan are the National Energy Independence Strategy (NEIS) adopted in June 2018[4] and the National Strategy for the Climate Change Management Policy[5] adopted in 2012 and updated in 2019, as well as the National Air Pollution Reduction Plan adopted in April 2019[6]. It is now clear that these objectives and targets were developed or derived from other strategies when the geopolitical situation was dramatically different from the one today, that is before the Russian invasion of Ukraine. This study reassesses high-level objectives in relation to security of supply, competitiveness and decarbonisation, including specific targets for renewable energy deployment, district heating and P2G. The outcome must be aligned with the newly expressed ambitions of the Lithuanian Ministry of Energy.

[3] https://energy.ec.europa.eu/system/files/2022-08/lt_final_necp_main_en.pdf Lithuanian NECP (2019)
[4] https://e-seimas.lrs.lt/portal/legalAct/lt/TAD/TAIS.429490/asr
[5] https://e-seimas.lrs.lt/portal/legalAct/lt/TAD/TAIS.437284
[6] https://www.e-tar.lt/portal/lt/legalAct/410fbe3067f511e9917e8e4938a80ccb

In 2023 the Ministry of Energy of Lithuania expressed new strategic-level ambitions with respect to energy system targets and put more emphasis on self-sufficiency and energy independence. The following new strategic objectives are used as the cornerstones of the strategy developed in this study.

STRATEGIC OBJECTIVES FOR THE LITHUANIAN ENERGY SECTOR

ENERGY INDEPENDENCY

Lithuania must become an energy independent and self-sufficient country by 2050; its total domestic production should be at least equal to its total domestic demand

This implies that on an annual basis Lithuania should be energy self-sufficient and potentially be a net energy exporter, although it is recognised that for shorter time intervals, such as hours or days, it is acceptable to import energy when there is a shortage of domestic production. Flexibility resources and interconnections ensure adequacy and flexibility. Annual domestic energy production covers annual domestic energy demand. Electricity self-sufficiency has to be reached by 2030.

100% DECARBONISATION

The Lithuanian energy system has to shift to 100% renewable energy as soon as possible and in a cost-effective way

Lithuanian stakeholders share the view that energy self-sufficiency should be achieved hand-in-hand with net zero in 2050. In order to meet these two objectives, the government plans to significantly ramp up RES electricity generation capacities, and drive decarbonisation of the industry and the transport sector. It is planned that by 2030 more than 93 percent of electricity demand in Lithuania will be produced from wind and solar resources. This is double the target expressed in the NECP of 2019 (45% RES share in electricity).

BECOME AN ENERGY EXPORTER

Lithuania needs to become an energy exporting country for the region

This goal is a further enhancement of the first objective. It is important that self-sufficiency is not seen in isolation from the neighbouring countries. As such, Lithuania has the ambition to remain an open energy system with well-developed cross-border capacities for both electricity and gas. Its geographic position on the edge of Central Europe, which in the future is likely to be a net energy sink, creates economic potential to emerge as a supplier of different energy carriers, ranging from electricity to high-value products such as hydrogen, synthetic methane, ammonia or oil derivatives. Lithuania to be the first mover leveraging strategic location in region and local H2 offtake, deploy RES for low-cost H2 production along Nordic and Baltic corridor and adopt LNG and gas infrastructure for zero-carbon product imports and exports.

PURSUE INDUSTRIAL GROWTH

The Lithuanian energy sector transformation should create opportunities for industrial growth

Stakeholders are considering whether Lithuania should aim at reaching total electricity demand levels of ca. 50 to 90 TWh per year. The objective is to create a business environment that will attract new industries by means of low and stable energy prices. For this to be possible, the industries will have to undergo deep decarbonisation by converting their processes to zero carbon energy sources such as renewable electricity and (green) hydrogen. Lithuania to create a market and business environment that will attract new zero-carbon driven and transforming industries such as fertilizer, refinery production of e-fuels, battery manufacturing, wind and solar services.

ENERGY COSTS & AFFORDABILITY

The transformation of the Lithuanian energy sector should be done in an affordable and cost-effective way and ensure affordability and maximisation of value from export opportunities

Transition to the future energy system needs to be affordable and all stakeholder groups in Lithuania should be protected as much as possible from negative impacts on their business cases or energy expenditures. The objective is to reduce the influence of global commodity markets on energy system costs.

2.1 Scope and methodological approach

This study covers the Lithuanian energy sector value chain from production to end-use, including cross-border exchanges across all major energy carriers. Geographic focus of the study is on the Lithuanian energy system, yet attention is also given to a broader energy context in the region, particularly to neighbouring countries. The study analyses and delivers the strategy for Lithuanian energy system transformation between 2023 and 2050 based on the overview of the current energy system state, strategic objectives for the Lithuanian energy sector, ongoing development and projects, EU and regional context, and analysis of scenarios for the future development.

As a first step of the study, information on the current state and ongoing developments in the Lithuanian energy system is provided, as based on a series of interviews with local stakeholders and a review of available studies for individual sub-sectors (e.g. hydrogen, power distribution, TSO plans, adequacy study, etc).

In the next step of the study, DNV considered a broader perspective and analysed the external context, such as EU energy policies, regional initiatives, and plans of the states bordering the Baltic Sea, and internal drivers such as ongoing projects in Lithuania and their impact on short-, medium- and long-term evolution of the Lithuanian energy sector.

Based on the review of available studies, interviews with stakeholders and analysis of external and internal context, three scenarios for the Lithuanian energy system in 2050 have been formulated by DNV, together with the Ministry of Energy of Lithuania. The 2050 energy scenario framework is designed to reflect the different levels of ambition across the five identified national energy objectives that are described above. To ensure a consistent strategic scenario framework, the study includes hourly energy balance calculations, energy system cost assessments, and electricity price impact analysis.

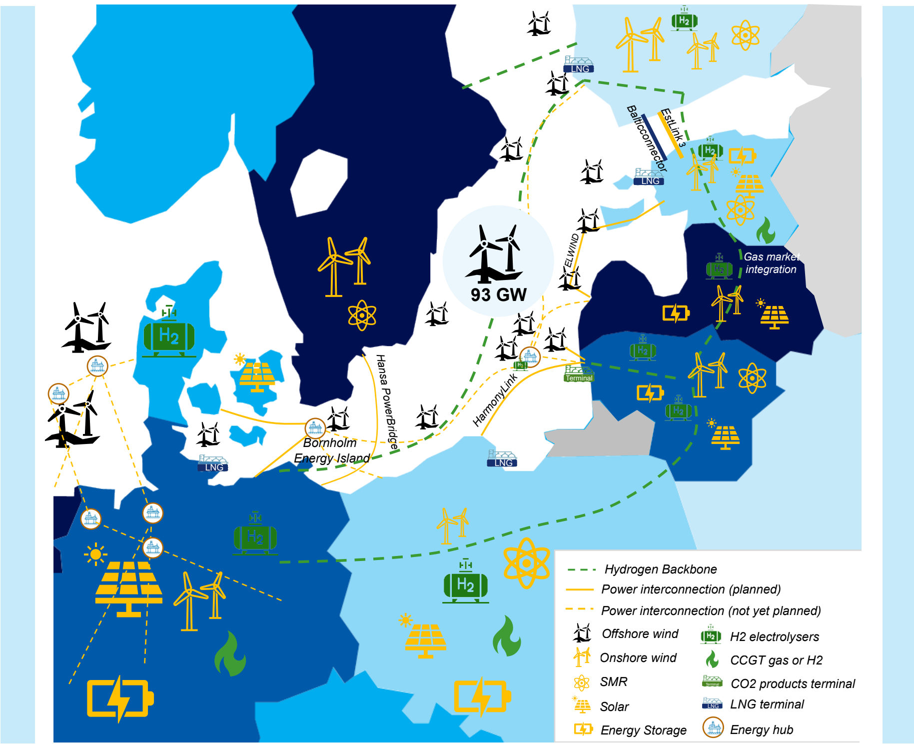
The results of the scenario modelling are used to inform individual sector plans for the generation, transmission, distribution, flexibility and demand side of the Lithuanian energy system. These are then used to deliver a coherent strategy for the whole sector.

This study can therefore be seen as a “lighthouse project” for the reassessment of long-term goals for the Lithuanian energy system, and the strategies required to drive the fundamental transformation changes in the energy system.

2.2 Lithuanian energy system in a broader context

FIGURE 2-1

Schematic regional context between 2025 and 2050 (non-exhaustive)



Response to Russian invasion of Ukraine
As a result of the Russian invasion of Ukraine, the energy landscape in EU changed dramatically, including discontinued imports of energy from Russia, short-term spikes in commodity prices and increased focus on rapid decarbonisaiton, energy efficiency improvements and further integration of EU Member States energy policies to ensure continuous security of supply and energy independence, and to minimise impacts on consumers. In this context, Lithuania is already taking actions in alignment with its EU counterparts. It became clear that energy independence and reduced exposure to global commodity markets should become a priority for the Lithuanian energy strategy. This can be achieved by fostering the dvelopment of domestic renewable energy production, decarbonising its economy and developing new energy value chains, e.g. including for hydrogen and its derivatives.

EU policies
The European Union's decarbonisation strategy started with the Fit for 55 (FF55) target to reduce emissions by 55% below 1990 levels. Following the invasion, the EU adopted the RePowerEU package to make Europe independent of Russian gas by pushing for renewables, hydrogen, and collective gas purchases from alternative producers. The EU Commission also proposed a reform of the Union energy markets targeting wholesale market design, retail market design, and the electricity system to increase resilience, boost renewables, protect consumers, and enhance industrial competitiveness. The EU implemented critical policies such as the Emission Trading System (ETS) and the Carbon Border Adjustment Mechanism (CBAM) to reduce emissions and price carbon emitted in producing imported goods. Emphasis was placed on renewable hydrogen industry. In the context of the above high-level measure, as an EU member state Lithuanian energy transformation strategy should build on the pillars of decarbonisation through RES development, reform of the energy markets, sustainable industry policy development, support to the development of carbo-free domestic industries, especially evolving around hydrogen value chains.

Baltic region developments
Lithuania and its neighbouring states stopped importing energy from Russia after the invasion, triggering policies to accelerate the deployment of renewable energy sources (RES) across Europe. The Baltic Energy Security Summit was held with an aim to strengthen regional cooperation to increase the energy security of the area in the context of the Russian aggression against Ukraine. The outcomes of this summit include the commitment to expand offshore wind power capacity, phase-out of Russian gas through RES, electrification, integration, hydrogen, increasing resilience and energy security, exploring cross-border RES projects, and strengthening cooperation at the political level regarding energy security.

The Nordic-Baltic Hydrogen Corridor is being planned by gas TSOs Gasgrid Finland (Finland), Elering (Estonia), Conexus Baltic Grid (Latvia), Amber Grid (Lithuania), GAZ-SYSTEM (Poland) and ONTRAS (Germany) to transport green hydrogen produced in the Baltic Sea area to meet demand and accelerate renewable energy adoption, supporting the EU target of 10 million tonnes of renewable hydrogen production by 2030.

Lithuania may experience challenges in securing low-carbon energy beyond 2030 unless more ambitious plans on RES deployment and strengthening power and gas transmission infrastructure are adopted. Given the regional dynamics around the Baltic Sea, Lithuanian energy strategy should entail continuous political dialogue and alignment of Lithuania with its peers in the region. Large-scale infrastructure projects can bring more benefits to Lithuania and its neighbours if realised in coordination and taking into account complementarities. Not only hydrogen production but also cross-border hydrogen connections will be key in order to maintain the balance in the Lithuanian energy system.

Especially, when it comes to offshore Lithuanian energy strategy should consider development of domestic offshore wind in tandem with building further electricity interconnections, which advocates for the construction of an integrated energy hub. Given the planned implementation of offshore hydrogen corridor, it would be a strategic move for Lithuania to develop such an energy hub to further integrate its domestic hydrogen sector with large scale network to enable trade and balancing of its own system.

Considering the LNG developments in the region, and apart from the fact that the role of Klaipeda's LNG terminal will most likely decrease as other countries are developing their own facilities, it is likely that with discontinued imports of natural gas from Russia, the terminal will keep having strategic importance for Lithuania and its nearest neighbours. In addition, in the future it may be used for the import and export of e-fuels globally.

Lithuania's role in the region
DNV remarks the importance for Lithuania to factor in its energy strategy the energy development plans and goals of not only their immediate neighbours such as Latvia and Estonia, but also those of countries like Finland, Sweden, Poland and Germany; they will provide opportunities for Lithuania to emerge as an exporter through their electricity, gas and hydrogen needs. Overall, these neighbouring countries' energy sector development targets present opportunities for Lithuania in areas such as transmission and conversion of primary energy carriers, electricity, CO_2 transport and e-fuels. However, Lithuania must also be aware of the implications of the growing energy exchange with neighbours and the need to upgrade its network to integrate the increasing amounts of renewable energy.

Countries in the Nordics have different from Lithuania weather patterns, thus should be considered for potential interconnection increase to help balancing each other's systems. Moreover, the ambitious plans of the Danish and German governments are of great relevance to Lithuania, for instance in relation to the potential future exchange of chemical products as well as transport and storage of CO_2.

The Lithuanian energy system is well interconnected with neighbouring markets, both in terms of electricity interconnection and gas infrastructure. Several countries, such as Denmark, Sweden and the Netherlands are planning to develop domestic hydrogen value chains posing potential competition to Lithuania both in hydrogen and some of its derivatives, including fertilisers (Lithuania-based Achema, the 5th largest fertiliser company in Europe, sells most of its fertilizer products in Europe) and e-fuels.

Further integration of the offshore wind sectors of Lithuania, Latvia and Estonia may support the construction of an offshore energy hub that would aggregate the infrastructure connecting the Nordic and Baltic countries, providing a North-South transmission corridor between the countries. In the long term, in a potential hydrogen corridor from Finland to Germany, Lithuania would potentially offer hydrogen production, demand and transit infrastructure.

3. SECTORAL OUTLOOK TO 2050

3. SECTORAL OUTLOOK TO 2050

3.1 Energy demand and enabling fuels

According to DNVs latest Energy Transition Outlook, Europe's primary energy demand is set to experience a gradual decline towards 2050 (see Figure 3-1). This shift will be fuelled by a notable decrease in the consumption of oil and gas, which are expected to become less dominant sources of energy over time. In contrast, RES, such as wind and solar, are expected to see a significant increase. It is worth noting that biomass (including all types of biogenic fuels, e.g. biofuels, waste, biogas, etc.) energy demand in Europe is expected to remain relatively stable. Although it is not expected to see the same levels of growth as wind and solar, energy produced from biomass will likely continue to play an essential role in Europe's energy mix, particularly in sectors like heating and transportation.

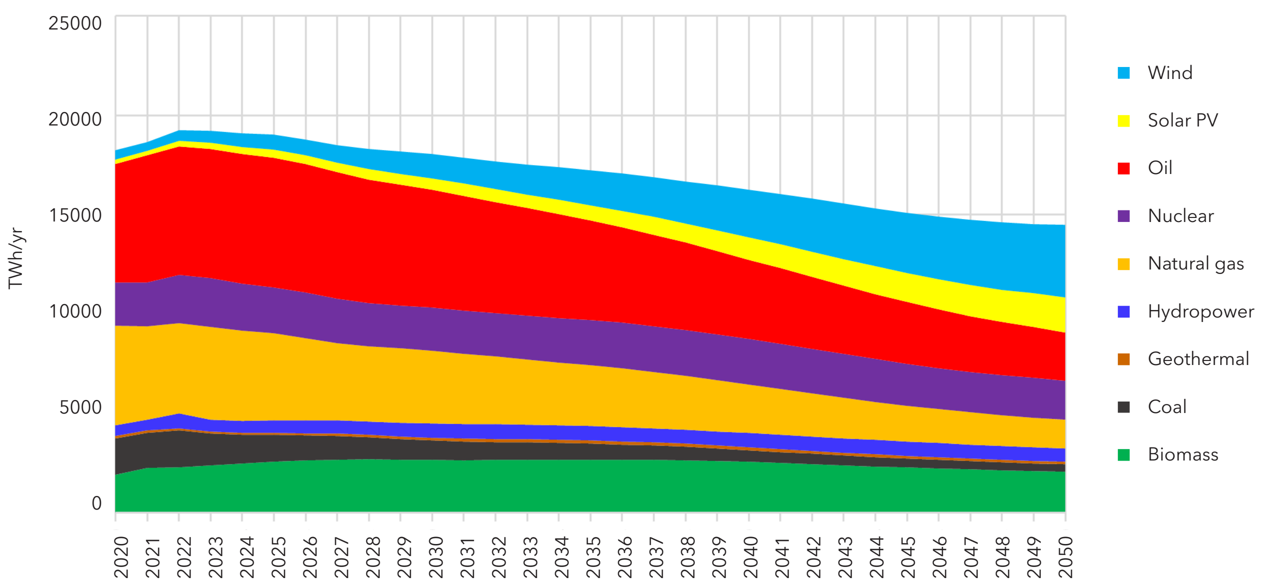
The evolution of Lithuanian energy demand will be subject to market conditions, regulatory regime (changes) and strategic directions indicated by the government.

As can be seen from the commodity prices projected by DNVs Energy Transition Outlook (ETO) (see Figure 3-2), the prices of biomass, waste, and uranium are predicted to stay constant, with some slight decreases, towards 2050. Despite having significant price increases in 2022, the price of natural gas is expected to decrease towards 2025, before stabilizing at around 40 EUR/MWh towards 2050. However, the overall trend is slightly increasing. Coal prices are expected to decline, which can reflect an expected decrease in demand. This is amongst others due to coal becoming a less attractive alternative due to the increasing costs of carbon emissions. Oil products are expected to see the same trend as natural gas and coal, decreasing towards 2030, before stabilising at about 40 EUR/MWh for liquified fuel oil and about 22 EUR/MWh for heavy fuel oil.

Related to these developments, the gap between the Levelised Cost of Energy (LCOE) for fossil fuels and for variable renewables is only going to increase as the transition unfolds, especially when considering the significant increase in CO_2 prices. As a result, the Lithuanian energy generation mix will become dominated by variable RES (vRES), such as solar photo-voltaic (PV) and onshore/offshore wind, towards 2050.

FIGURE 3-1

Primary energy demand forecast for European region per fuel type *(DNV ETO 2022)*[7]



[7] https://www.dnv.com/energy-transition-outlook/

Hydrogen is seen as a carrier that will experience the largest growth in terms of its share in the energy system across Europe in the next decades. Hence, for Lithuanian energy system transformation strategy it is important to consider its potential.

The hydrogen production in Europe will predominantly be sourced by electrolysis towards 2050, with grid connected electrolysis being the most used hydrogen production approach in 2050. Overall, it can also be observed that the hydrogen production will shift from fossil fuel based, via gasification and methane reforming, to renewable based via electrolysis in the future. The production and transport of hydrogen can position Lithuania as a first mover in the Baltic region for deployment of renewable energy and a simultaneous build out of a hydrogen-based energy system, to serve its domestic natural sinks for hydrogen (fertiliser, bio-refinery, synthetic fuels and other smaller industries) and to export to the European or even global markets.

FIGURE 3-2

Commodity price outlook for European region *(DNV)*

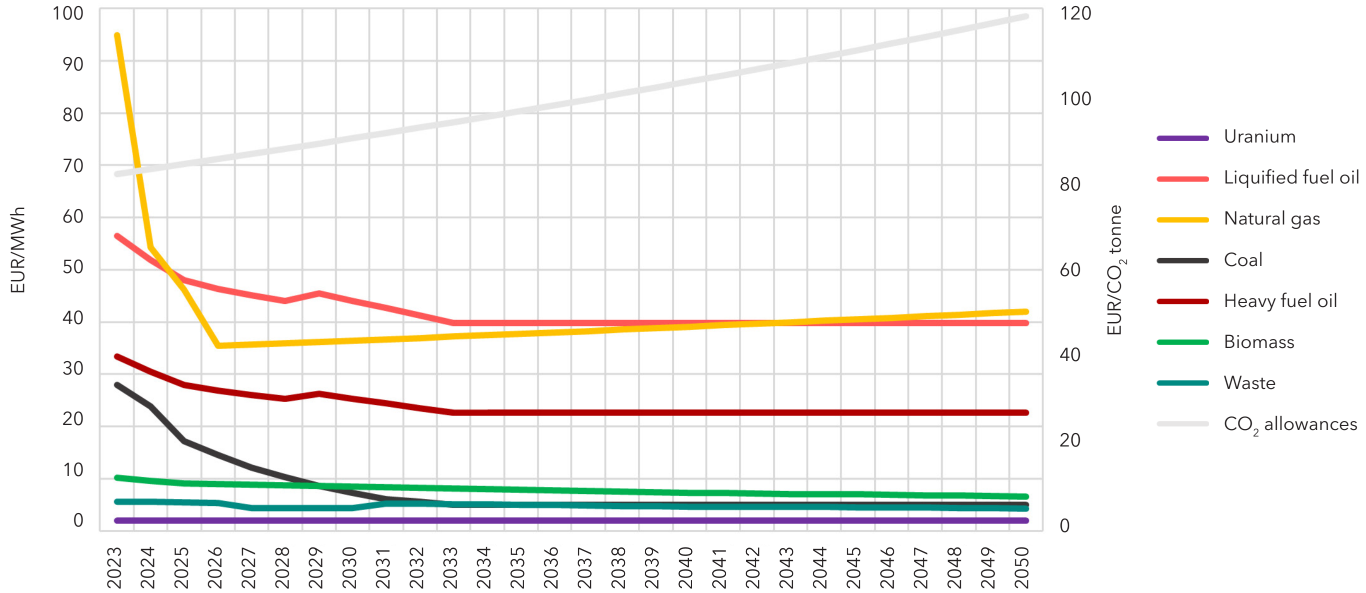
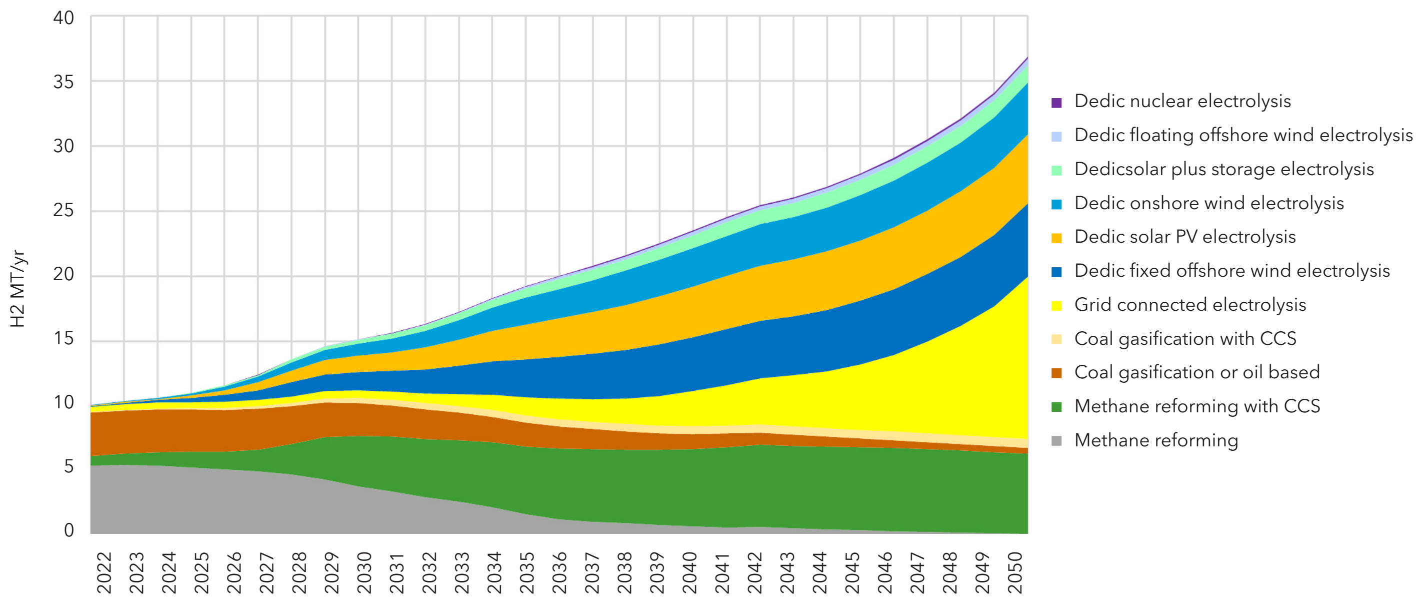


FIGURE 3-3

Europe hydrogen production by source outlook *(DNV outlook)*

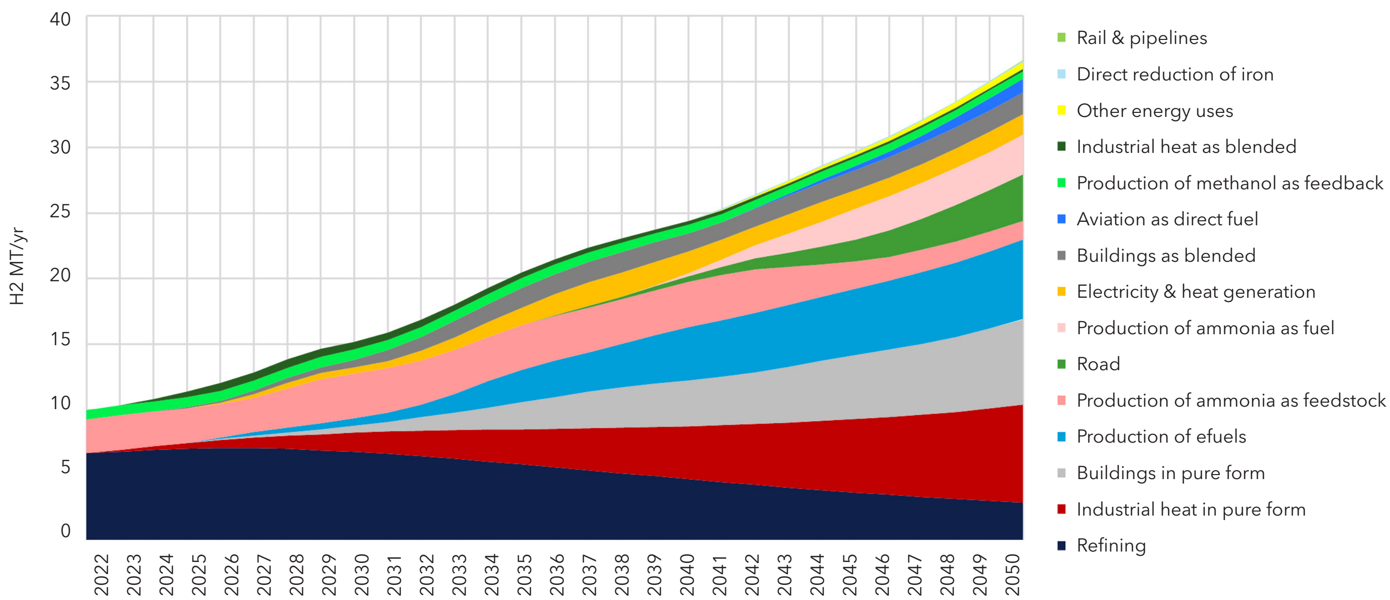


The EU European Hydrogen Strategy provided a clear political signal that hydrogen will play a prominent role in mid- to long-term. There are various aspects that advocate for its uptake also in the Lithuanian energy sector as it transforms towards 2050. The technical opportunities to utilise hydrogen in Europe are abundant, making hydrogen an energy carrier which will serve multiple applications/processes in different sectors (see Figure 3-4).

In the Lithuanian energy system hydrogen is expected to play a role in the production of derivative products as a feedstock, meeting the EU decarbonisation targets as a heat source, and providing backup power during occasional periods of lower RES production.

FIGURE 3-4

European hydrogen demand per application outlook *(DNV)*



3.2 Technology outlook

Figure 3-5 provides an overview of the expected developments of future Levelised Cost of Energy (LCOE) per generation technology in the European region. The LCOE for fossil fuels is approximately 5 to 10 times higher than it is for variable renewables such as offshore wind, onshore wind, and solar PV. Due to the expected significant increase of the CO2 price, DNV projects that this price gap is only going to increase as the transition unfolds.

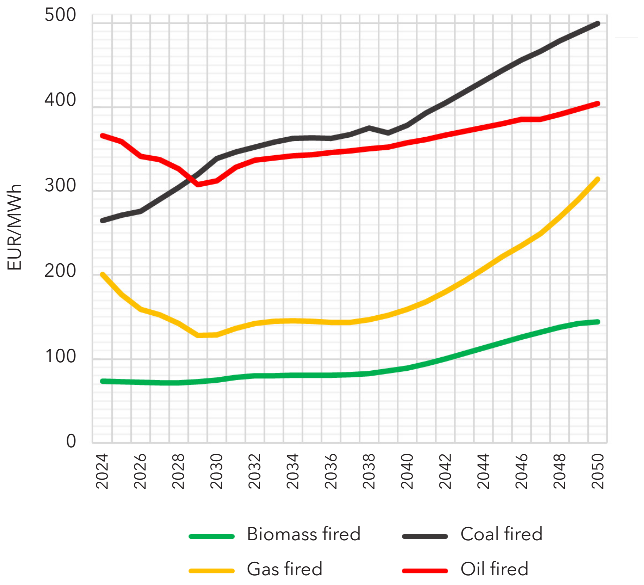
The LCOE for onshore wind is expected to be higher than for offshore bottom fixed wind, as can be seen in the figure below. This is partly due to an average higher capacity factor for offshore wind versus onshore wind and an expected increase in land area shortage. For solar PV, the levelized cost of electricity is below 47 EUR/MWh and is expected to reduce to around 28 EUR/MWh by mid-century, with individual project costs well below 20 EUR/MWh. DNV modelling also shows that fixed offshore wind will likely fall below the LCOE of solar PV, which is the leading renewable technology in terms of cost so far.

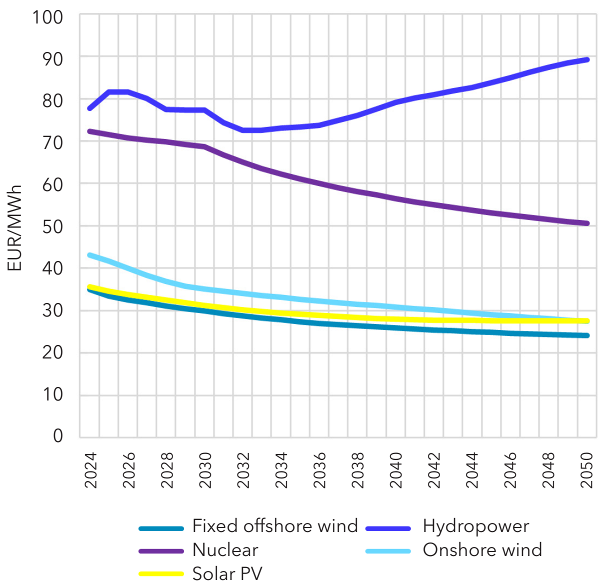
According to the ETO, the LCOE for nuclear energy is expected to decline towards 2050, with lower costs than other dispatchable renewables. Additionally, there is an expected increase in the LCOE of biomass-fired energy production, and it will be higher than other renewable dispatchable energy production sources, mainly due to decreased operational hours. This again relates to the availability of biomass (and waste), which is expected to experience pressure due to competition for resources, such as biofuels and biomethane.

These developments in LCOEs are also reflected in the fact that the capacity of the Lithuanian energy generation mix will become dominated by vRES with low LCOEs, such as solar PV and onshore/offshore wind, towards 2050.

FIGURE 3-5

Generation technologies LCOE forecast for European region *(DNV ETO 2022)*[8]





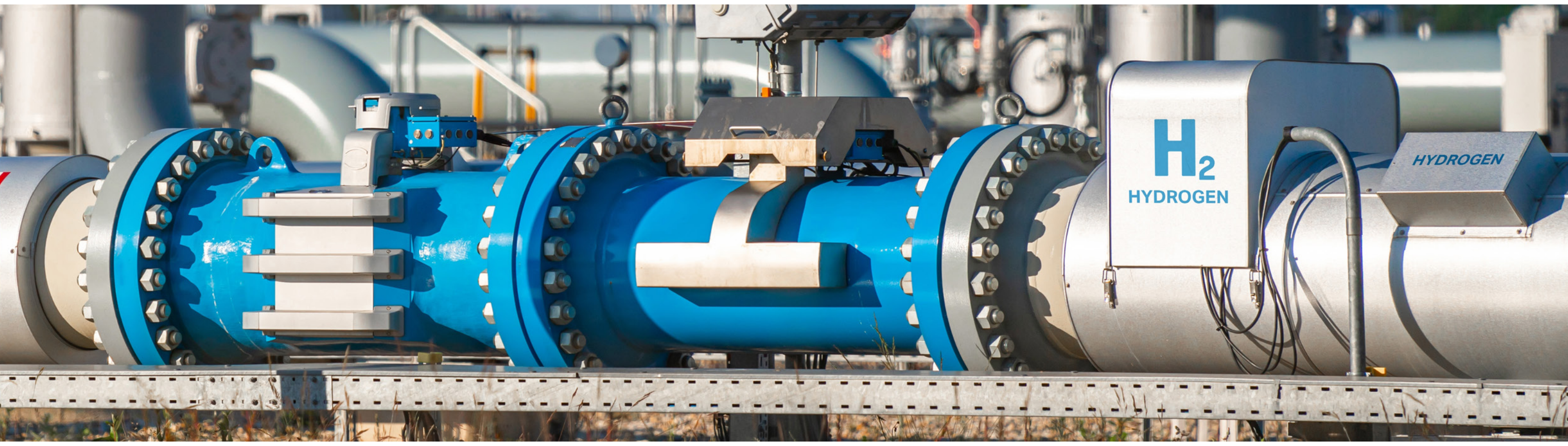
New innovations/technologies and energy management systems will facilitate the energy transition in Lithuania. Virtual Power Plants (VPPs), for instance, which are formed by a portfolio of decentralized power generation sources (e.g., solar PV, wind, BESS) that are connected and coordinated through a central control system, are operated as a unified entity to provide reliable and flexible power supply to the grid. Another promising technology, still in its early stages of development, is Small Modular nuclear Reactors (SMR) which has the benefits of being low-carbon dispatchable technology characterised by presumed lower capital costs compared to a standard nuclear power plant, built-in safety and waste management features.

Energy storage technologies will also play an important role in the future Lithuanian energy system, especially by providing flexibility in the short-term, via Battery Energy Storage Systems (BESS), but also in the medium- to long-term, via pumped hydro storage (PHS) and hydrogen. Additionally, also 'regular' electric vehicles (EVs), and EVs with Vehicle-to-Grid (V2G) technology represent an opportunity for flexibility provision in the short-term, especially once a significant share of EVs is introduced in the road transport sector. Full control V2G capacity can be regarded as similar to BESS. The main need and benefit for the Lithuanian energy system is the additional flexibility with the foreseen increase of vRES into the power system, especially at LV/MV levels where grid connections are restrained. V2G can potentially support a range of additional benefits including frequency and voltage stabilization, network investment savings, portfolio optimization for utilities and energy traders, reduced grid connection costs and peak power requirements at charging sites.

In the future, electrode boilers and heat pumps are also expected to play a role in district heating systems. The deployment of electrical heat pumps typically requires a larger number of hours with low power prices compared to electrode boilers, given the relatively high capital costs of electrical heat pumps. These assets will serve as an instrument between the power and heat sector, enabling synergies in the operation of two systems.

CCUS, especially for non-fossil-based carbon, will play a crucial role in the energy transition in Lithuania. The most efficient way to capture CO_2 is generally from large point source emitters, where economies of scale are possible. There is also great potential to capture CO_2 from the bioenergy production processes. CO_2 transport is generally more economic in pipelines than by truck, especially for larger volumes. The main uses of CO_2 in Lithuania are likely to be in refineries for e-fuels and for fertiliser production, both of which could be at a large scale. There is a wide range of mature (TRL above 8) caron capture technologies with commercial applications worldwide, including pre- and post-combustion capture. For example, liquid solvent-based CO_2 capture has been assessed to have TRL 9 already in 2014[9]. Saline aquifers and depleted gas fields can be used for CCS in theory. All current commercial projects, however, are in saline aquifers, hence this option is assessed to have TRL of 8 or 9 (commercial scale projects in operation, e.g. Slepner, Snehvit).

[8] https://www.dnv.com/energy-transition-outlook/
[9] https://www.globalccsinstitute.com/wp-content/uploads/2021/03/Technology-Readiness-and-Costs-for-CCS-2021-1.pdf, p.11



Hydrogen will play a central role in the future energy system, and the domestic value chain around it will become a large driver for the economy. Figure 3-6 shows the projected Levelised Cost of Hydrogen (LCOH) by production technology, after incentives in the EU. The incentive level is projected based on mappings of existing and projected policies in the EU. The figure shows that the LCOH for renewable-based hydrogen production remains relatively stable, positioning it as a competitive alternative to the more traditional fossil fuel-based methods. The projections also indicate that grid-connected hydrogen production is likely to emerge as one of the cheapest methods for hydrogen production by 2050. Grid connected electrolysis will become the largest hydrogen production source, also due to its decreasing LCOH over the next decades.

Besides hydrogen, it is also crucial to consider alternative fuels in the future market. Thereby, the future alternative fuels market and prices are highly dependent on considerations regarding available fuels for shipping, aviation, industry, and other sectors, as well as their respective prices. The price elasticity, or the responsiveness of demand to price changes, can vary across different segments and various sectors. As such, future alternative fuels' prices are hard to predict. In DNVs Maritime Forecast 2022, DNV estimated spans in production and distribution costs for different fossil and alternative fuels using DNVs Marine Fuel Price Mapper tool.

FIGURE 3-6

Hydrogen LCOH forecast for European region *(DNV ETO 2022)*

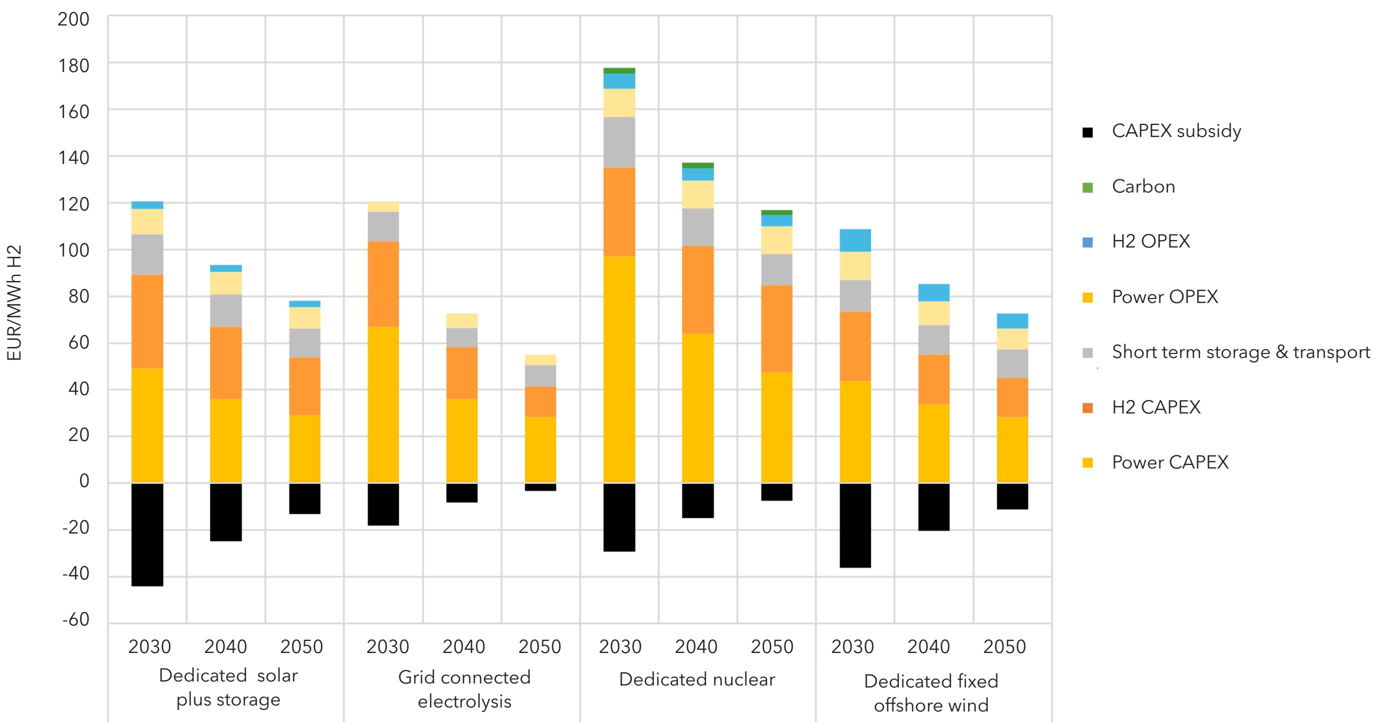


FIGURE 3-7

Estimated prices for alternative fuels in 2050 (VLSFO = very low sulphur fuel oil, MGO = marked gas oil, HFO = heavy fuel oil, LNG = liquified natural gas, LPG = liquified petroleum gas, LH2 = liquid hydrogen)

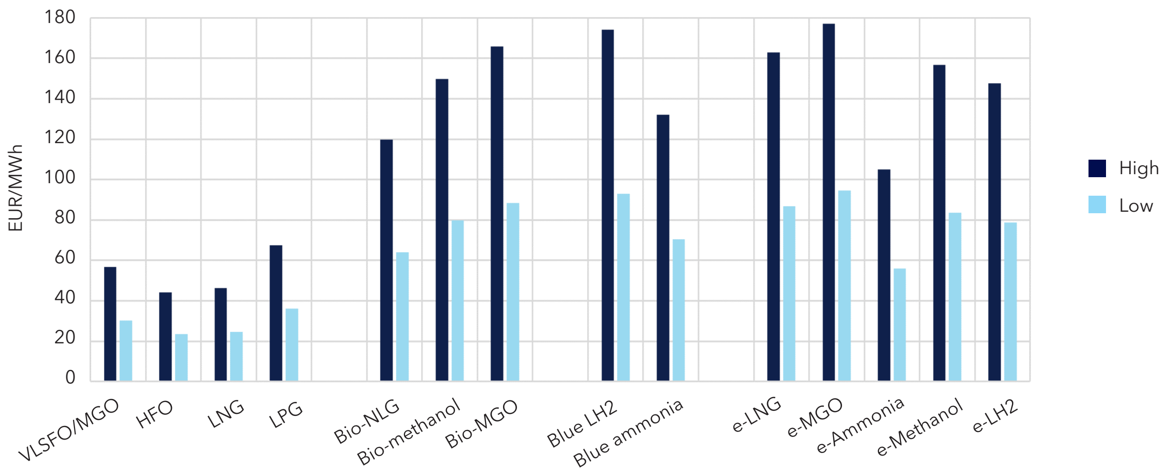


Figure 3-7 shows high and low alternative fuels' prices in 2050, calculated as a global mean average of all 10 global regions as defined in DNV's ETO, comparing them to the four fossil variants on the left-hand side of the graph. As this is an assessment for the maritime industry, emission costs projections are not added to the fossil fuels. The results show a large gap between the estimated high and low prices in 2050 for the alternatives, emphasising the high uncertainty in these projections. Although not in line with policies and applicable costs in the energy sector, it is evident that in the absence of carbon pricing, projections are that fossil fuels would still be considerably cheaper than carbon-neutral alternative fuels.

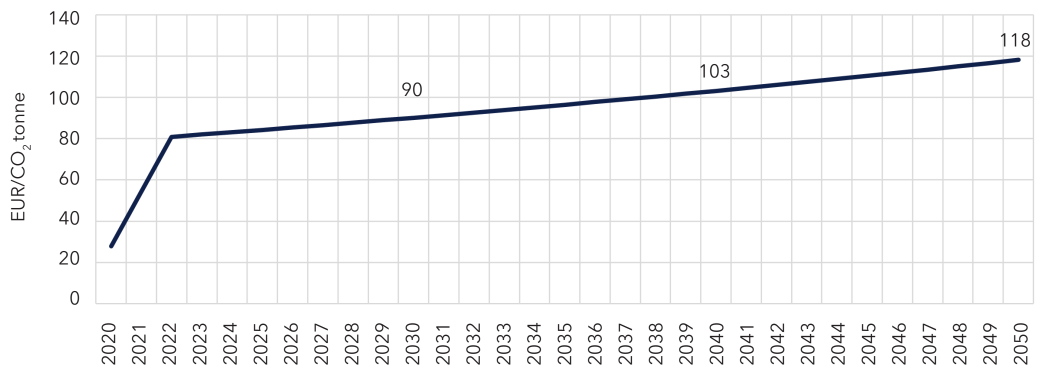
3.3 Emissions

In DNVs ETO 2022 forecast, the European region represents a lead pioneer in carbon pricing with both regional (EU ETS) and supplementary national taxes. Figure 3-8 shows an average regional carbon price trajectory towards 2050 considering hybrid pricing (ETS and carbon taxation). This price development of CO_2 is also relevant for Lithuania.

In Europe, established carbon schemes are being tightened (e.g., EU ETS cap continuous decline and inclusion of more sectors, such as maritime (2026); separate ETS for road transport/buildings (2026); and free allocation phaseout (2027) for aviation). There is no indication that the EU will relax its focus on decarbonisation and on the Green Deal, as these are closely linked to energy security objectives. Thereby, the EU ETS is an important tool to finance the transition costs and achieve net zero ambitions. In addition, the EU Cross-border Adjustment Mechanism (CBAM) will go in force from 2026 to safeguard European competitiveness by levelling the playing field between EU and non-EU producers.

FIGURE 3-8

Carbon price regional outlook for Europe (DNV forecast)



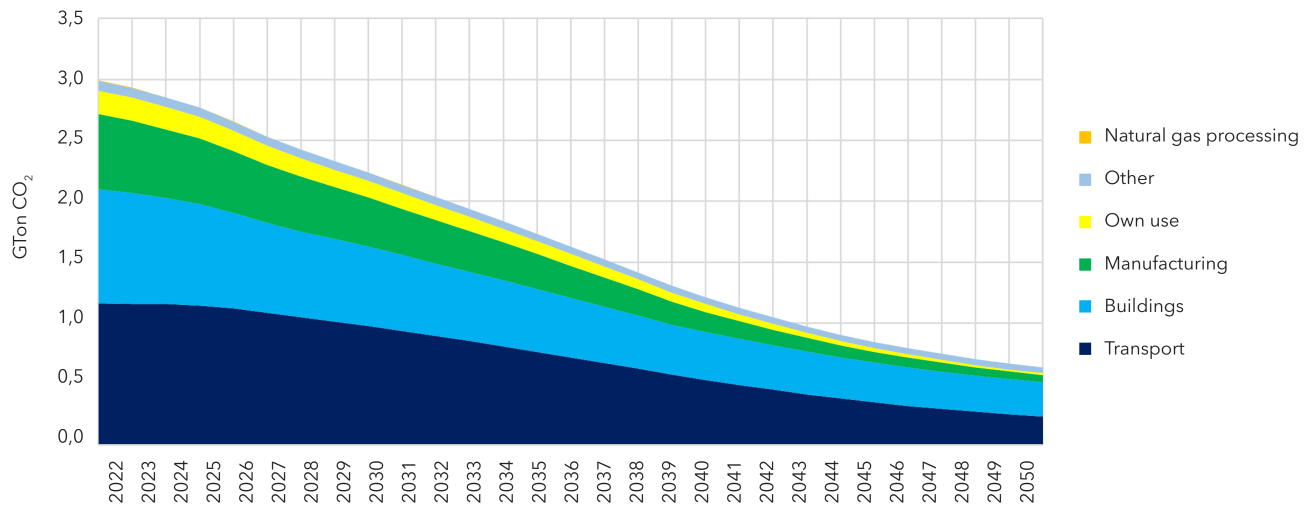
Overall, the expect increase in CO_2 price is another important driver and signal to decarbonise the Lithuanian energy system and to transition towards a fossil-free future.

The energy transition and its related decarbonisation and electrification is expected to decrease the European CO_2 emissions in the energy sector significantly towards 2050. The transport, buildings and manufacturing sectors are expected to experience the largest decrease in CO_2 emissions, due to the electrification of heating processes, switching to alternative energy carriers (e.g., hydrogen and synthetic fuels) but also due to the adoption of new and emerging technologies (e.g., EVs). Overall, the energy related CO_2 emissions are projected to decline from around 3 Gtonne in 2022 to around 0.5 Gtonne in 2050.

This decline in energy related CO_2 emissions can also be expected in Lithuania, especially since currently 60% of the total GHG emissions are coming from energy use, with transport emission accounting for half of it.

FIGURE 3-9

Energy-related CO_2 emissions volume projection for Europe *(DNV ETO)*[10]



[10] Own use refers to own energy system use

3.4 Digitalization

Digitalisation is a key enabler in achieving the rapid decarbonisation needed during the energy transition. It is expected that the energy sector will need to deploy millions of low or zero carbon assets including solar panels, wind, battery storage, electrolysis, heat pumps, electric vehicles, and smart appliances that will need to be integrated with the energy systems.

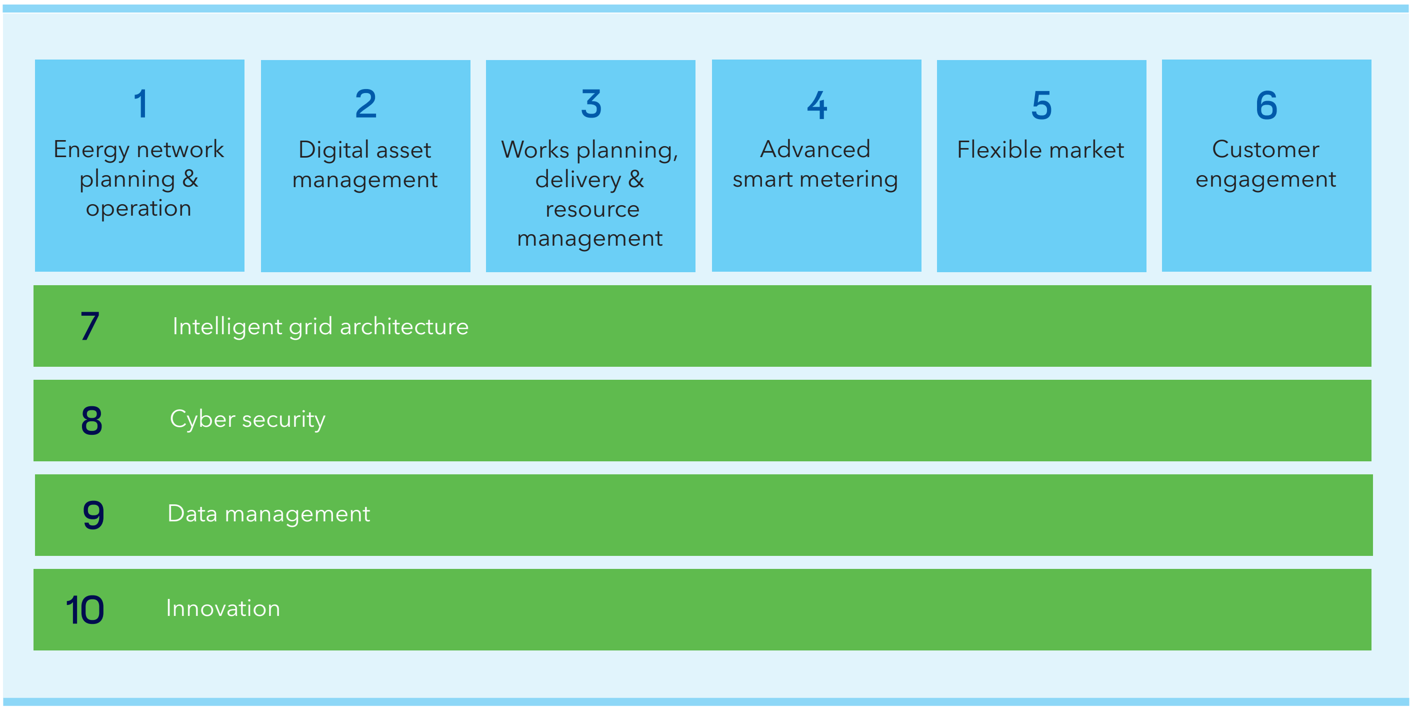
The whole system would require digitalisation on all levels of demand, supply, market and networks. The benefit of this flexible system is immense, enabling a faster, more efficient energy transition and at lower costs. All these technologies would be needed to be digitally connected and will create an immense amount of data, which will result in better insights and decision making with the right level of data governance supporting it.

Lithuanian context

To best support digitalisation of the Lithuanian energy system, a 10-points plan is proposed to develop a flexible energy system. It focuses on the role of system operators, supported by close cooperation between transmission and distribution system operations, appropriate regulation, and collaboration with technology providers, research institutions, and other industry stakeholders to drive innovation, share best practices, and develop pilot projects for testing and deploying new digital solutions. Collaboration fosters knowledge sharing and helps accelerate the adoption of digitisation across the energy ecosystem. Figure 3-10 shows six business capabilities (in lightblue) supported by intelligent architecture, cyber security, data management and innovation (in green).

FIGURE 3-10

10-points plan towards flexible energy systems



4. SCENARIOS FOR THE LITHUANIAN ENERGY SYSTEM

4. SCENARIOS FOR THE LITHUANIAN ENERGY SYSTEM

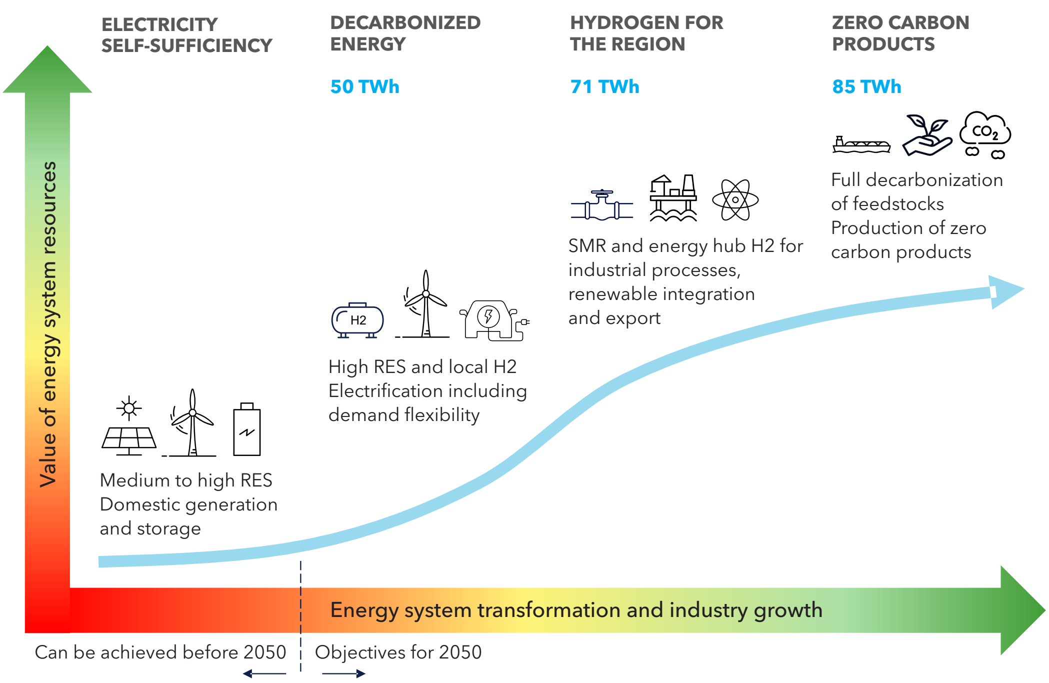
The 2050 energy scenario framework is designed to reflect the different levels of ambition across the five identified national energy objectives:

1. Become energy independent by 2050 and electricity self-sufficient by 2030
2. Achieve a full transition to renewable energy and a 100% decarbonization of the energy system
3. Become an energy exporting country
4. Pursue industry growth and export of high-value products
5. Ensure a cost-effective and affordable transition

Three scenarios for 2050 are defined in reflection of the national objectives and other contextual factors, such as EU, regional and neighbouring countries developments. Lithuanian energy system planning is seen in the context of regional developments, especially in terms of infrastructure development. Scenarios are reflective of the sectoral outlooks and technology trends and innovations across energy supply, and end use, sectoral integration, storage and flexibility, infrastructure and market & regulatory domains. The three scenarios vary in the level of domestic electricity generation (50, 71, 85 TWh) deployment of available energy system resources and in the level of energy system transformation requirements and industry growth, as shown conceptually in Figure 4-1.

FIGURE 4-1

Conceptual representation of the defined 2050 scenarios for Lithuania



It is noted that the scenarios are not deemed to be forecasts of the most likely developments neither representations of an optimal future energy system. The purpose of these scenarios is to formulate three outlooks of the future energy system of Lithuania which are different in their ambition to achieve energy system transformation and to drive deployment of energy system resources, such as generation, storage, demand flexibility and cross-border infrastructure. These three scenarios support an impact analysis of different factors on the evolution of the energy system against the strategic objectives, including an assessment of their interdependencies, in order to deliver a sound strategy for Lithuanian energy system development.

From the results of these scenario modelling an additional scenario is later defined - Roadmap. The Roadmap scenario reflects the recommended strategic direction that the transformation of the Lithuanian energy sector should take. This scenario aimed to use the learnings from the original three scenarios and combine their building blocks in an attempt to design an optimal system (achieving strategic objectives).

A more detailed storyline of what each scenario represents focusing on decarbonisation, RES deployment, production sources and infrastructure, flexibility and industry growth is given below.

Decarbonised energy
This scenario is characterised by the most modest growth ambition. In line with the captured trends, the end-use demand will electrify across residential, transportation and industrial sectors, supporting the decarbonisation goals. This electrification will be supported by the growth in renewable generation capacity, mainly comprised of onshore (9 GW) and offshore wind (2.5 GW), and solar (7 GW). Flexibility assets such as P2G, BESS, Power to Heat (P2H), V2G and electricity interconnectors with the neighbouring countries are added to help balance the system. Hydrogen production is growing but merely to cover domestic needs in industry. As soon as a significant hydrogen production is introduced, Lithuania requires construction of cross-border hydrogen connections in order to balance the demand and supply of this carrier – this is a common requirement for all scenarios, given that Lithuania does not have opportunities to store hydrogen in large quantities domestically.
As the industry growth is limited and capacity of production technologies is only increasing moderately, not reaching the full potential for onshore wind and solar, the scenario does not envisage large energy imports. At the same time, as well as the other scenarios, it aims to achieve decarbonisation and energy self-sufficiency, making use of domestically available energy carriers, such as electricity and biomass (including biofuels and waste), including the intermediate goal of electricity self-sufficiency by 2030.

Hydrogen for the region
This scenario represents a further growth in ambition compared to decarbonised energy. Its main vision is producing enough hydrogen domestically to begin exporting it to the wider region. While assumptions on the end-use trends in decarbonisation and electrification are identical, the scale of changes is bigger. Namely, the industry growth is assumed to be higher (2050 growth of 150% vs 130% for DE), which is to be complemented by a corresponding increase of domestic electricity generation from onshore wind (10 GW) and solar (9 GW), as well as a higher hydrogen production ambition. These are supported by higher capacities of BESS and electricity interconnections. Importantly, in addition to variable renewable generation, this scenario features development of small modular nuclear reactors of 1 GW by 2050 in total, to ensure a sufficient amount of zero carbon dispatchable generation. Since Lithuania does not have domestic uranium production, deployment of nuclear generation introduces dependency on foreign uranium supplies. Notable changes are also introduced on the infrastructure side, where, apart from higher electricity interconnection capacity, Lithuania builds its own offshore energy hub bringing its offshore wind to 4.5 GW. This hub comprises both electrical and hydrogen infrastructure, aiming to unlock synergies with offshore sectors of the neighbouring countries, as well as to enable hydrogen connection to Nordic-Baltic offshore hydrogen corridor, creating additional opportunities for hydrogen export from its offshore production on the hub.

Zero carbon products
This scenario represents the highest level of growth ambition, featuring 170% industry growth by 2050 and large electrolysis capacities, as in the Hydrogen for the Region scenario. The difference is that the objective of this scenario is to maximise industrial growth opportunities by having zero carbon products production capacities in Lithuania. As such, the scenario aims to minimise export of domestically produced electricity and hydrogen and uses the surplus for local production of higher value zero carbon products, such as synthetic fuels and fertilisers. This marks this scenario as aiming to secure higher revenues for the economy compared to the previous ones. This requires extra investment across the whole energy system, especially in the development of domestic carbon capture capabilities and corresponding production facilities. On the supply side, the capacity of onshore wind is pushed to its currently regarded maximum potential of 12.5 GW, while capacity of SMR is expanded to 2.1 GW. Although larger SMR creates even higher dependency on external uranium supplies, the fact that instead of electricity and hydrogen, the exports are mainly comprised from high value products, can make scenario economically attractive. In terms of flexible capacity resources, this scenario resembles hydrogen for the region.

Roadmap
This scenario is characterised by the same level of demand growth ambition as hydrogen for the region (150% industry growth) but it maintains somewhat higher domestic generation capacities to drive domestic hydrogen value chain's export potential and achieve a lower energy dependency. Like in the ZCP scenario it features maximising the internal use of hydrogen and electricity surplus for higher value zero carbon products such as synthetic fuel production. An energy hub and SMR are its main distinguishing building blocks. The installed capacity of SMR is however lower – 1.5 GW by 2050. Similarly, the total capacity of interconnectors is somewhat reduced compared to ZCP – 5 GW by 2050. The roadmap scenario is taken as a basis for strategy development and will be the focus of the following sections.

The key differences between the input assumptions of the scenarios in terms of generation capacities, amount of flexibility resources (including P2G and BESS) and the level of industry growth are summarised in Table 4-1.

4.1 Electricity generation

Installed capacity increases over time in all scenarios, reaching a 6-to-8-fold increase from 2022 levels.
The increase in solar PV, onshore and offshore wind capacity boost the total capacity increase in Lithuania. Hydropower and biomass & waste capacities remain constant across years, with minor increase mostly between 2022-2030. Gas-fired generation capacity decreases after 2022, and it is replaced by SMR units in the scenarios HR, ZCP and RM.

TABLE 4-1

Summary of 2050 scenarios - input assumptions (DE = Decarbonized energy, HR = Hydrogen for Region, ZCP = Zero carbon products, RM = Roadmap)

KEY PARAMETER	UNIT	2022[11]	DE	HR	ZCP	ROADMAP
Electricity generation	TWh	4.3	50	71	85	74
Onshore wind	GW	0.7	9	10	12.5	10
Offshore wind (radial, energy hub connected)	GW	0	2.5	4.5 (2, 2.5)	4.5 (2, 2.5)	4.5 (2, 2.5)
Solar (large scale, rooftop)	GW	0.4	7 (4, 3)	9 (5, 4)	9 (5, 4)	9 (5, 4)
SMR	GW	0	0	1	2.1	1.5
Combined cycle gas turbine (CCGT) or gas turbine (GT) gas / H2	GW	1.5	0.5 / 0.5	0.26 / 0.5	0.26 / 0	0 / 0.5
BESS	GW	0	3	4	4	4
Power to Gas (P2G) (grid-connected, energy hub connected	GW	0	4	8.5 (6.5, 2)	8.5 (6.5, 2)	8.5 (6.5, 2)
Industry size (chemical, fertiliser)	% vs 2022	100%	130%	150%	170%	150%
Interconnectors	GW	2.2	5	5.6	5.6	5
DH / Heat pump (households)	%	40 / 0	40 / 60	40 / 60	40 / 60	40 / 60
El / H2 in transport	%	1 / 0	75 / 25	75 / 25	75 / 25	80 / 20
CCUS	-	No	No	No	Yes	Yes

[11] As modelled in Energy Transition Model (ETM)

4.2 Flexibility capacities

The Lithuanian system is foreseen to become a very flexible energy system. With 1.01 GW of pumped hydro storage by 2050 and a BESS capacity of 3 GW in the DE scenario and 4 GW in the HR, ZCP and RM scenarios, a large amount of the non-dispatchable demand could be supplied by electric storage when looking at installed capacity. Unfortunately, these flexible options have volume restrictions, especially BESS.

Therefore, other flexible electricity supply and demand technologies are necessary in order to ensure that non-dispatchable load is served at all times. SMR is a dispatchable source of electricity. It can reduce its production when electricity is (almost) zero or negatively priced. Thereby, SMR will not solely be a must-run generator in the system, but it will flexibly react on price signals. In the HR, ZCP and RM scenario SMR is available as dispatchable generation. SMR is only switched off in a very high solar and wind oversupply situation where all flexible demand capacity is also already saturated.

FIGURE 4-2

Installed generation capacity across the scenarios

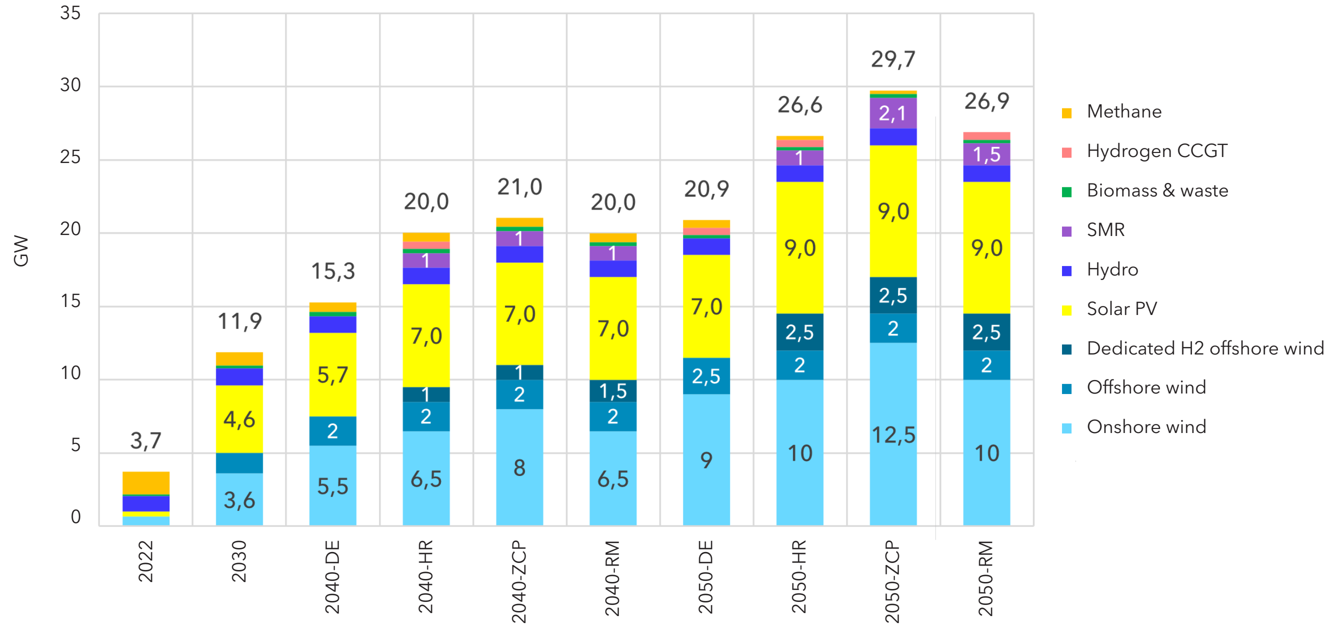
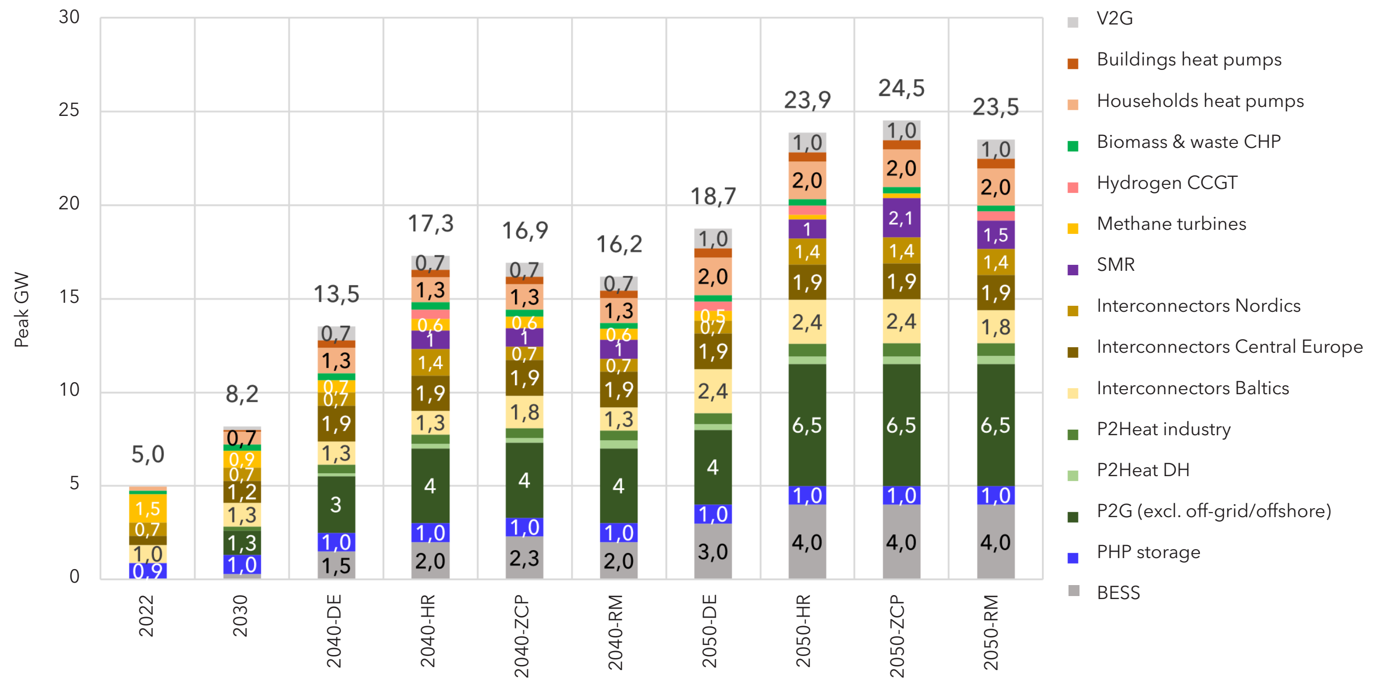


FIGURE 4-3

Overview of dispatchable flexibility sources in the system across the scenarios



Other flexible supply options are gas turbines. New build or retrofitted natural gas (methane) fired turbines to hydrogen fired CCGT are modelled. In the DE, HR and RM scenario hydrogen CCGT capacity is 0.5 GW. The methane turbines, using biomethane or imported natural gas, have a capacity of 0.51 GW in the DE scenario and 0.26 GW in the HR and ZCP scenario for 2050.

Biomass and Waste CHPs are also present in the model by 2050 with a capacity of 0.24 GW. They have an electric efficiency of 26% and a heat efficiency of 19% on top. In situations where electricity prices are too low power-to-heat sources are used. Produced heat that is not directly utilised can be stored in heat storage for later use.

Power to Heat (P2H) applications such as heat pumps installed in households and buildings, as well as V2G will play a role, in total providing up to 3.5 GW of flexible capacity by 2050.

4.3 Demand

On the demand side all scenarios have identical assumptions. Table 4-2 is an overview of key technology and fuel inputs used in our modelling of the four scenarios across the studied years.

4.4 Infrastructure

Figure 4-4 provides a conceptual regional infrastructure outlook for 2050 with a focus on electricity, natural gas, hydrogen, power to heat and CO_2. Only additional infrastructure added beyond existing assets is shown. Note that all transmission routes, landing points and generation locations are indicative.

FIGURE 4-4

Conceptual representation of the key infrastructure in scenario Roadmap - 2050

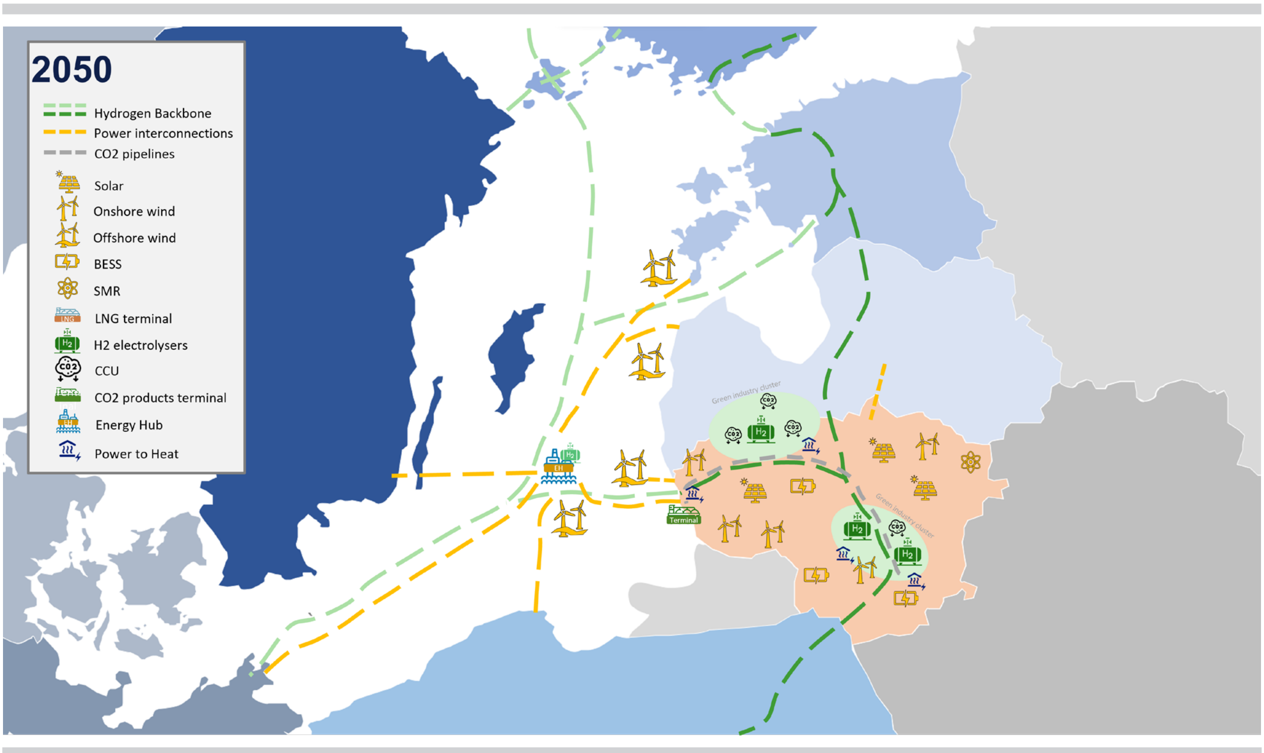


TABLE 4-2

Summary of scenarios assumptions across years

KEY PARAMETER	SCENARIO	UNIT	2020[12]	2030	2040	2050
Built environment						
Population	All	Million	2.80	2.70	2.65	2.60
Number of houses	All	Million	1.29	1.29	1.29	1.29
Households heat demand reduction	All	% vs 2022	-	-5	-10	-15
Households heat pumps/district heat	All	% of houses	11 / 41	20 / 45	40 / 40	60 / 40
Commercial buildings heat pump/district heat	All	% of bulding	7 / 50	30 / 50	55 / 40	70 / 30
Agriculture heat pump	DE HR/ZCP/RM	% heat demand	0	10	25	50 100
DH P2Heat boiler + HP	DE HR/ZCP RM	MW heat	0	0	150 + 33 200 + 44 180 + 78	250 + 56 330 + 73 330 + 78

KEY PARAMETER	SCENARIO	UNIT	2020[12]	2030	2040	2050
Transport percentage per demand type			Electricity/hydrogen	Electricity/hydrogen	Electricity/hydrogen	Electricity/hydrogen
Passenger cars	All	%	0 / 0	15 / 0	70 / 0	100 / 0
Passenger trains	DE HR/ZCP RM	%	9 / 0	60 / 0	70 / 0 70 / 0 100 / 0	80 / 20 90 / 10 100 / 0
Freight trains	All	%	4 / 0	30 / 0	55 / 0	75 / 20
Busses	DE HR/ZCP RM	%	14 / 0	30 / 20	40 / 40 40 / 40 60 / 20	50 / 50 60 / 40 80 / 20
Trucks	DE/HR/ZCP RM	%	0 / 0	15 / 5	20 / 45 40 / 25	50 / 50 60 / 40
Other vehicles	DE/HR/ZCP RM	%	0.1 / 0	15 / 5	30 / 40 50 / 15	50 / 50 80 / 20
Domestic navigation	All	%	7 / 0	5 / 5	10 / 10 + ammonia / synthetic fuels 30	10 / 10 + ammonia / synthetic fuels 60

[12] 2022 assumptions may deviate from the actual statistics since the model has been adjusted to represent a typical year in terms of e.g. methane demand, while not taking into account some of the latest development that took place in the end of the 2022.

KEY PARAMETER	SCENARIO	UNIT	2020[12]	2030	2040	2050
Industry demand			Gas/hydrogen/ fossil fuels	Gas/hydrogen/ fossil fuels	Gas/hydrogen/ fossil fuels	Gas/hydrogen/ fossil fuels
Refinery heating (*oil)	DE HR/ZCP/RM	%	11 / 0 / 0 / 89*	35 / 5 / 10 / 50*	35 / 25 / 10 / 30* 25 / 45 / 10 / 20*	30 / 60 / 10 10 / 80 / 10
Petrochemical heating (*direct HP, remainder DH)	DE HR/ZCP RM	%	0 / 0 / 4 / 0.6*	30 / 10 / 0 / 20*	20 / 15 / 0 / 30* 15 / 25 / 0 / 30* 20 / 30 / 0 / 30*	0 / 25 / 0 / 45* 0 / 35 / 0 / 40* 0 / 45 / 0 / 40*
Fertilizer heating (*oil)	DE HR/ZCP/RM	%	57 / 0 / 0 / 44*	55 / 15 / 0 / 30*	50 / 40 / 0 / 10* 50 / 45 / 0 / 5*	30 / 70 /0 0 / 100 / 0
Petrochemical feedstock (*oil)	DE HR/ZCP/RM	%	84 / 0 / 0 / 16*	80 / 10 / 0 / 10*	50 / 20 / 20 / 10* 45 / 25 / 20 / 10*	20 / 40 / 30 / 10* 10 / 40 / 40 / 10*
Fertilizer feedstock	DE HR/ZCP/RM	%	100 / 0	85 / 15	55 / 45 50 / 50	30 / 70 0 / 100
Other industry demand (*electricity, remainder oil)	DE HR/ZCP/RM	%	18 / 0 / 14 / 6*	20 / 0 / 25 / 40*	10 / 0 / 25 / 50* 15 / 5 / 15 / 60*	0 / 10 / 10 / 70* 0 / 20 / 10 / 70*
Synthetic fuels industry	ZCP/RM	TWh output potential	0	0	0 / 2	4.7 / 3
Hybrid e-boiler capacity in all industry	DE HR ZCP RM	MWe	0	230	445 505 525 515	580 670 715 690

KEY PARAMETER	SCENARIO	UNIT	2020[12]	2030	2040	2050
Energy network and flexibility						
P2G + dedicated offshore wind electrolyser capacity	DE HR/ZCP/RM	GW	0	1.3 + 0	3 + 0 4 + 1	4 + 0 6.5 + 2
BESS	DE HR/RM ZCP	GW	0	0.3	1.5 2 2.3	3 4 4
Pumped hydro storage	All	GW	0.9	1	1	1
Interconnectors	DE HR ZCP RM	GW	2.2	3.1	3.9 4.5 4.3 3.9	5.0 5.6 5.6 5.0
H2 storage modelled	DE HR/ZCP RM	TWh	0	0.7[13]	1.0 1.6 1.1	2.7 3.9 3.6
Vehicle-to-grid (V2G)	DE/HR/ZCP/RM	GW peak	0	0.17	0.73	1
Power-to-heat (P2H)	DE/HR/ZCP/RM	GW	0.2	1	2.4 / 2.5 / 2.5 / 2.7	3.4 / 3.6 / 3.6 / 3.6
DH LT-storage	DE HR/ZCP RM	TWh	0	0.01	1.6 0.8 1.8	1.9 1.7 2.3

[12] 2022 assumptions may deviate from the actual statistics since the model has been adjusted to represent a typical year in terms of e.g. methane demand, while not taking into account some of the latest development that took place in the end of the 2022.
[13] DNV assumes that the hydrogen corridors will not be developed by 2030, hence Lithuania will not be able to access underground hydrogen storage facilities in Poland or Germany. Hence, DNV assumes that the hydrogen offtake facilities will be capable to ramp up/ down their offtake in line with electrolysis operations.

4.5 Comparing performance of the scenarios

Table 4-3 provides an overview of scenario outcomes for the year 2050 for different key performance indicators (KPIs) to measure progress against the energy strategy objectives as defined in this study.

The key insights are:

- All scenarios reach zero CO_2 emissions in the energy sector. All scenarios feature some level of GHG emissions which cannot be abated.
- Energy system costs (in EUR/MWh) are relative scenario independent and remain relatively stable. The cost structure (capital costs, operation and maintenance costs, energy carrier costs) can be different for respective sectors. It will be therefore key to determine how the cost burdens will be shared.
- Annual operating costs will strongly decline given the strong reduction of the contribution of commodity prices including CO_2.
- Scenarios with SMR result in higher level of energy dependency since uranium needs to be imported.

TABLE 4-3

Scenario outcomes - key performance indicators for 2050[14]

SCENARIO KPI	UNIT	2022	DE-2050	HR-2050	ZCP-2050	RM-2050
Energy dependency	%	73%	11%	25%	32%	30%
Electricity dependency	%	67%	2%	3%	-4%	0%
CO_2 emissions	Mton	15	0	0	0	0
GHG emissions	Mton	22	6.9	6.3	6.3	6.2
Hydrogen exports	TWh	0	-3.0	4.4	1.4	1.4
Zero carbon product exports	TWh	0	5.0	6.1	11.9	9.1
Total energy system costs (2022-2050, in net present value 2022)	bln EUR (EUR/MWh)	NA	107 (41.7)	117 (39.9)	122 (39.4)	118 (39.4)
Total infrastructure capital costs (2022-2050) (non-discounted)	bln EUR	NA	49	68	79	71
Annual energy system operating costs (energy carriers and O&M)	EUR/MWh	75	17.3	12.0	12.4	12.5

[14] Electricity dependency equals annual electricity imports/final electricity demand. Energy dependency equals annual net imports/total primary energy supply (incl. non-energetic). Zero Carbon products export includes ammonia and synthetic fuels. Energy system costs cover all costs (capex, opex, energy carriers) and relate to total primary energy supply (in TWh) from 2022-2050. Energy system costs are discounted to Net Present Value of 2022 at a Weighted Average Cost of Capital (WACC) of 4%.

5. SCENARIO OUTCOMES AND STRATEGY

5. SCENARIO OUTCOMES AND STRATEGY

This section presents strategic guidelines and projections for transformation of the Lithuanian energy system based on the recommended Roadmap scenario. The system developments are categorised across supply, demand, exchanges, flexibility and storage, costs and emissions categories. Both intertemporal and structural evolutions are shown and explained.
Where possible, DNV provides breakdown for specific energy carriers or end-use sectors.

5.1 Energy flows

This section provides an outlook on the flow of different energy carriers from the supply to the demand side, including conversions in the intermediate steps.

FIGURE 5-1

2022 Energy flows

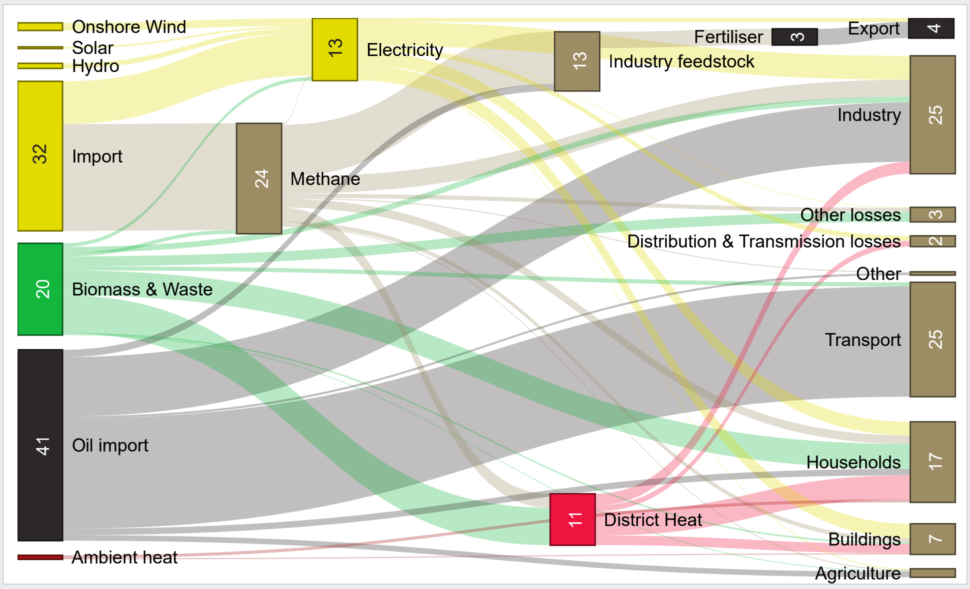


Figure 5-1 shows the energy flows in 2022. In 2022 the system was dominated by oil which was mainly consumed in the transport sector and industry. A major share of electricity and 100% of methane was imported. Biomass (including biofuels) and waste accounted for another large part of the energy mix with a majority being consumed in the district heating.

FIGURE 5-2

2030 Energy flows outlook

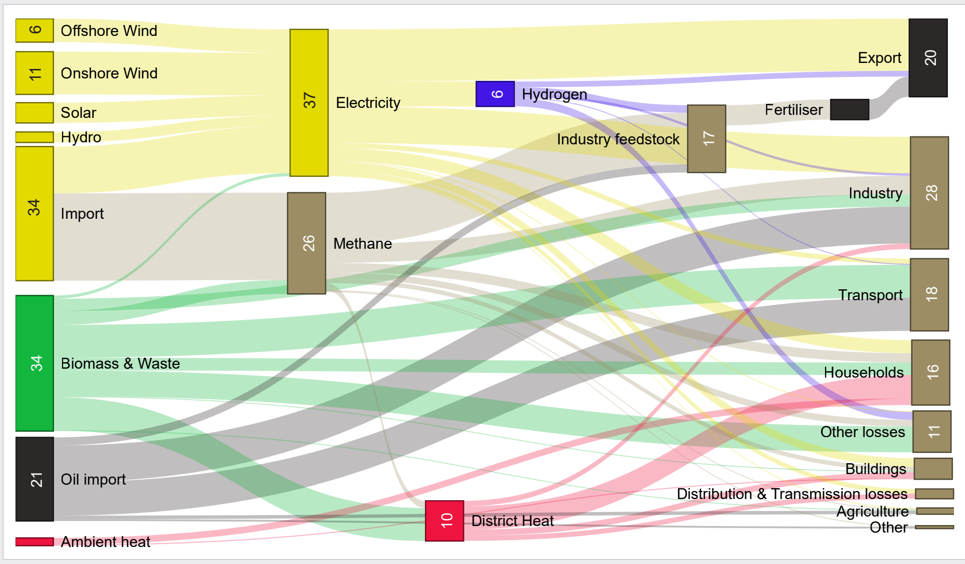


Figure 5-2 shows the energy flows in 2030. Lithuanian final energetic and non-energetic energy demand reaches 88TWh in 2030, of which 20% is covered by electricity. By 2030 electricity is largely domestically produced, whereas net imports (the balance of electricity imports and exports) is close to zero. The amount of methane in the energy system is similar to 2022 (level of 25TWh), whereas a larger share is now used as industry feedstock. Hydrogen production is already taking off, although at minimal levels (6TWh). The role of biofuels in transport has significantly increased, contribution to the decarbonization of the transport sector and a reduction on the dependency of oil imports. The contribution of biomass & waste to the energy system is significant and in fact peaking in 2030.

FIGURE 5-3

2050 Energy flows outlook[15]

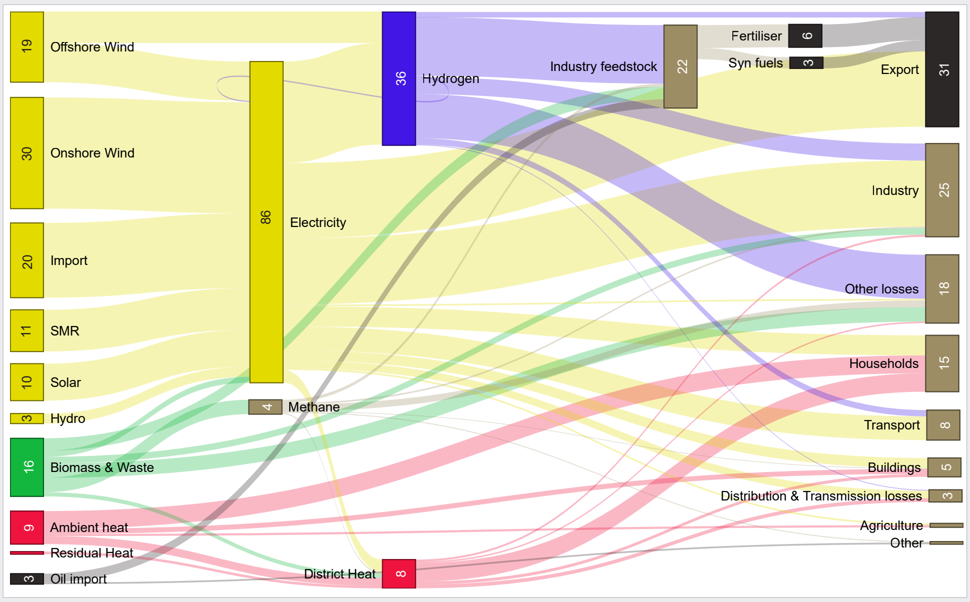


Figure 5-3 shows the energy flows in 2050. Lithuanian final energetic and non-energetic energy demand reaches 75TWh in 2050, almost half covered by electricity. Hydrogen serves as feedstock for fertilizer, chemical and synthetic fuel industries, heat production for industry, and transportation fuel. Remaining energy carriers include biogenic fuels, methane, and oil. Industry sector emerges as largest energy off-taker (>50% of final energetic and non-energetic demand). Energy demand for households, transport and buildings decline due to energy efficiency and fuel switch. Ambient heat has become a significant energy resource for electrical heat pumps applied in district heating and households.

[15] Sankey diagrams visualisation performed with Acquire Procurement Services tool. http://sankey-diagram-generator.acquireprocure.com/

5.2 Supply

Supply is structured around primary energy supply and production, electricity supply and exchange, gaseous fuel supply, CO_2 production, heat and biomass supply.

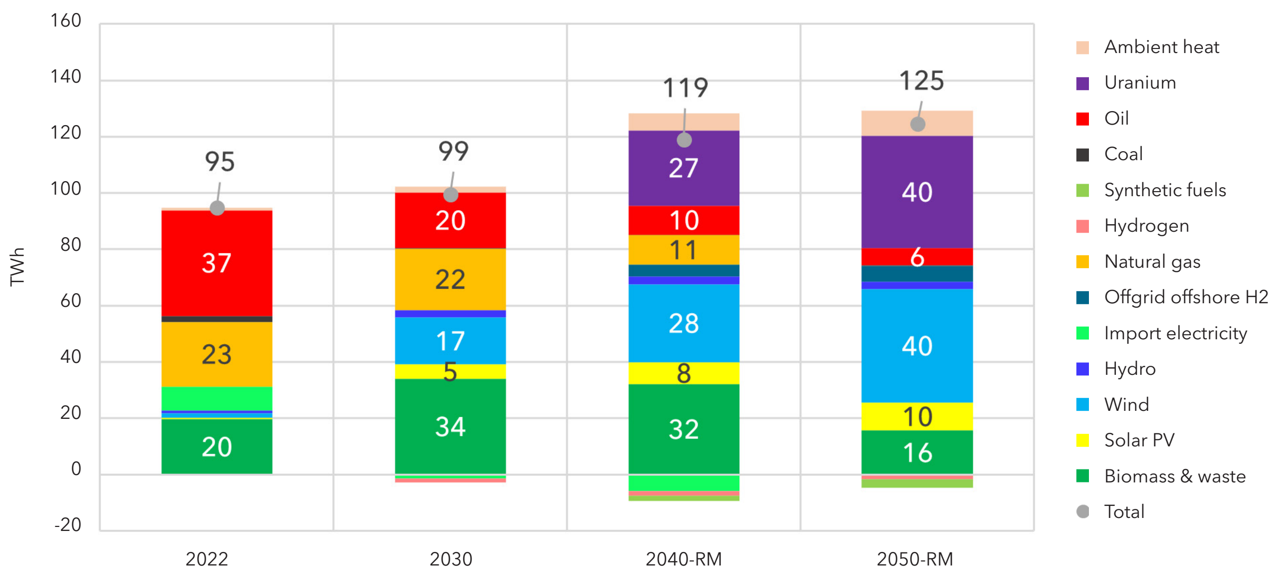
5.2.1 Energy

Lithuanian net primary energy supply will grow from 95 to 125 TWh between 2022 and 2050. Whereas oil and natural gas dominate the energy mix today, by 2050, most of the primary energy supplied will be in the form of uranium and onshore wind generated electricity, the two being the main sources of energy in Lithuania. Biomass (and waste) will continue to account for a sizeable share of the primary energy supply mix up until 2040, being gradually replaced by hydrogen. Oil's share will almost completely diminish by 2050.

Notably, when comparing the volumes of primary energy supply (domestic+net imports) with production (domestic), one can highlight that even in 2050 Lithuania will continue importing a significant share of its primary energy supply from abroad. This mainly concerns uranium (40 TWh) in 2050, and biomass and natural gas in 2030 (34 and 22 TWh) and 2040 (32 and 11 TWh). Uranium and natural gas are not available domestically. Biomass is for a large part sourced domestically, however in 2030 and 2040 a significant part needs to be imported as domestic potential in Lithuania is below the demand. By 2050 biomass imports are only minor. However, the major change in primary energy supply is in the ratio of total supply to domestic production in 2022 (95 vs 22 TWh) and in 2050 (125 to 81 TWh), indicating that the energy dependency of Lithuania will fall from the current 73% to 30% in 2050. Most of this remaining dependency is driven by uranium, something that cannot be circumvented.

FIGURE 5-4

Primary energy supply outlook[16]



[16] Ambient heat refers to heat captured from the atmosphere by heat pumps

FIGURE 5-5

Primary energy production outlook

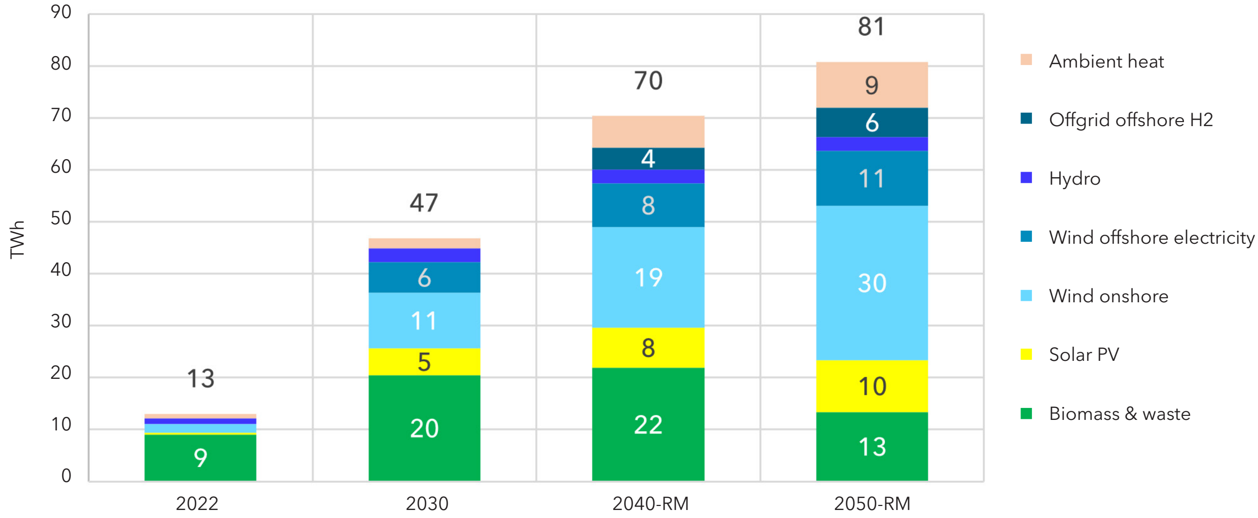
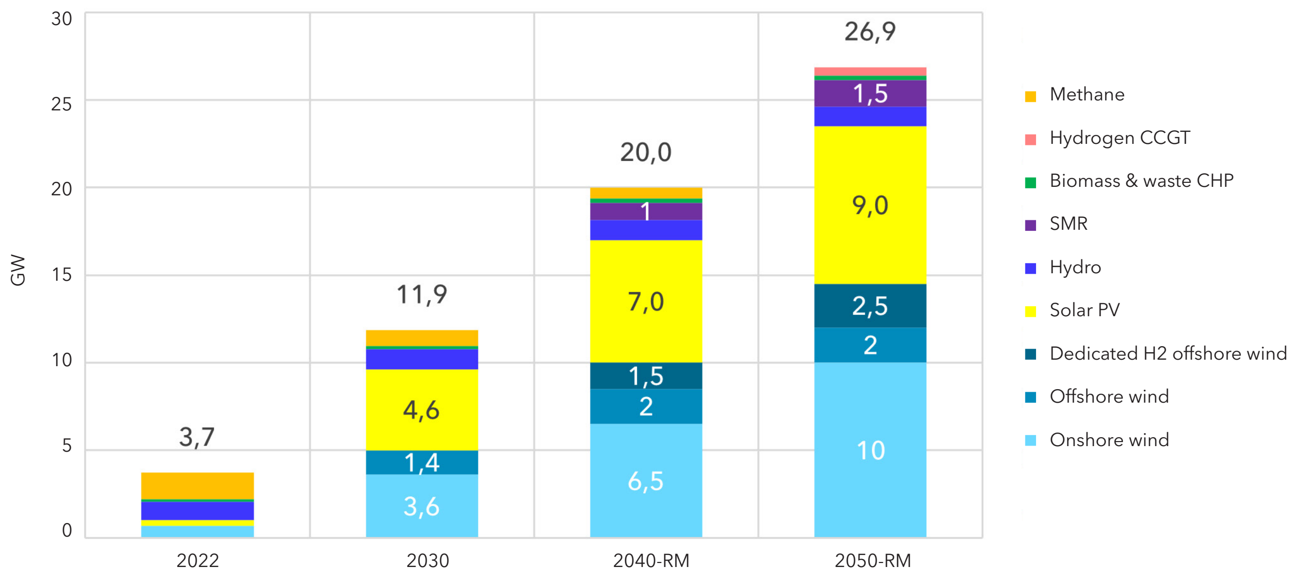


FIGURE 5-6

Electricity generation installed capacity outlook



5.2.2 Electricity

In Lithuania, the net installed capacity for electricity generation is projected to significantly increase from today's 3.7 GW to 26.9 GW by 2050. While today methane and hydropower account for the majority of installed capacity, it is foreseen that by 2050, methane will become insignificant whereas hydropower capacity will remain the same.
In contrast, solar PV capacity will significantly increase, almost doubling from the 4.6 GW in 2030 to 9 GW by 2050. Similarly, onshore wind capacity will leap to 10 GW by 2050. Although not present in today's installed generation base, offshore wind, both grid-connected and dedicated to hydrogen production offshore will see a substantial growth to a total of 4.5 GW by 2050. Finally, Lithuanian electricity generation will be complemented by SMR at a total installed capacity of 1.5 GW by 2050.

Currently, Lithuania relies heavily on net imports of electricity for its supply. However, it is anticipated that the situation will change drastically, and already by 2030. As domestic generation will increase significantly, net imports are foreseen to decrease by more than 8 TWh by 2030.

Onshore wind will be the major domestic electricity generation source, accounting for 28 TWh increase in 2050 compared to 2022. Offshore wind, SMR, solar power, and dedicated H2 offshore wind together will deliver almost 40 TWh more compared to 2022. Additionally, the mix of the electrical supply will continue to include hydro and bioenergy, including waste combined heat and power (CHP).

FIGURE 5-7

Electricity supply (including net imports) outlook

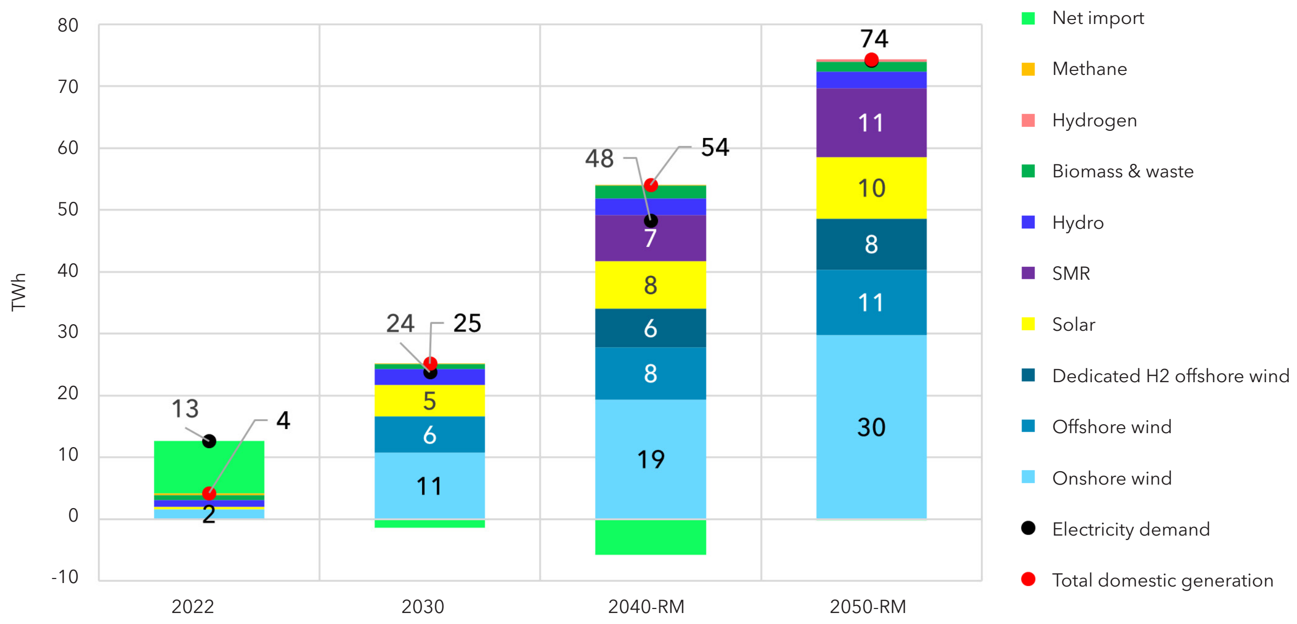
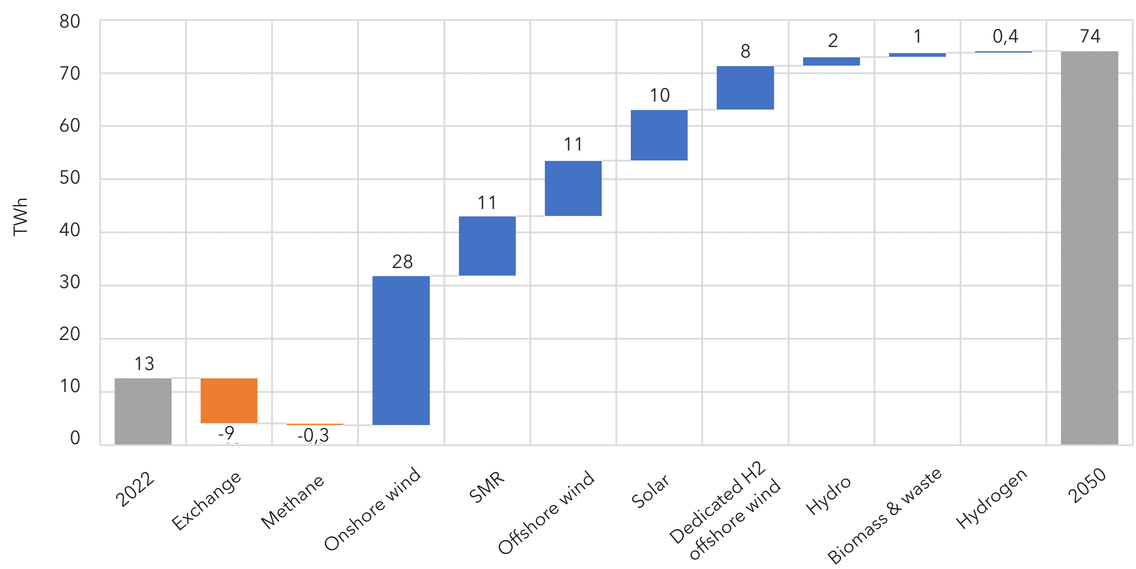


FIGURE 5-8

Electricity supply change between 2022 and 2050



5.2.3 Gas

At the moment, Lithuania is significantly dependent on imported natural gas with domestic demand of 23 TWh in 2021[17]. By 2050, demand for methane will almost disappear, with the remaining supply of 2.1 TWh full consisting of biogas that can be produced from domestically available biomass resources. Demand for biogas peaks in 2030, until it is outcompeted by hydrogen.

Lithuania currently has no hydrogen electrolysers installed, but ambitions to build hydrogen production facilities are strong. By 2030 Lithuania will have 1.3 GW built in power-to-gas hydrogen facilities. The total installed capacity for producing hydrogen is anticipated to reach 8.5 GW by 2050.

By 2050 this will allow producing 5.7 TWh of hydrogen offshore off-grid and 18.5 supplied by onshore grid-connected facilities, reaching a total hydrogen supply of almost 25 TWh in 2050, expressed in lower heating value (LHV).

[17] The year 2021 is used for methane demand since 2022 was an abnormal year in terms of methane demand due to the impact of the Russian invasion in Ukraine

FIGURE 5-9

Methane supply outlook

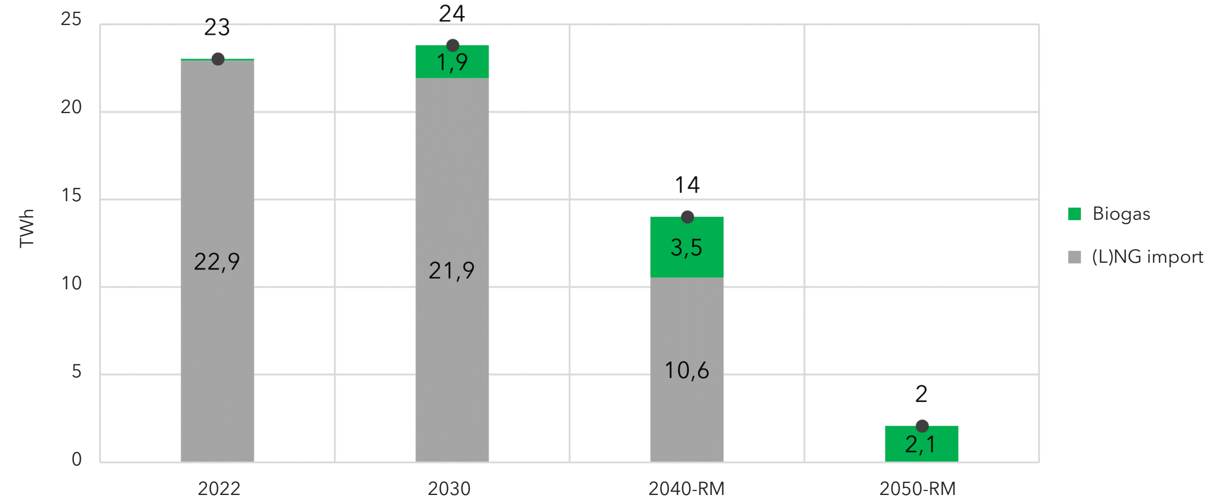


FIGURE 5-10

Hydrogen production installed capacity outlook

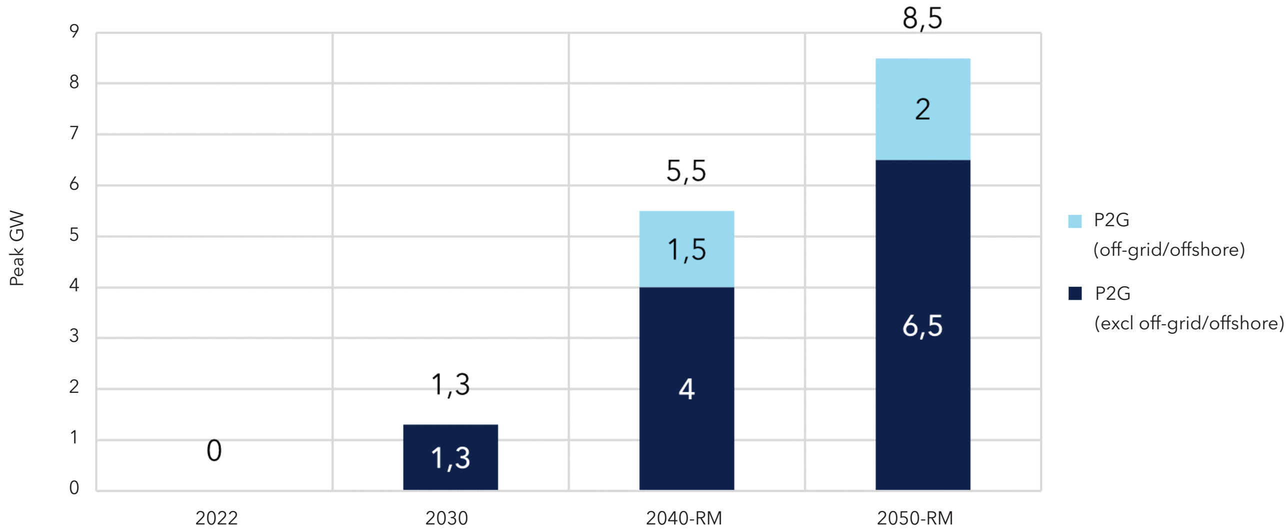
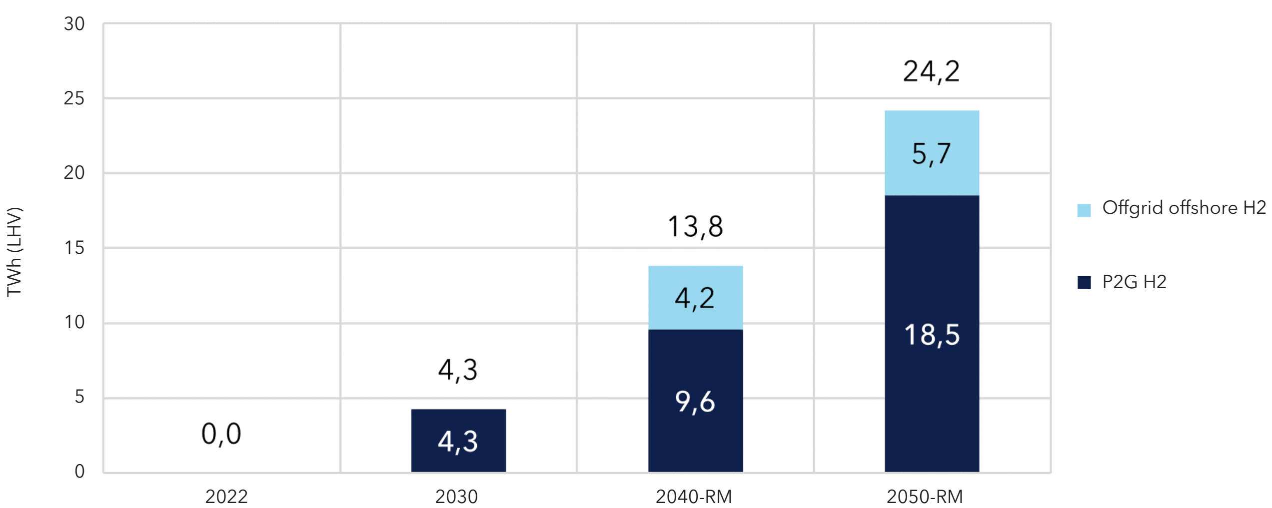


FIGURE 5-11

Hydrogen supply outlook



5.2.4 CO_2

At the moment, there are no CCUS (Carbon Capture, Utilisation, and Storage) facilities in Lithuania. CCUS will have increased by 2050 reaching 2.2 MTon of CO_2 captured by 2050. The majority will be captured from electricity generation (at biomass and waste CHPs) - 1.5 MTon, with the remainder coming from industrial processes, and mainly cement. Captured CO_2 will enable the production of synthetic fuels – almost 1 MTon could be used for this purpose. It is also noted that CO_2 captured from biomass can result in negative CO_2 emissions from biomass plants, whereas the captured carbon can contribute to zero-carbon production of synthetic fuels. Overall, captured amounts of CO_2 (in Mton) are expected to be minimal and can be too small to support the build out of a CO_2 pipeline infrastructure.

It can be foreseen that CO_2 transport by truck could be sufficient to accommodate needs. DNV recommends a more detailed analysis on CCUS, for instance to obtain a more detailed view on carbon utilisation, as the value vary per application depends on other synthetic fuel feedstocks.

5.2.5 Synthetic fuel production

Development of CCUS technology creates opportunities for Lithuania to develop synthetic fuel production even before 2040, depending on the availability of domestic hydrogen and CO_2 capture. By 2040, as much as 1.5 TWh of synthetic methanol and 0.5 TWh of synthetic kerosene can be produced. By 2050, these figures are projected to increase to a total synthetic fuel generation of 3 TWh.

FIGURE 5-12

CCUS capture and usage outlook

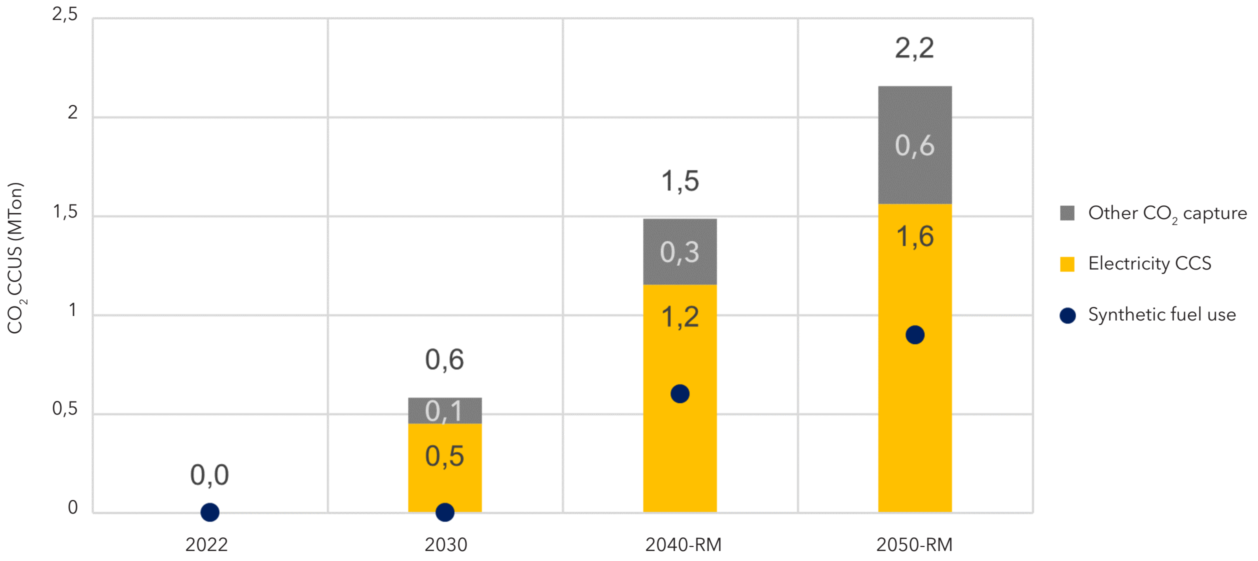
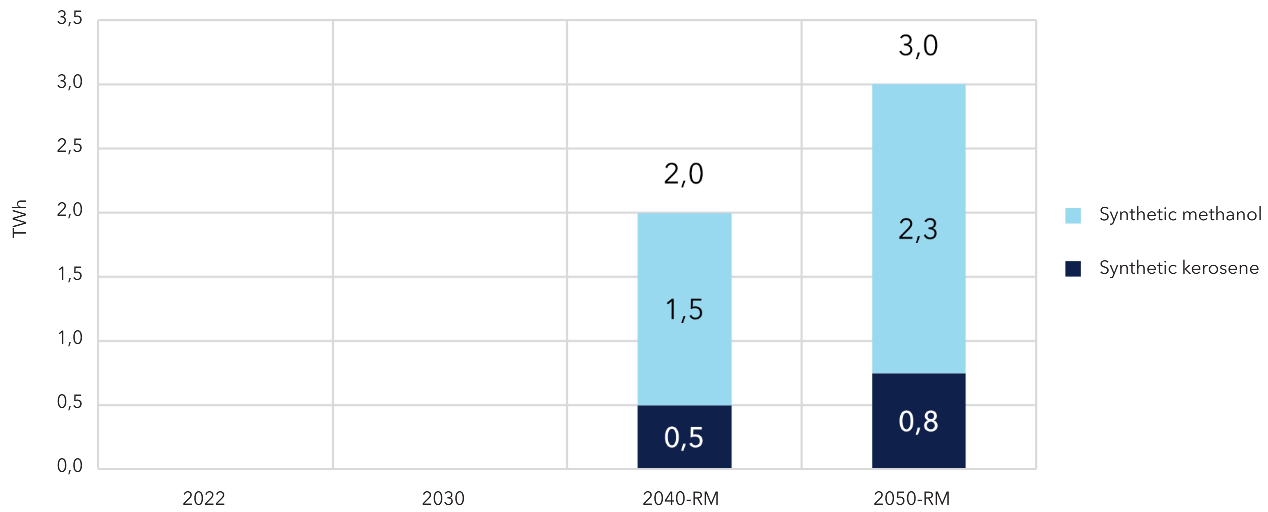


FIGURE 5-13

Synthetic fuel production outlook



5.2.6 District heating

Due to the shift to decentralised renewable energy based heating and advancements in building energy efficiency, it is foreseen that the district heat supply would decline by 2050. Currently, Lithuania produces 11.1 TWh of district heat using 8 TWh of biomass and 3.1 TWh of methane. However, by 2050, it is expected that this demand would have decreased to 7.7 TWh in total where ambient heat, residual heat from industry, electrical heating, biomass, and waste will all contribute to district heating. Even though it is now insignificant, district heat supply from electrical heating will account for 3.4 TWh by 2050. As more buildings switch to electric heating systems, they will no longer require heat supplied by centralised district heating networks. Demand for cooling, whilst negligible today (0.6 TWh), can increase significantly by 2050 due to the desire to provide high-quality services (thus mainly coming from buildings sector). If so, the demand could reach up to 3.5 TWh and will be supplied by

It is noted that energy demand for cooling is expected to increase in Lithuania from the current 0.7 TWh in 2020 to 1.4 TWh by 2030, 2.3 TWh by 2040 and 3.4 TWh by 2050[18]. This increase relates to a common increasing need for cooling, additional cooling demand from newly constructed buildings, and to increasing needs for cooling in relation to the impact of climate change.

In 2022, there were 0.21 GW of heat pumps installed in households in Lithuania, converting electricity into heat. By 2050, this value will rise sharply to 2 GW for households. Similarly, power-to-heat capacity for buildings, industry and district heating will grow, mainly consisting of heat pumps and electric boilers. In total the capacity of power to heat technologies in Lithuanian energy system in 2050 will reach more than 3.5 GW. The deployment of electrical heat pumps in households, buildings, industry and district heating not only drives decarbonisation of these sectors but will also significantly contribute to the provision of flexibility to the energy system of Lithuania.

FIGURE 5-14

District heat supply outlook

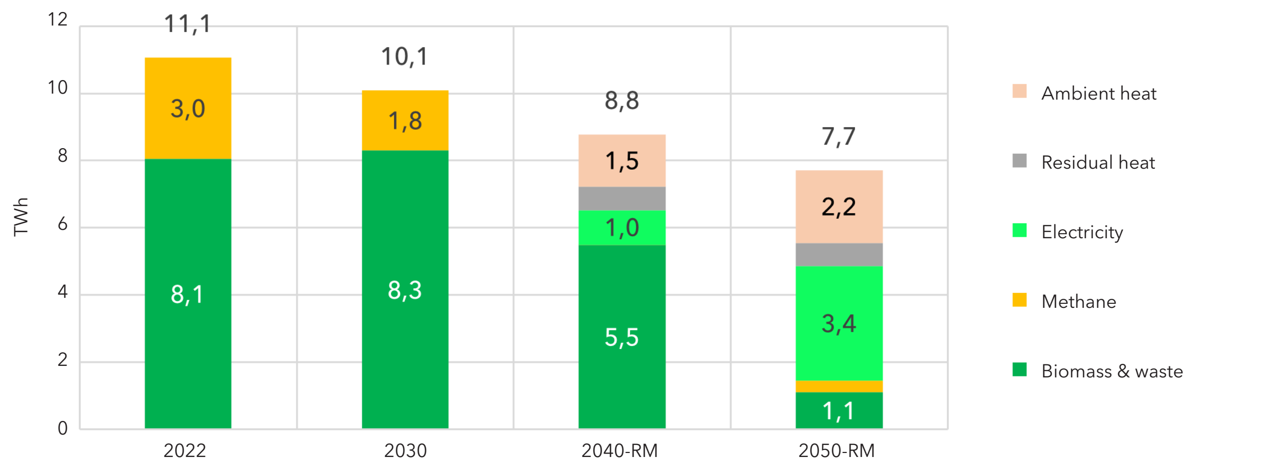
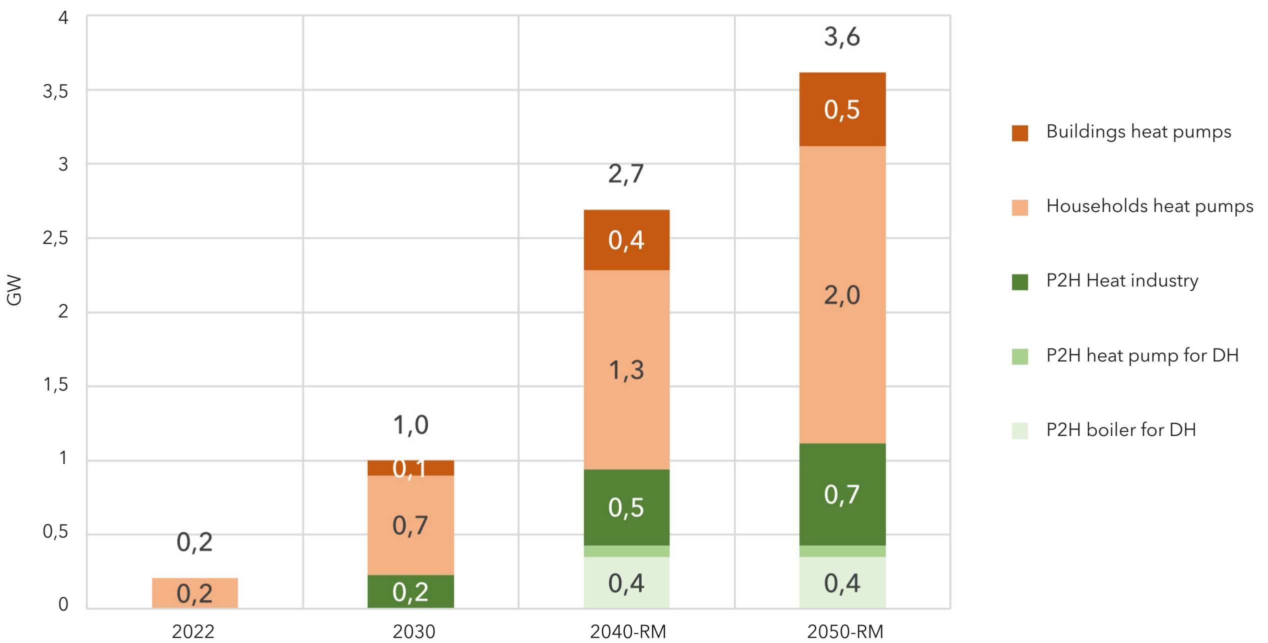


FIGURE 5-15

Power to heat sources outlook



[18] As per forecast from "Išsamaus nacionalinio šilumos ir vėsumos potencialo įvertinimo studija", Vilnius Economics and TES, 2022

5.2.7 Biomass including biofuels and waste

By 2030, Lithuania's biomass supply (in this study 'biomass', if not explicitly specified otherwise, includes not only dry wood and it's derivatives, but also agricultural waste, organic and other waste or different types of biofuels processed from biomass, e.g. biodiesel, biogasoline, biogas, etc; a combination of different biomass types can also be referred to as 'biogenic fuel') is projected to grow compared to current amounts, including imports and domestic generation. By 2030, it is anticipated that domestic biomass supply will amount to 20 TWh and the biomass imports will be 14 TWh, in order to fulfil increasing demand for biomass. However, as demand for biomass is expected to decrease after 2030, the supply of biomass will decrease as well. By 2050, domestic biomass supply is expected to reach 13 TWh, whereas the import of biomass is estimated to decrease significantly to only 2 TWh given the lower demand for biomass. Section 5.3.3 describes the main drivers underlying these changes in demand for biomass.

5.3 Demand

Demand is structured per energy carrier, such as electricity, hydrogen, biomass and methane, with some additional insights into end-use sectors, namely transport, industry and built environment. Finally, the national energy demand is presented per fuel type and per sector.[19]

5.3.1 Electricity

Lithuanian electricity demand will grow tremendously, from 12 TWh in 2022 to 74 TWh in 2050. The rate of growth is somewhat higher between 2030 and 2040 but overall stays at around 20 TWh per decade. Notably, the system will go from net electricity importer in 2022 (8.4 TWh of net imports) to net exporter already by 2030, with the largest net electricity exports foreseen by 2040 (5.7 TWh).

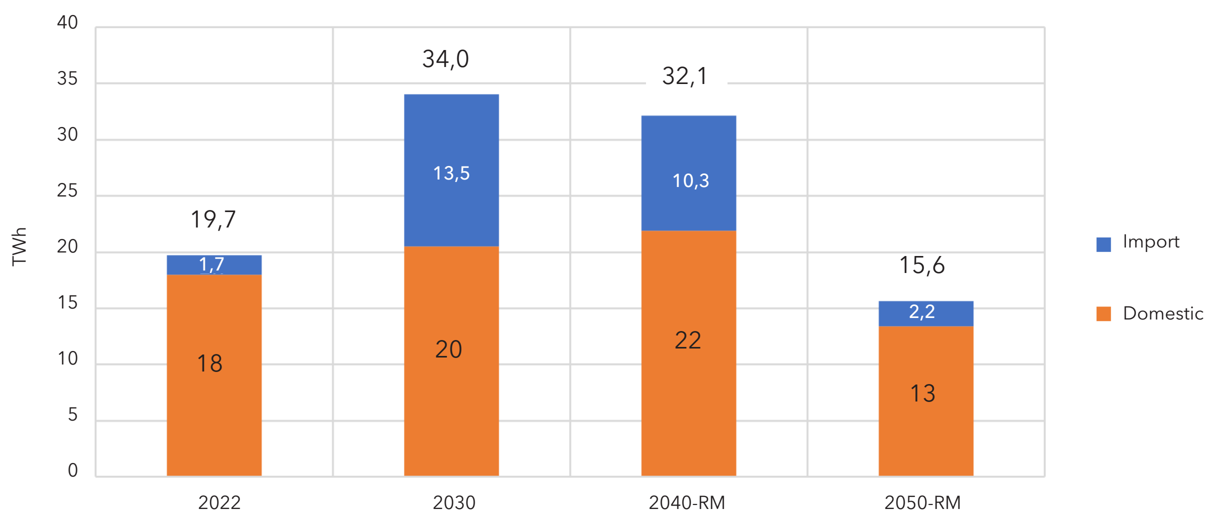
The majority of electricity demand uptake is driven by power to gas (hydrogen production) sector, accountable for 35.5 TWh, electrification and growth of industry – 12.6 TWh, and electrification of passenger transport – 6.3 TWh. The only sector where electricity demand experiences a slight decrease is in buildings, where it is mainly driven by efficiency improvements.

5.3.2 Hydrogen

Hydrogen demand in Lithuania will grow to 24 TWh by 2050, with moderate increase to 4 TWh by 2030 and 10 TWh per decade from then onward. The main driver behind the increasing demand is industry decarbonisation, where hydrogen will play a major role both as a feedstock (15.7 TWh in 2050, which includes synthetic fuels) and heat source (4.6 TWh by 2050). Another demand sector where hydrogen use is not negligible is transport, where hydrogen will be primarily featured in aviation and long-distance heavy weight trucks, as shown further. Finally, a certain volume of hydrogen will be exported to the neighbouring countries, around 1.5 TWh (net) per year. In all other sectors hydrogen will not play a role.

FIGURE 5-16

Biomass supply outlook (including biofuels and waste)



[19] Note that the feedstock demand of refinery is excluded in all figures presented in this section (where could be relevant) due to significant uncertainty of how the refinery will develop in the next decades. This has no impact on other end-use sectors demand.

FIGURE 5-17

Electricity demand outlook

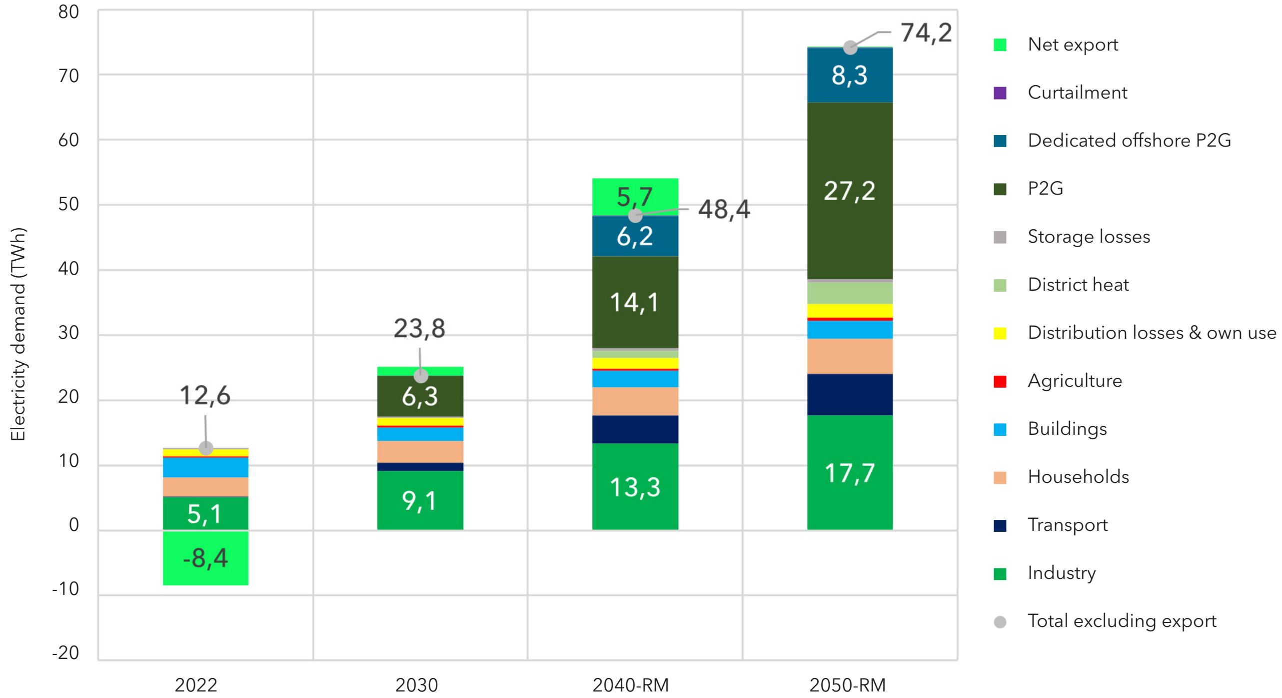


FIGURE 5-18

Electricity demand change per sector

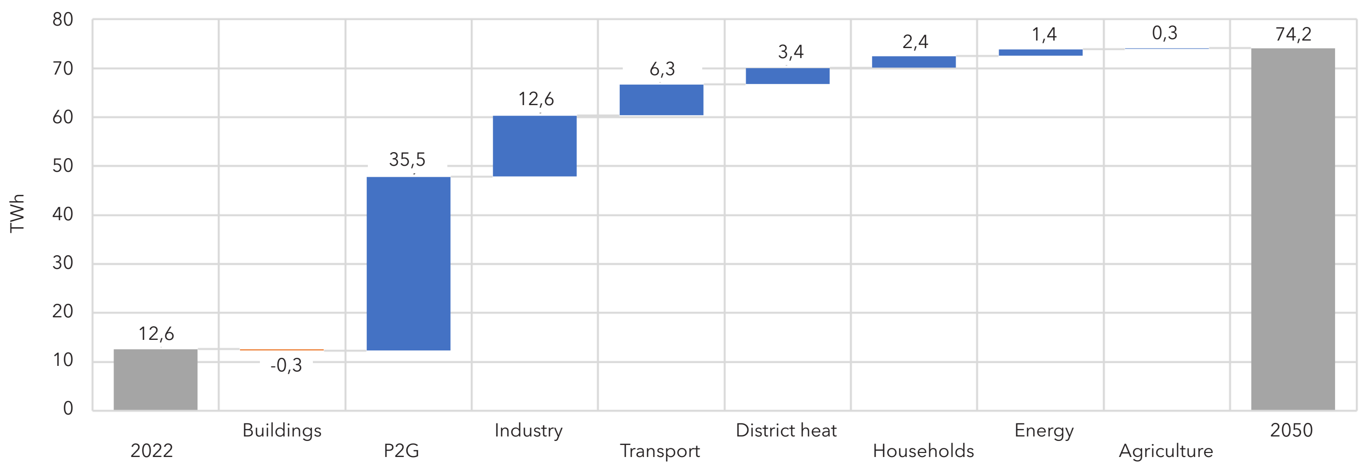
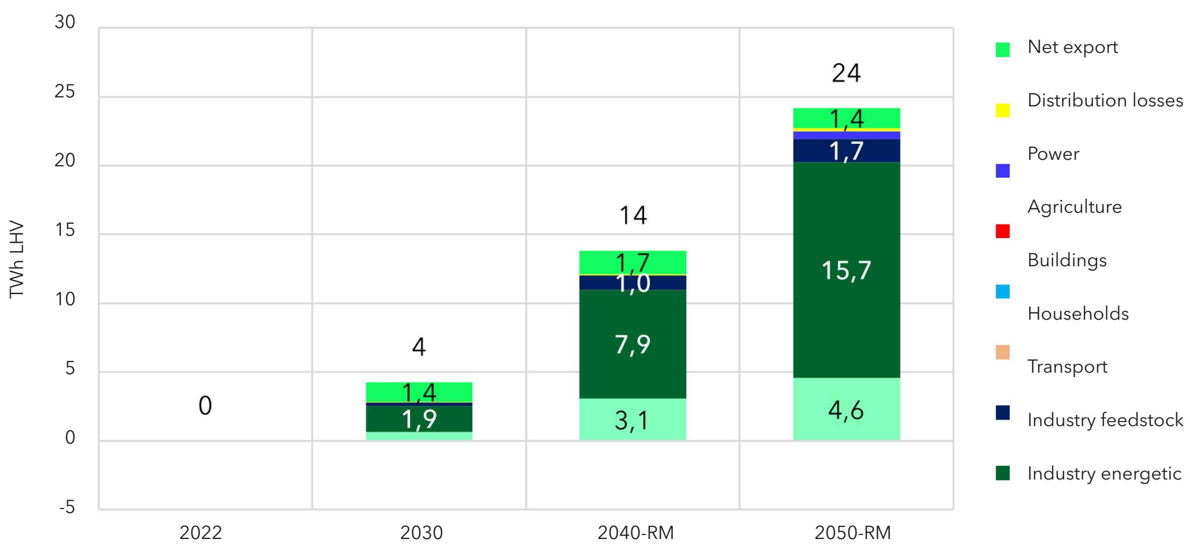


FIGURE 5-19

Hydrogen demand outlook



5.3.3 Biomass including biofuels and waste

Demand for biomass (in this study 'biomass', if not explicitly specified otherwise, includes not only dry wood and it's derivatives, but also agricultural waste, organic and other waste or different types of biofuels processed from biomass, e.g. biodiesel, biogasoline, biogas, etc; a combination of different biomass types can also be referred to as 'biogenic fuel') will experience growth in the period between now and 2030 from 20 to 34 TWh, as biomass will become the main low-carbon energy carrier in that period, to be later replaced by hydrogen. From 2030 to 2050 demand for biomass will decline – by 2 TWh in the first decade, and by 16 TWh between 2040 and 2050.

The main sectors driving changes in both directions are district heating and transport. The latter one is highly uncertain, as the share of biofuels in 2030 is subject to a complex political and economic factors interplay, which is hard to forecast. This study assumed a bullish uptake of bio-gasoline and biodiesel in the coming years aiming to drive down emissions from the transport sector, which results in 8.3 TWh of demand. If this is not realised, the 2030 value could be lower by 2-4 TWh.

The other demand sectors are better predictable. Biogas production is expected to scale up to reach up to 6.4 TWh in 2040. The use of biomass in households will decline from the current 5.3 TWh to almost zero in 2050 due to electrification of heat. Biomass will see higher utilisation in district heating and industrial heating towards 2030 but will decline afterwards, especially in the district heating sector. In contrast, biomass will become an important source of carbon for the industry and its use as a feedstock will grow after 2030 to reach 3.4 TWh by 2050.

In terms of types of biomass used, dry biomass accounts for more than 50% of all biomass used and is the only type that needs to be imported in different quantities depending on the year. Dry biomass is primarily used for heating and as feedstock in industry. Domestic stocks of Lithuania of wet and oil-containing biomass, which are mainly used for the production of biogas and biofuels are sufficient.

FIGURE 5-20

Biomass demand outlook

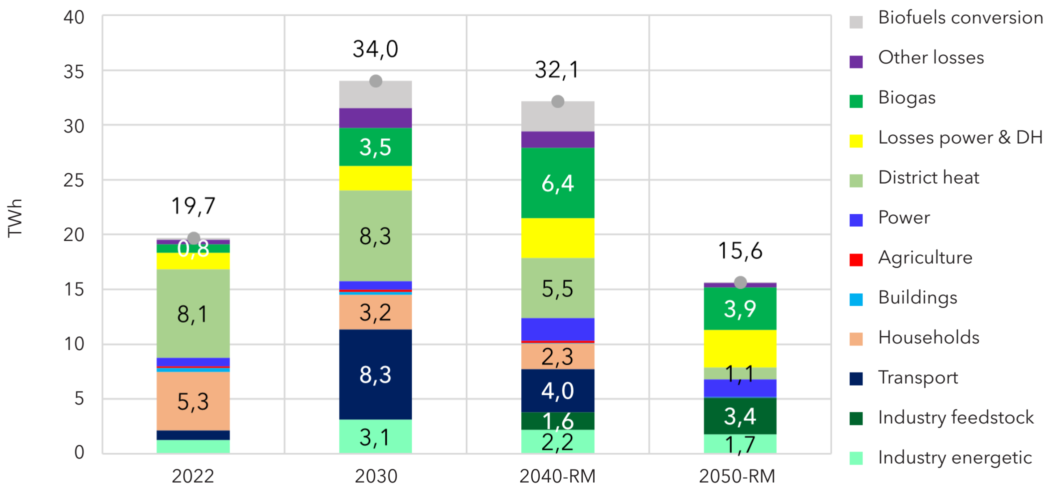
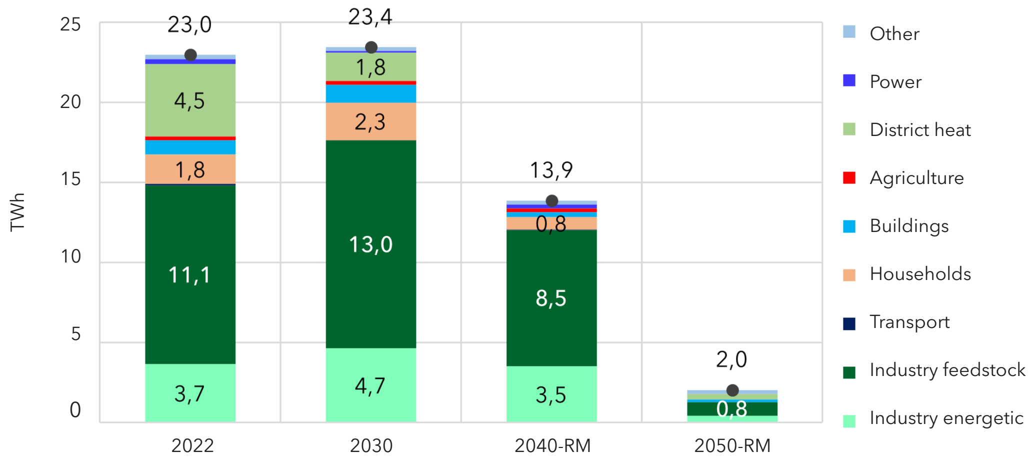


FIGURE 5-21

Methane demand outlook



5.3.4 Methane

Demand for methane will remain stable until 2030 to diminish rapidly from 23 TWh to 2 TWh by 2050. Between 2022 the share of methane in district heating will decline (due to substitution by biomass) but will be offset by its growth as industry feedstock, mainly in fertilisers. From there onwards, the role of methane in the industry will go down, as it will be replaced by hydrogen, and to some extent biomass.

5.3.5 District heating

Demand for district heating will maintain a steady downward trend falling from 11 TWh in 2022 to 7.7 TWh by 2050. The main causes of this trend are improvements in energy efficiency in households and buildings which account for a major part of demand. Both industry and buildings will switch to alternative heat supply options (heat pumps and boilers) which will further reduce the role of the district heating.

From the perspective of sector coupling, it is projected that the demand for electricity for heating purposes will increase up to 13.8 TWh, resulting in higher loads on power networks but also providing potential for flexibility. Industrial electric heating is the largest consumer of electricity, followed by heat pumps in the residential sector and power to heat in district heating. The residential sector contains 1.29 million residences and, thus, representing a large demand for space heating.

It is noted that energy demand for cooling is expected to increase in Lithuania from the current 0.7TWh in 2020 to 1.4TWh by 2030, 2.3TWby 2040 and 3.4TWh by 2050[20]. This increase relates to a common increasing need for cooling, additional cooling demand from newly constructed buildings, and to increasing needs for cooling in relation to the impact of climate change.

FIGURE 5-22

District heat demand outlook

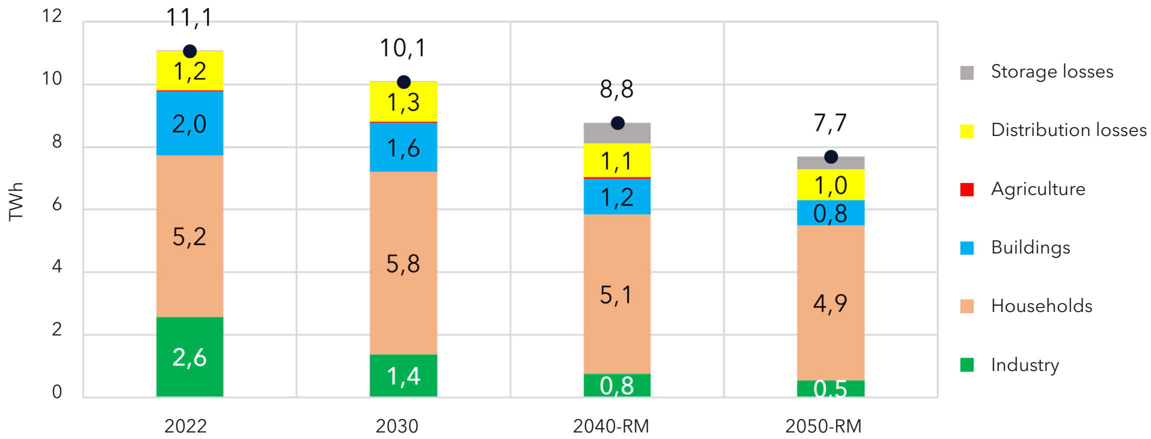
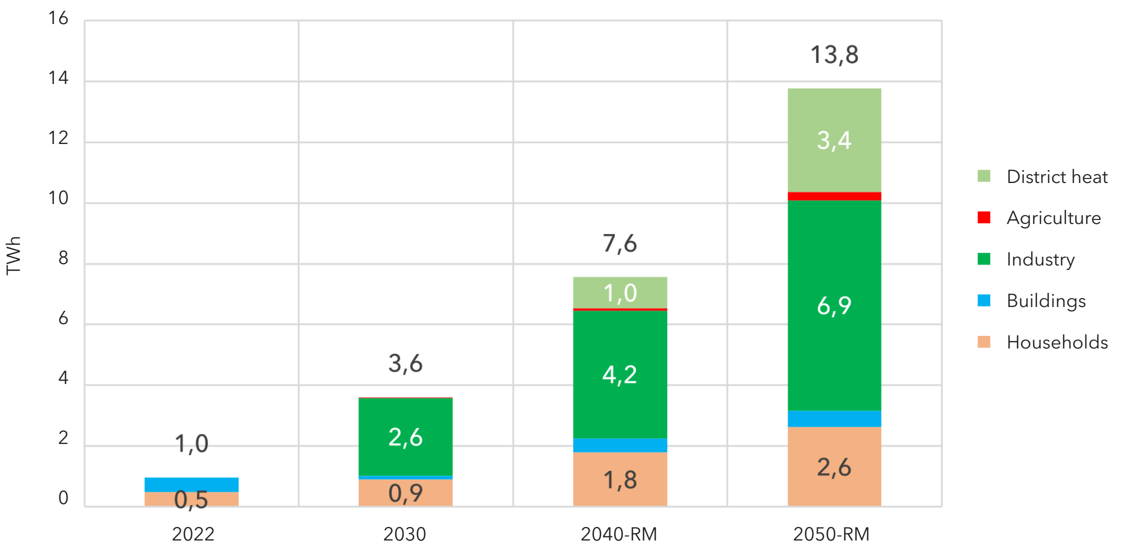


FIGURE 5-23

Demand for electricity for heating outlook



[20] As per forecast from "Išsamaus nacionalinio šilumos ir vėsumos potencialo įvertinimo studija", Vilnius Economics and TES, 2022

5.3.6 Energy use in transport

Looking at the demand sectors, road transport is one which will experience the most dramatic changes due to fuel switch – from oil products to electricity. This will result in a decrease of demand from almost 18 TWh to 4 TWh for passenger cars and a somewhat less sharp change for trucks and vans, which constitute the minority of road transport demand, and will also feature some usage of hydrogen by 2050.

As discussed, this study made an ambitious assumption on the role of bio-gasoline and bio-diesel in 2030. If reality turns out less optimistic for these fuels, they will be replaced by conventional oil-based analogues, thus the rate of decrease between 2022 and 2030 will be slower and the share of oil in the mix will be higher than here shown. Nevertheless, this would have no impact on the final situation in 2050 where 100% of passenger cars are electrified, while part of truck and van fleet features hydrogen-based engines.

Other than road transport types are responsible for a significantly lower part of the final demand and are dominated by rail (from 0.65 TWh in 2022 to 0.3 TWh by 2050). There, the switch will be in favour of the mix of electrical and hydrogen fuelled trains, depending on whether these are passenger or cargo trains. The shipping sector will switch to ammonia and potentially also other synthetic fuels and maintain approximately the same total demand volume.

To support the uptake of EVs, a coordinated roll-out of urban, but also rural charging infrastructure is required in close coordination with grid developments. Special attention should be placed on heavy-duty fast charging and electricity system development opportunities for optimal planning and usage. Important to note here, is that electrical road transport will become an additional source of flexibility for the power system to be provided by regular EVs and those equipped with vehicle-to-grid (V2G) capability. This is discussed further in section 5.5.

FIGURE 5-24

Road transport final demand outlook

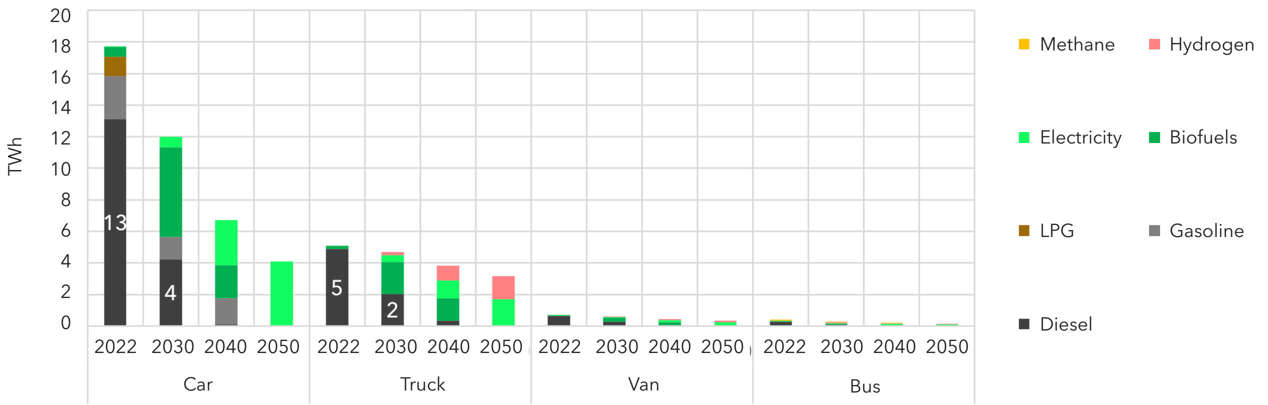
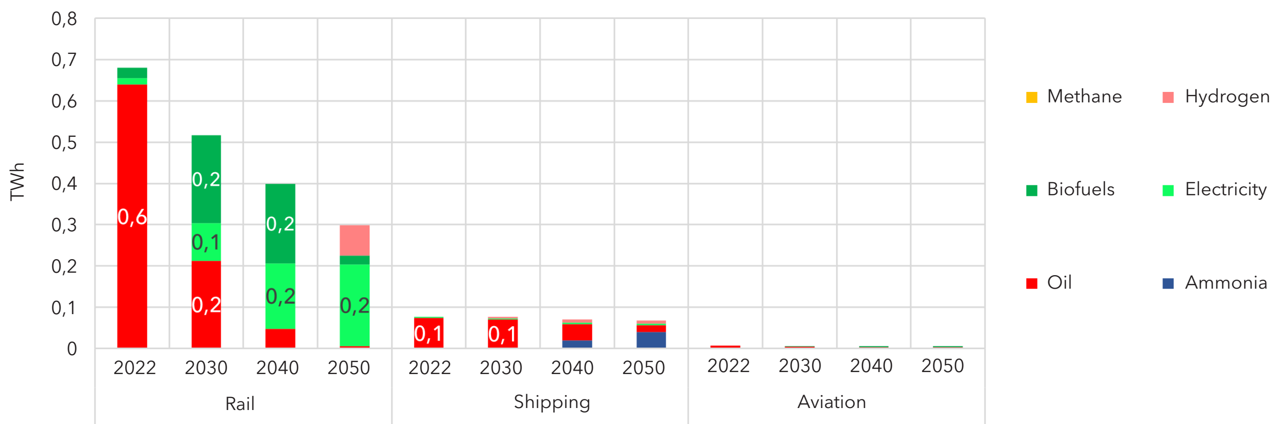


FIGURE 5-25

Other domestic transport final demand outlook



5.3.7 Energy use in industry

The Lithuanian industry can be broadly divided in chemical, fertiliser, refinery and other (with a large share of cement production) clusters. While a common assumption for all of these industries is their growth in the absolute output by 50% towards 2050, the breakdown per fuel type is different. The chemical industry will switch from methane as its main feedstock to a mix of biomass and hydrogen. Fertilisers will experience the same trends, where hydrogen will play a major role, according to the modelling performed but the reality will largely depend on the price of biomass and hydrogen. Refinery and other industry will see a shift to higher shares of electricity, hydrogen and biomass towards 2050.

5.3.8 Energy use in households and buildings and agriculture

Energy demand in the built environment is projected to decline between 2022 to 2050 mainly driven by heat electrification and efficiency improvements. In particular district heat demand in buildings will reduce by 50% to be compensated by heat pumps. In households, district heat demand will remain rather constant, but demand from biofuel boilers will fall to zero. Instead, heat pumps will take over, covering almost 50% of the final demand.

FIGURE 5-26

Industry final demand outlook

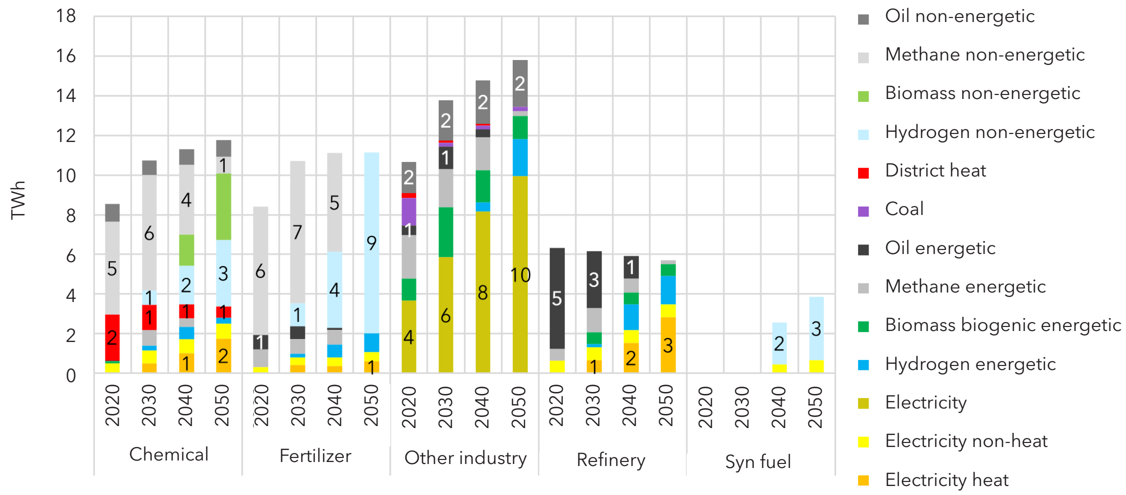
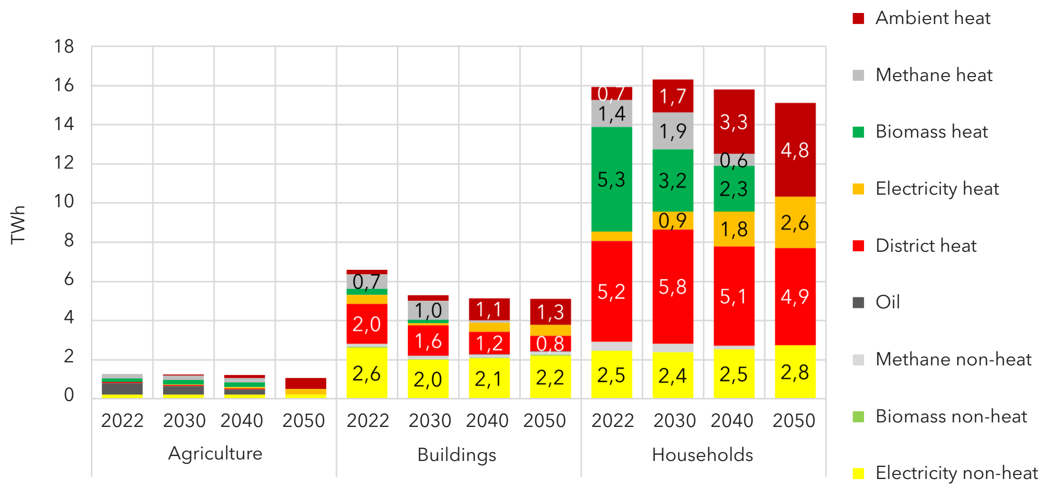


FIGURE 5-27

Built environment final demand outlook



5.3.9 Domestic energy demand

This section summarises the individual sector trends – ceased reliance on fossil fuels, such as oil and methane; increased role of biomass, waste and other biogenic fuels towards 2030 to almost disappear by 2050; increased electrification with more than doubling of electricity share; uptake of hydrogen as the main feedstock carrier. The overall final energy demand will decrease slightly from 93 TWh in 2022 to 75 TWh in 2050.

When considering the evolution of final energetic and non-energetic demand per sector, it can be seen that most of the sectors will experience a gradually falling energetic demand over the period from 2022 to 2050. Industry is the only exception where the reduction is minor since efficiency improvements there will be compensated by the overall output growth. At the same time, the share of non-energetic demand will increase significantly as Lithuanian domestic industry will grow and more products will be produced.

FIGURE 5-28

Final energetic and non-energetic demand per fuel outlook

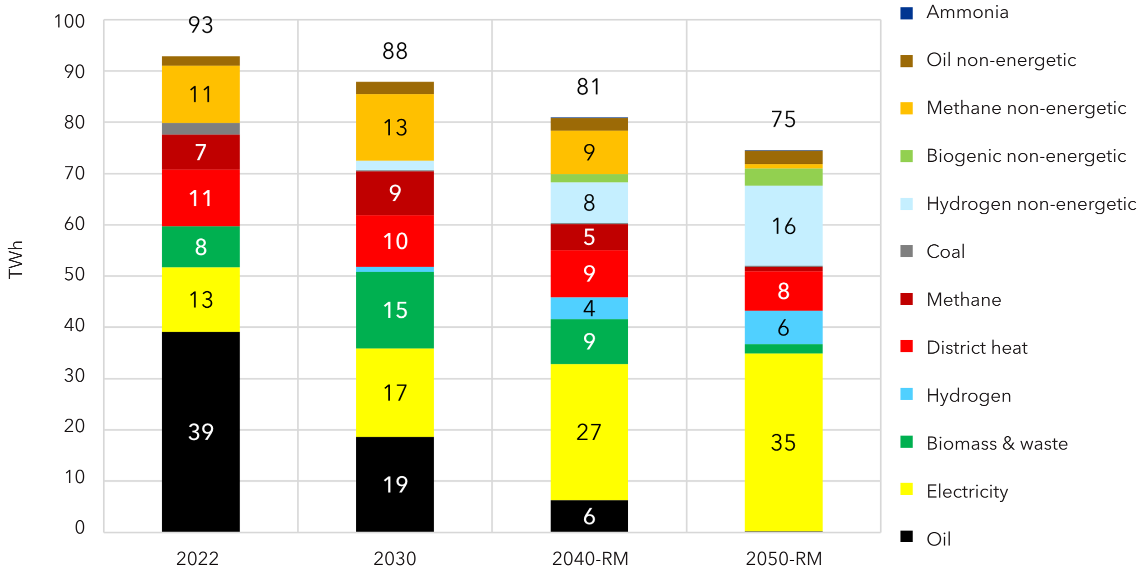
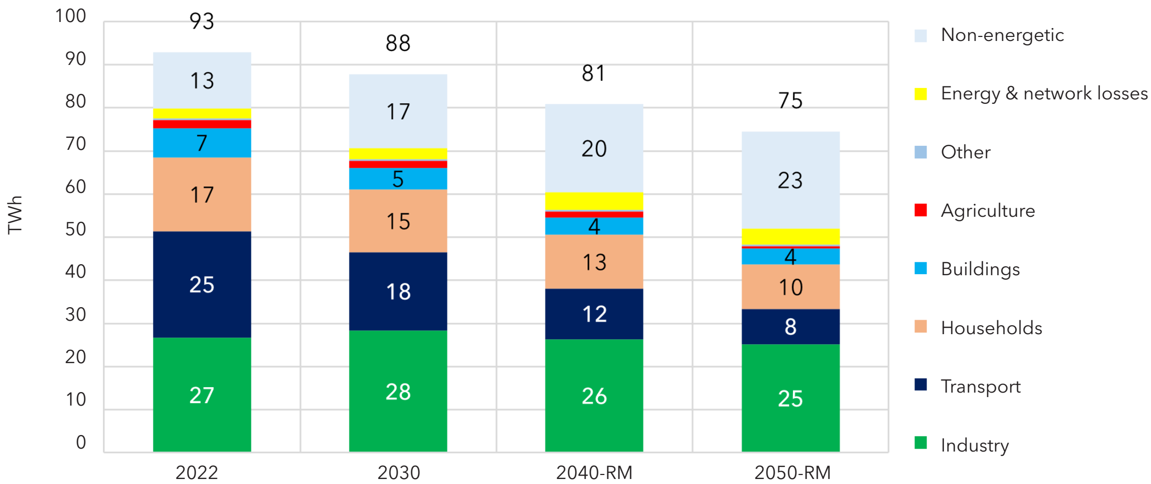


FIGURE 5-29

Final energetic and non-energetic demand per sector outlook



5.4 Cross-border energy exchanges

Despite the strategic objective of becoming a net energy exporting country, the applied modelling shows that this is hardly achievable as Lithuania does not have domestic resources of some key fuels, namely uranium, oil and sufficient quantities of biomass for the foreseen system size. Nevertheless, the level of energy dependence will decline significantly both in relative and in absolute terms – from 69 TWh of net imports in 2022 to 38 TWh in 2050. In fact, uranium will comprise the majority of imports in 2050, electricity imports and exports will level off, and fertiliser products and synthetic fuels will become the main export carriers.

It is important that Lithuania will have abundance of cheap electricity and hydrogen that could be exported as well. However, economically it makes more sense to convert those into higher value products, which albeit reducing the exports in energy terms (in TWh) increases the exports in monetary value (see energy system costs results further).

The applied modelling performed within this study captured electricity exchanges with neighbouring regions. For this, DNV aligned with stakeholders on a projection of the required interconnection capacities, among others considering the growth in domestic generation and the potentially large economic benefits from electricity trade with regions characterised by thermal generation, hydro and non-correlated weather patterns with respect to Lithuania, i.e. Central Europe and Nordics. Lithuanian electricity interconnection capacity will grow from just above 2.2 GW in 2022 to 5 GW in 2050, split among Baltics (1750 MW), Nordics (1400 MW) and Central Europe (1900 MW).

The growth in domestic electricity generation, dominated by low marginal costs generation, and interconnection capacity will change the annual net trade position of Lithuania from a net importer to a net exporter, balanced out by 2050 due to a significant annual domestic demand for electricity, as indicated by the below Figure 5-32. It is noted that net import positions will become increasingly volatile on an hourly basis towards 2050.

FIGURE 5-30

Net energy import outlook

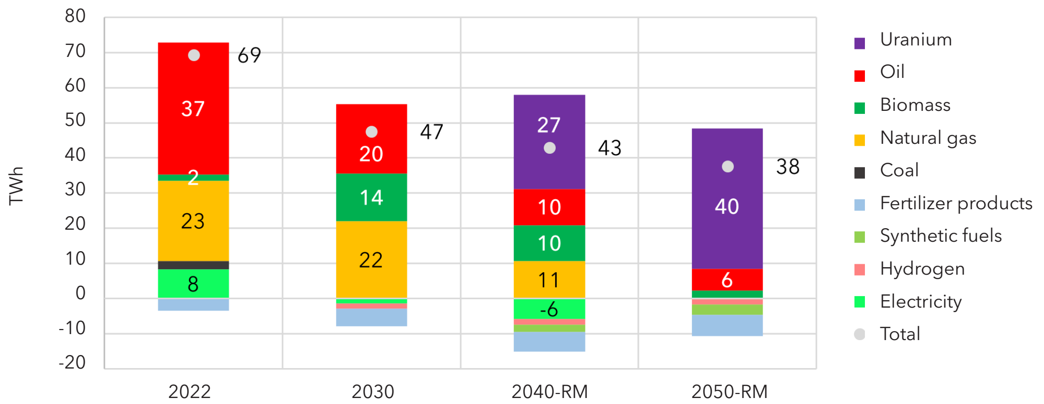


FIGURE 5-31

Electricity interconnection capacity outlook

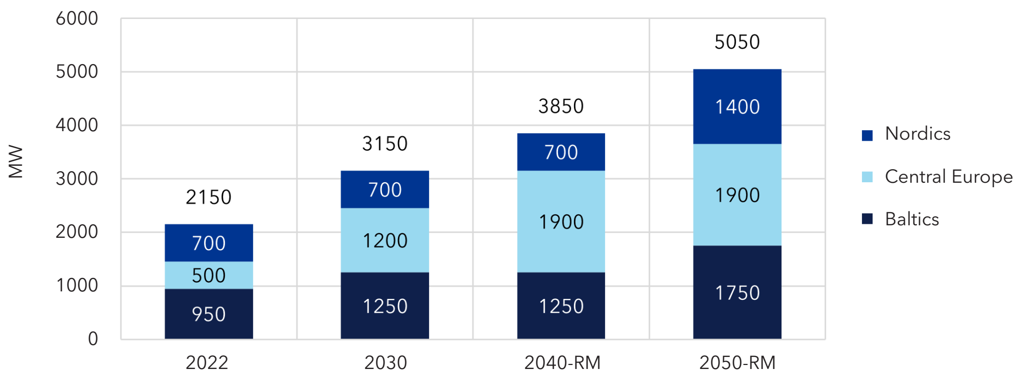
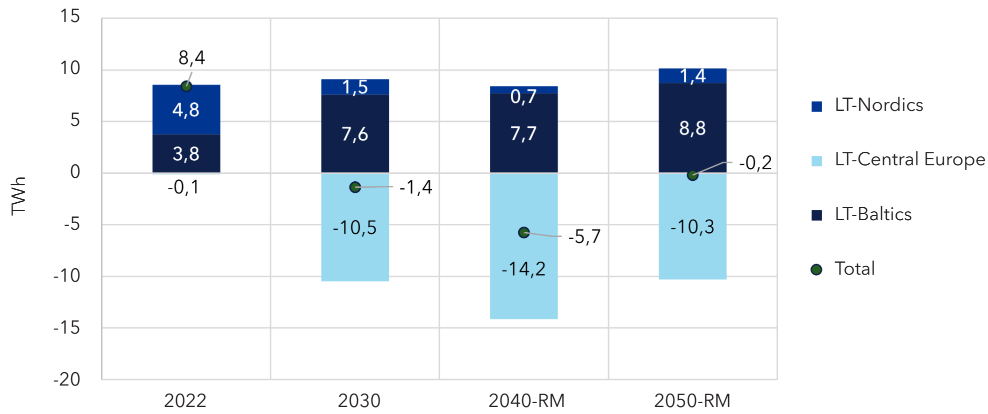


FIGURE 5-32

Electricity net import outlook



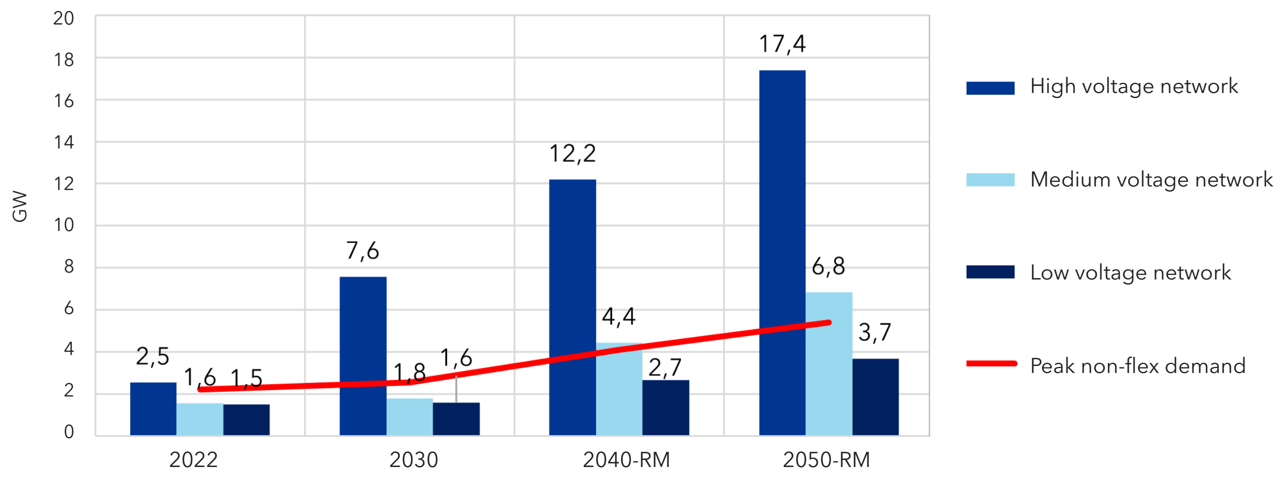
Whereas in 2022 Lithuania imported 8.4 TWh of electricity from Nordics and Baltics, already in 2030 Lithuania will emerge as net exporter at 1.4 TWh with the majority of exports in the direction of Central Europe. The largest electricity exports are expected around 2040, reaching a total net position of 5.7 TWh. In 2050, Lithuanian electricity imports and exports will be well balanced, with net imports from Baltics being almost equal to net exports to Central Europe.

5.5 Adequacy, flexibility and storage

The adequacy and flexibility of the Lithuanian energy system concerns its capability to meet residual load at all times (adequacy) and to serve variable residual load (flexibility). Residual load is here defined as non-dispatchable demand minus infeed of solar and wind generation, since solar and wind are seen as non-dispatchable resources. Residual load has to be served by dispatchable resources. A positive residual load requires supply from dispatchable supply resources. A negative residual load indicates an oversupply situation which needs to be absorbed by demand from dispatchable demand resources. Typically, adequacy relates to firm capacity requirements (GW) to serve residual load (GW) at all times, whereas flexibility relates to ramping requirements (GW/hr) induced by residual load variability. In this section we first assess the development of non-dispatchable demand and network peak load across different energy carriers. Thereafter we assess adequacy and flexibility of the Lithuanian energy system, as well as the requirements for storage across energy carriers.

FIGURE 5-33

Network peak load evolution in RM scenario



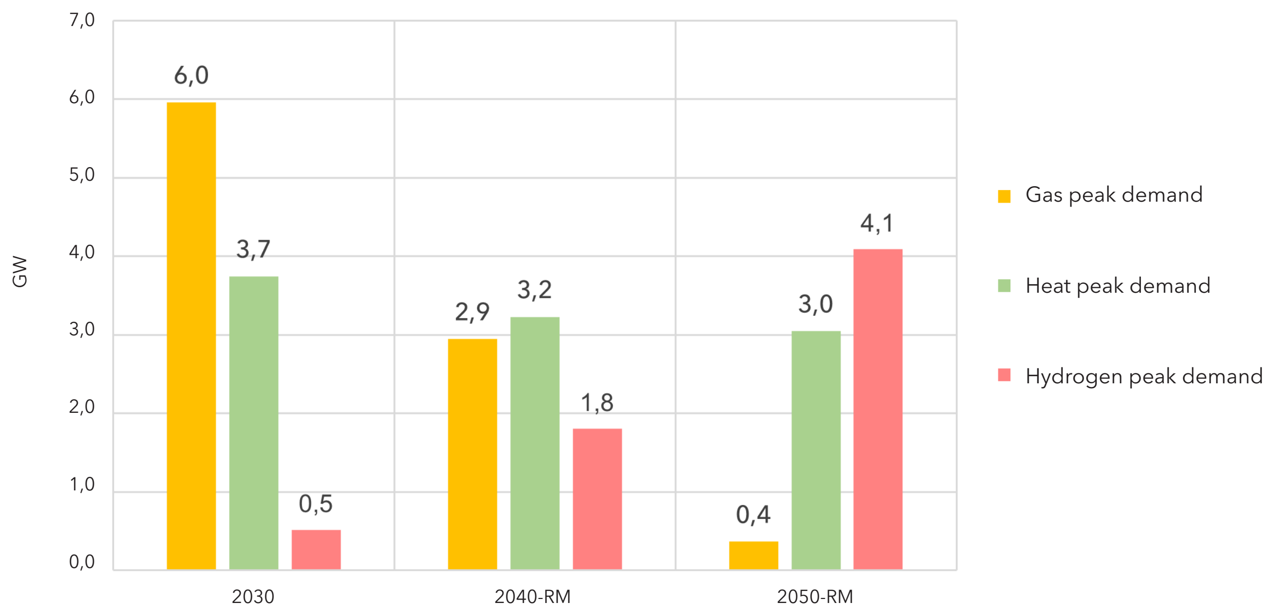
5.5.1 Network load for electricity, gas, heat and hydrogen

Electricity network peak load will grow immensely at all voltage levels reaching as much as 17.4 GW at the high voltage grid in 2050 (compared to 2.5 GW in 2022). The medium voltage grid will experience peak loads up to 6.8 GW compared to today's 1.5 GW, and the low voltage grid will be subject to peak loads of up to 3.7 GW. The larger share of this load will be coming from dispatchable resources, whereas the non-dispatchable peak demand will be limited to about 6 GW in 2050.

The network for natural gas, district heat and hydrogen will experience a different development in peak load. While for natural gas the peak load will gradually decrease from 6 GW to 0.4 GW in 2050, the situation for hydrogen will be the opposite – growing from 0.5 GW in 2030 to reach up to 4.1 GW in 2050. At the same time, the peak load of the district heat network will decrease only slightly, reaching 3 GW in 2050.

FIGURE 5-34

Gas, heat and hydrogen network peak demand evaluation in RM scenario



5.5.2 Adequacy

In order to manage these peaks, the Lithuanian energy system will need to be equipped by a broad range of dispatchable resources. These include demand resources such as EVs with V2G capability, hydrogen electrolysers, and power to heat; pure storage such as pumped hydro and batteries; dispatchable generation such as SMR and CHP plants; and electricity interconnectors. Section 4.2 provides a detailed description of flexible resources as projected for all scenarios. These resources are required to ensure that non-dispatchable load is served at all times, i.e. the amount of hours of energy not served (ENS) equals to zero.

DNV has also assessed the capability of the energy system during so-called "dunkelflaute" periods. A "dunkelflaute" period is a relatively large time-interval with low wind and solar generation levels. For Lithuania this is likely to be a period of ~10 days in January. A typical way of assessing the adequacy of the system is by running a simulation for such a period whereby all domestic flexibility sources are being dispatched in response to the prevailing situation, and the capacity of cross-border interconnections is gradually decreased until an Energy Not Served-situation is reached. Table 5-1 indicates how much of the total interconnector capacity needs to be available during a "dunkelflaute" period for each scenario, before the model shows ENS, in other words showing how dependent the system is on cross-border capacity for managing adequacy issues.[21]

TABLE 5-1

Interconnector availability for ENS occurrence in RM scenario

Minimum IC availability requirement before occurrence of Energy Not Served in scenario	Unit	2040-RM	2050-RM
Interconnector availability	%	14%	17%

A correlation can be observed between the amount of available dispatchable resources and the need for interconnector availability to prevent ENS. A higher amount of dispatchable capacity allows a lower amount of interconnector availability before ENS occurs. Since by 2050 the Lithuania energy system will have significant flexibility resources to support system adequacy, the analysis indicates that only about 20% of interconnector capacity must be available during so-called "dunkelflaute" periods to avoid ENS. This example indicatively shows that the Lithuanian energy system in 2050 is adequately covering its demand requirements.

A traditionally very significant source of highly flexible capacity that can help to ensure adequacy are existing gas-fired (in Lithuania's case: CCGT) power plants. Should the adequacy of the system come under threat, due to a lacking availability of flexible alternatives and import capacity, for example as an outcome of more detailed (stochastic) adequacy assessments by the TSO, Lithuania has the option of considering implementing schemes to keep such an aging, more expensive form of generation available by incorporating it into a national strategic reserve generation pool, or another type of Capacity Remuneration Mechanism (CRM). The remuneration connected to this reserve should then be sufficient to ensure a proper maintenance of such assets, guaranteeing their immediate availability in case they are needed. It is noted that in the long term such natural gas fired generation plants might be replaced by (small or large scale) hydrogen fired generation plants.

Typically, system adequacy can be significantly improved by increasing interconnections with neighbouring countries in order to benefit from available flexible capacity in neighbouring markets and differences in load patterns. However, an increasing dependency of Lithuania and neighbouring countries on wind and solar resources could potentially also have a negative impact on system adequacy. Table 5-2 shows the correlation of the hourly wind speed in Lithuania with countries in the region. Onshore wind in Lithuania has a strong correlation with onshore wind in Latvia, Estonia and Poland, but a moderate correlation with generation profiles (i.e. wind profiles) in Sweden, and a weak correlation with Finland, Germany and Denmark. A green colour indicates a low correlation which can be seen as a positive attribute for cross-border exchange between the two countries.

TABLE 5-2

Correlation in hourly wind speed in Lithuania with countries in the region

	FI	EE	LV	SE	DK	DE	PL
LT	0.33	0.67	0.90	0.42	0.36	0.35	0.65

The regional wind speed correlation indicates that it is critical for Lithuania to be part of a large and well interconnected power system in Northern Europe, so that it can benefit from differences in wind patterns in nearby countries. It also indicates that electricity interconnections with countries such as Finland, Denmark and Germany can be complementary when only considering the differences in wind patterns.

[21] Energy Not Served indicates the amount of energy in MWh, that is demanded by consumers, which cannot be supplied due to insufficient generation and/ or import capacity

5.5.3 Flexibility

The future Lithuanian energy system will become dominated by variable renewable energy, such as offshore/onshore wind and solar PV, which inherently introduces variability and also uncertainty to the power system. This brings along various challenges regarding system flexibility for the purpose of balancing of supply and demand in order to guarantee security of supply. In the Lithuanian future energy system, much of the conventional flexibility resources will be retired and, thus, alternative resources need to be introduced while also unlocking maximum demand side flexibility.

Figure 5-35 indicates flexibility requirements in relation to residual load variability among different timescales (daily, weekly, monthly and seasonal). The required flexible capacity is significantly growing towards 2050 induced by residual load variability of as much as 10 GW on a daily scale in 2050. Additional flexibility will also be required on a weekly and monthly levels where residual load may shift by a few GWs within the respective period. Technologies and measures that are able to provide flexibility at hourly or daily timescale are typically short-cyclic (e.g., BESS) and differ from the flexibility options that are operational for weeks or months (e.g., PHS, hydrogen).

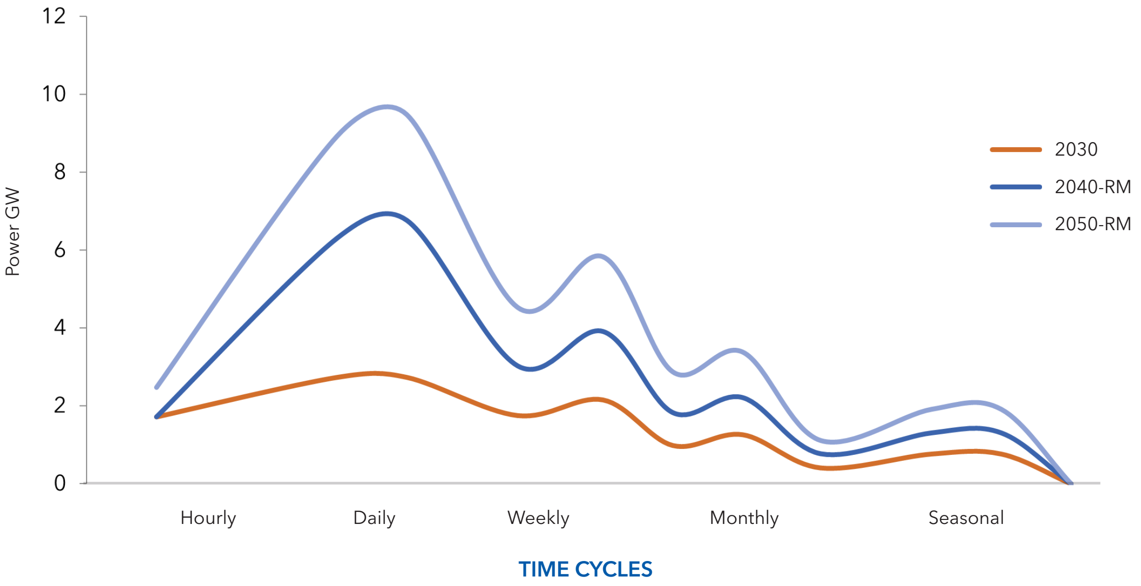
As indicated in the previous section, according to the conducted modelling, the availability of flexible capacities in the Lithuania energy system until 2050 is sufficient to serve residual load at all times (the amount of hours of ENS equals to zero).

Typically, flexibility relates to ramping requirements (GW/hr) induced by residual load variability. It is therefore important to assess the required hour-to-hour peak ramping capability of dispatchable resources in the future Lithuanian power system, by examining the variability of residual load for electricity. Upward ramping capabilities typically have to be matched by dispatchable resources (generation, storage, demand), whereas downward ramping could also be compensated by curtailment of variable renewable energy. Figure 5-36 provides an overview of the development of current and future required hour-to-hour upward/downward ramping capability of the Lithuanian power system.

The ramping requirements are significantly increasing in the future to a level of 5 GW in 2050, compared to 0.3 GW in 2022 and, thus, Lithuania needs to operate sufficient ramping capabilities to guarantee the security of supply also in the future.

FIGURE 5-35

The Power Spectrum of the Lithuanian residual load among different time cycles (hourly, daily, weekly and seasonal)[22]



[22] The peak power variability of the residual power load among different time-cycles is assessed, by a so-called power frequency spectrum analysis like a Fast-Fourier-Transformation (FFT). The outcome gives a valuable understanding of the peak power variability per time-cycle, whereby the value indicates the required peak power to flatten the residual power load per time-cycles.

5.5.4 Energy storage for electricity, gas, district heat and hydrogen

Electrical storage in the Lithuanian energy system will be provided by a pumped hydro plant of 1 GW and BESS system of 4 GW. Pumped hydro plant is technically capable of providing up to 11 GWh of storage, depending on the circumstances (water availability). BESS system will be able to deliver around 6.5 GWh of storage. Both of these plants can be suitable for managing short-term variations.

In terms of the storage for other carriers, Lithuanian energy system will see a decreasing need for methane storage to be compensated by growing heat and hydrogen storage requirements. Heat storage is projected to grow up to 2.3 TWh by 2050. The volume of required hydrogen storage can reach as much as 3.6 TWh assuming that the demand for hydrogen is non-dispatchable.

FIGURE 5-36

Overview of the required peak upward/downward ramping of dispatchable resources in the future Lithuanian power system[23]

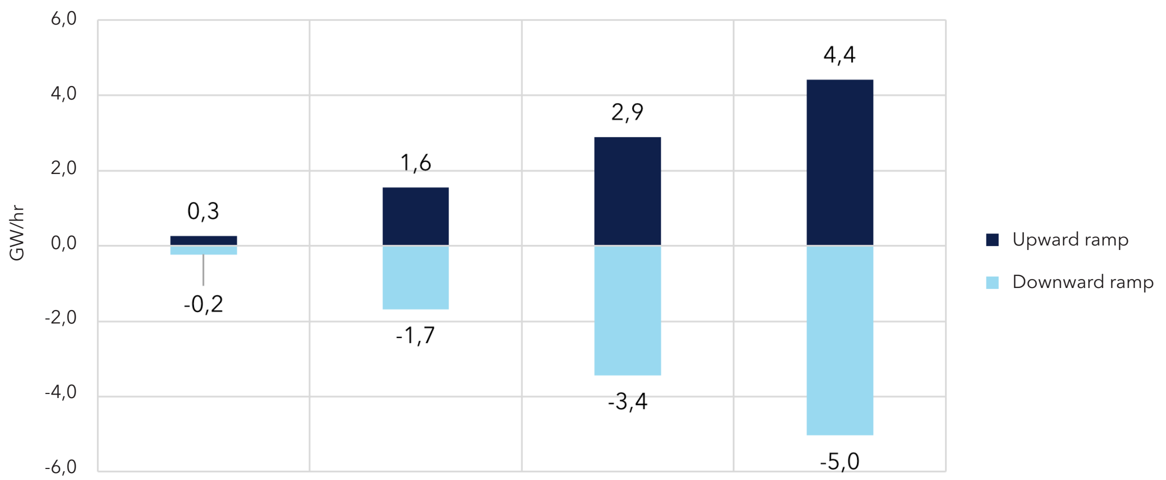
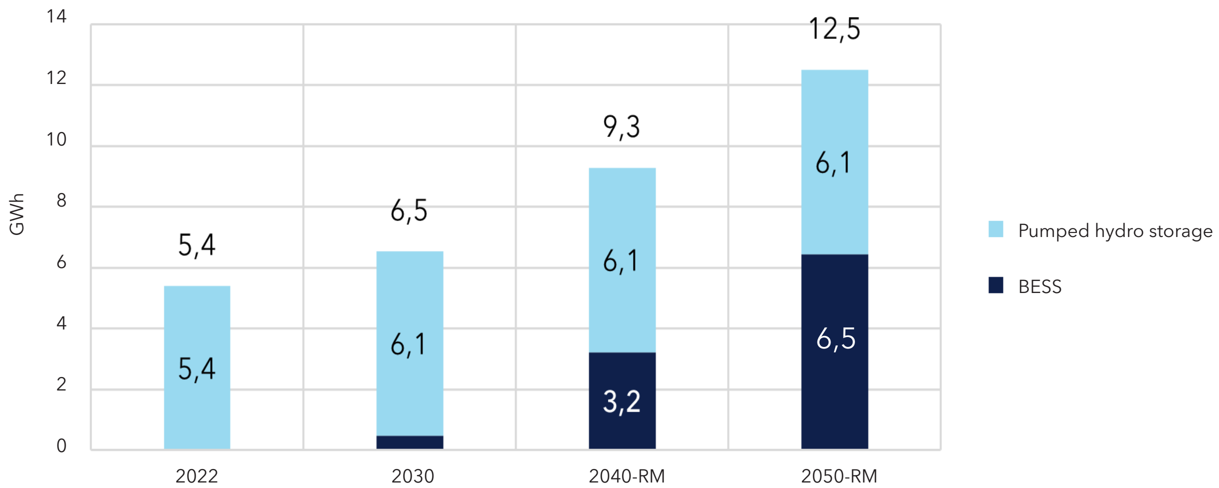


FIGURE 5-37

Short-term electricity storage energy volume installed per technology outlook



6 GWh was used in the model for pumped hydro plant (rated capacity is 11 GWh) as a conservative assumption to reflect potential water shortages and to assess how secure the system is under potentially unfavourable weather conditions.

[23] Based on the residual power load, the hourly peak upward and downward ramping was assessed, which subsequently has to be compensated by dispatchable resources.

FIGURE 5-38

Evolution of seasonal storage volume for network gas, network heat and hydrogen outlook

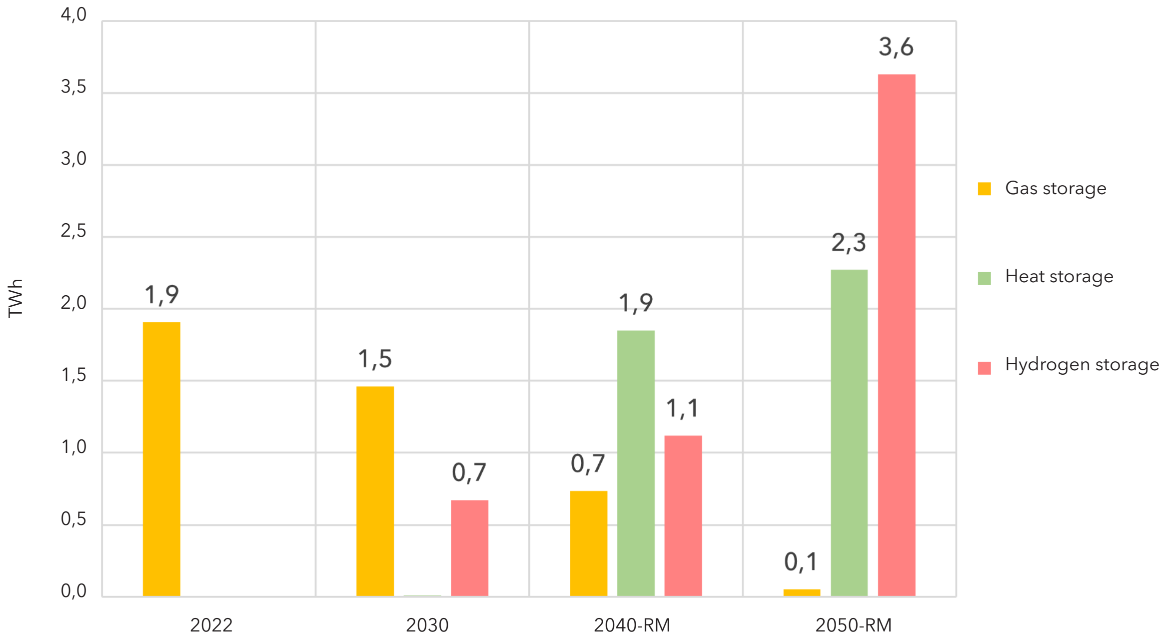
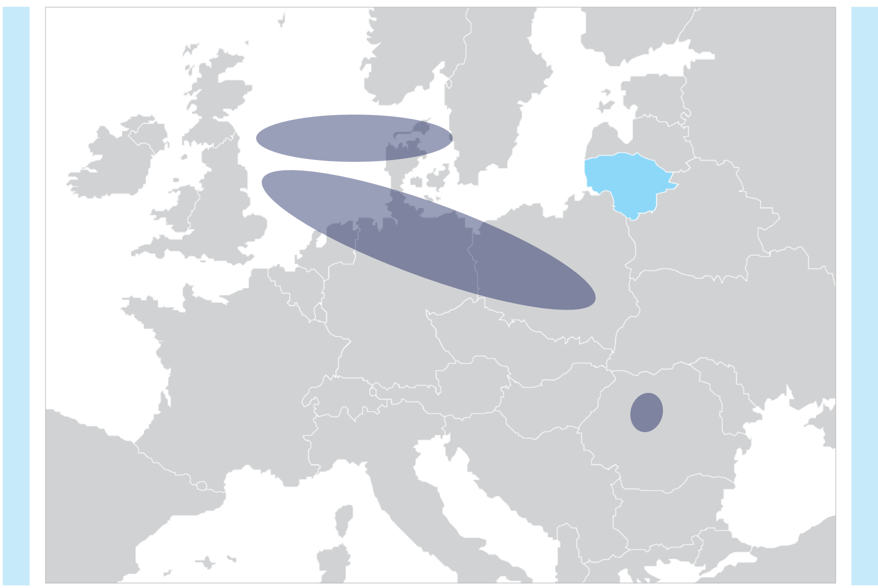


FIGURE 5-39

Geological hydrogen storage potential (indicative) in salt caverns (salt deposits in dark blue areas)



Notably, Lithuania does not possess own geological capacities to store hydrogen domestically. This means that it will have to make use of neighbouring countries storages in order for the domestic hydrogen sector to reach the foreseen scale. The indicative Figure 5-39 shows salt deposits (dark blue areas) in Northern Europe where H2 can be stored. Additional information can be found here.

5.6 Costs

Energy system CAPEX will amount to more than 70 blnEUR over the period to 2050. Figure 5-40 presents the total CAPEX for infrastructure additions from 2022 to 2050 for the Roadmap scenario. The main categories contributing to the total CAPEX are onshore wind, internal transmission network, SMR, offshore wind and hydrogen (P2G) electrolysers.

Figure 5-41 presents the annual fixed OPEX evolution along the modelled years for the Roadmap scenario. O&M costs are increasing over the years given the larger installed base. It is important to indicate that most of the fixed OPEX is located in the electricity and heat generation segment, predominately in the wind generation plants. The different wind generation penetration rates explain to a high extent the annual OPEX difference across scenarios. As can be observed in Figure 5-42, approximately 50% of fixed OPEX is related to onshore wind generation capacity.

FIGURE 5-40

Total CAPEX for infrastructure additions until 2050, Roadmap scenario (excluding transport, household, building, industry and agriculture sectors)[24, 25]

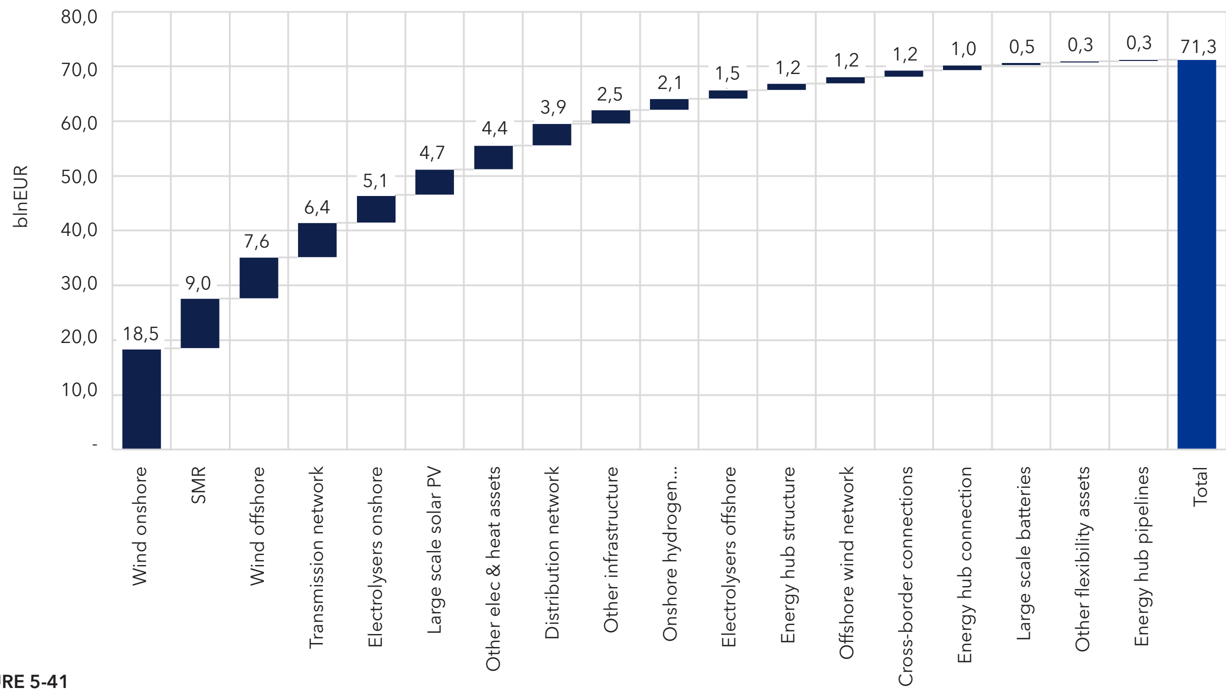
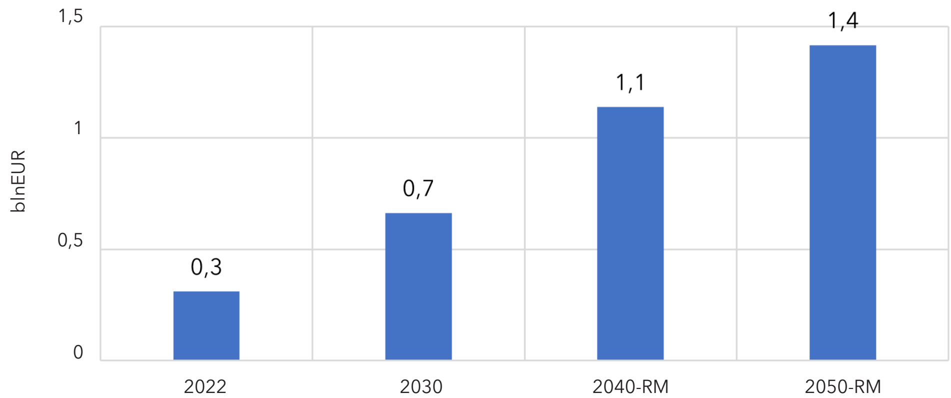


FIGURE 5-41

Annual fixed OPEX



[24] Cross-Border connections includes both onshore and offshore electricity interconnectors. For offshore interconnectors going through the hub, the cost of offshore HVDC converters located on the hub is attributed to Energy hub connection category. Offshore wind network includes the costs of electrical infrastructure from offshore substation to onshore substation. Energy hub connection includes the costs of electrical connection from the energy hub to shore, including all HVDC converters on the hub and cables to Lithuania but not the cables from hub to the other countries. Note that only capex for new assets (additions) are accounted for, not the existing assets.

[25] Other El & Heat assets include replacement and new-build capacity for electricity and heat production from gas GT, hydropower, biomass, waste, and H2 CCGT. Other infrastructure includes new-build heat and gas network investments including heat storage and biogas upgrades. Other flexibility assets include additional investment in PHP storage as well as P2H boilers and heat pumps for district heating.

The annual energy carrier costs will decline dramatically as Lithuania minimises imports of natural gas and oil. By 2030, biomass (including biofuels and waste) will emerge as the main cost driver replacing a large share of natural gas.

As Lithuania increases its domestic production fleet, it becomes possible for the country to export some of the products, such as fertilisers and synthetic fuels. Notably, by 2050 the annual energy carrier costs even become negative, implying that the export revenues from high-value products outweigh the costs of imports.

FIGURE 5-42

Annual fixed OPEX electricity and heat resources

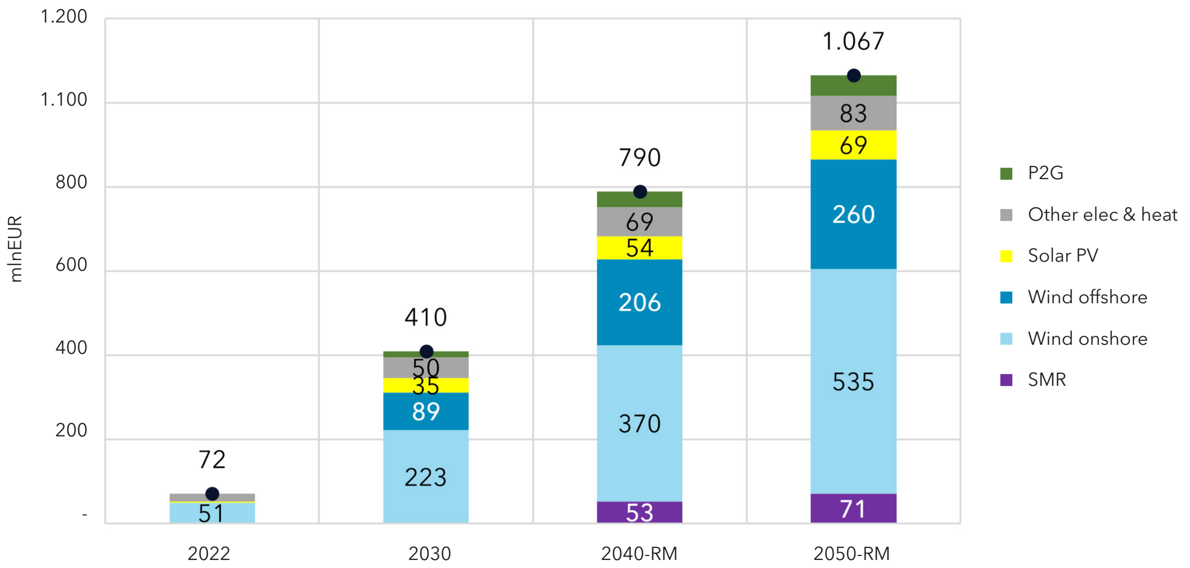
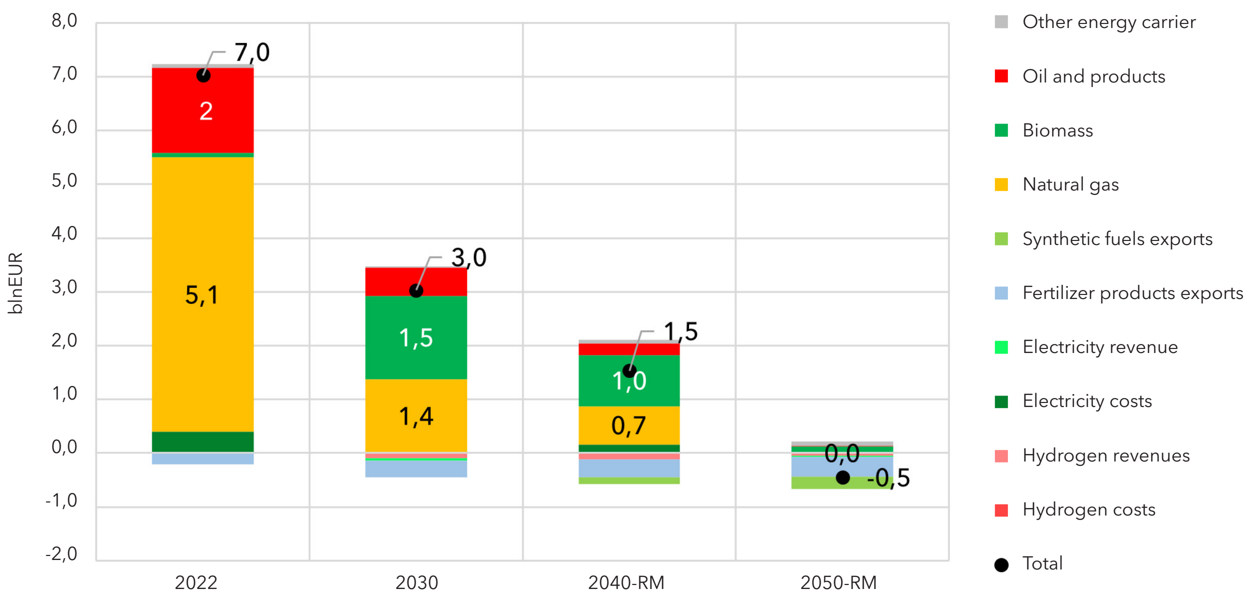


FIGURE 5-43

Annual energy carrier cost and revenues[26]



[26] Other energy carrier includes ammonia, uranium, CO_2 and coal costs

The total system cost of the Lithuanian energy system is the sum of all three cost categories and discounted with a uniform WACC of 4% (real) to obtain the net present system cost value in year 2022 terms. The necessary infrastructure investments and energy carrier costs are the major contributing categories. Figure 5-44 shows that the energy system costs increase is highest from 2030 to 2040, due to high capital costs and still significant energy carrier costs in this period. Annual energy carrier costs significantly decline (shown by minor increase in the net present value from 2040 to 2050), which is typical for net-zero energy systems, and increasing Operation and Maintenance (O&M) costs due to a much larger installed base indicate job creation throughout the energy transition.

5.7 Impacts on employment and economy

In addition to the system costs, this study at a qualitative level considers the impact of the Roadmap scenario on the Lithuanian economy. Two metrics are evaluated – impact on GDP and on employment growth[27].

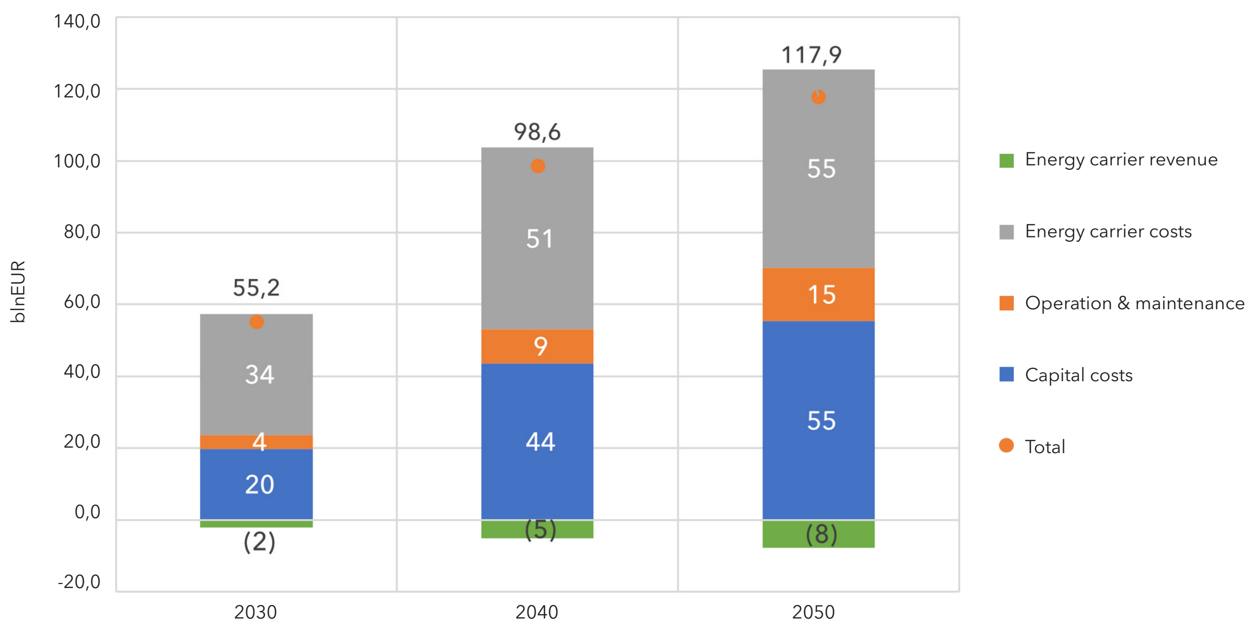
Impact on employment

The impact of employment and GDP is approximated as a range based on the results of applying job multipliers from two recognized international studies.

- The lower job creation number is based on the job multipliers derived from the IMF report (2022), "Jobs Impact of Green Energy"[28]. The job multipliers consider the direct[29] and indirect[30] job creation linked to installing and operating different electricity generation capacities. It is worth noting that jobs occurring up-front in the investment cycle (e.g. construction and manufacturing) are levelized and employment creation is spread out over the typical project lifecycle. Thus, job multipliers consider FTE job of 1-year duration per additional annual GWh from different generation sources. For instance, solar photovoltaic electricity generation has the largest impact on job creation, followed by other renewable technologies. By applying these inputs, the Roadmap scenario could entail the creation of additional ~44k jobs in 2050
- Based on the academic research available for the case of the United Kingdom, the approaches to estimate the impact of RES deployment may use technology-specific or technology-agnostic values[31]. Such an approach only accounts for the generation sector, not accounting for the effect of parts of the value chain and offtake sector growth, hence is likely to underestimate the impact. The Roadmap scenario could entail the creation of additional ~140k jobs in 2050.

FIGURE 5-44

Net present total system costs RM scenario until 2030, 2040 and 2050 (4% WACC)



[27] Disclaimer: Note, that the estimates are presented for information purposes and are attained using simplistic "rule of thumb" approaches, with high-level assumptions, without conducting any dedicated economic modelling. Therefore, the estimates should be treated as such and not as future forecasts, unlike the other values presented in this chapter earlier. Evaluation of both parameters is characterized by numerous uncertainties and is highly non-homogeneous around the world – different regions and countries will experience varying effects from the decarbonisation, depending on the proportion of the value chain hosted domestically, existing sectors that are displaced, openness of the economy, availability and access to resources, feedback effects, etc.

[28] Jobs Impact of Green Energy by Jaden Jonghyuk Kim, Adil Mohommad :: SSRN

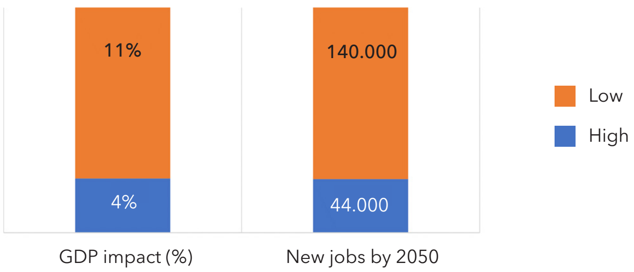
[29] Direct multipliers capture jobs generated in the execution of projects, including design, manufacturing, construction, installation, operation, maintenance, and other directly related jobs

[30] Indirect multipliers capture upstream job-creation linked to the supply chain

[31] https://www.researchgate.net/publication/347440736_Review_of_Energy_Policy_2020
https://discovery.ucl.ac.uk/id/eprint/10112216/3/Agnolucci_Revised%20Manuscript%20-%20final%20edits%20-%20final%20mauscript.pdf

FIGURE 5-45

Low and high range estimated impacts on job creation and economy



It should be noted that this approach ignores offtake-related jobs in the hydrogen value chain and industry. Assuming an average annual salary of 45 kEUR/year, the economic impact is between 2.0 to 6.3 blnEUR, representing approximately 4% to 11% growth of Lithuanian GDP in 2021, see also Figure 5-45.

It is recommended to deploy appropriate econometric or computational general equilibrium models to adequately assess the entire impact of the energy transition on the economy of Lithuania. Such an assessment is not in scope of this study, however the here provided estimation reflects a conservative assessment for job creation and resulting GPD impact.

5.8 Emissions

Currently, the major sources of CO^2 emissions in Lithuania include transport and industry. Among these sources, national transport is the largest emitter, accounting for 7.2 million tonnes of CO^2 emissions, just below 50% of the total. Industries and buildings also contribute significantly to CO_2 emissions at present.

All CO_2 emitting sectors are projected to reach negative emission values by 2050, aligning with Lithuania's climate goals for that time period. Already by 2030, CO_2 emissions can half to around 9 million tonnes.

Currently, the highest contributors to CO_2 emissions are related to energetic use, accounting for 13.8 million tons of CO_2 equivalent, followed by non-energetic greenhouse gases (GHG) at 5.8 million tonnes. By 2050 all energetic emissions are projected to reach negative values with only non-energetic emissions still remaining in the economy. These other greenhouse gas emissions are particularly difficult to get rid of as technologies for their capture and utilisation are not yet developed.

FIGURE 5-46

CO_2 emissions outlook

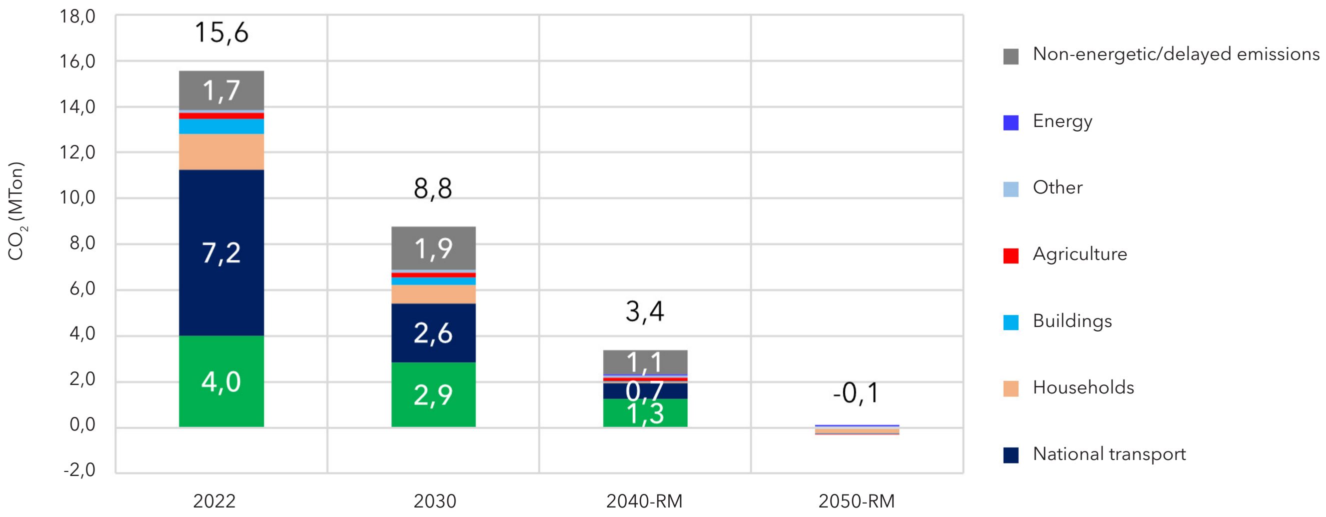
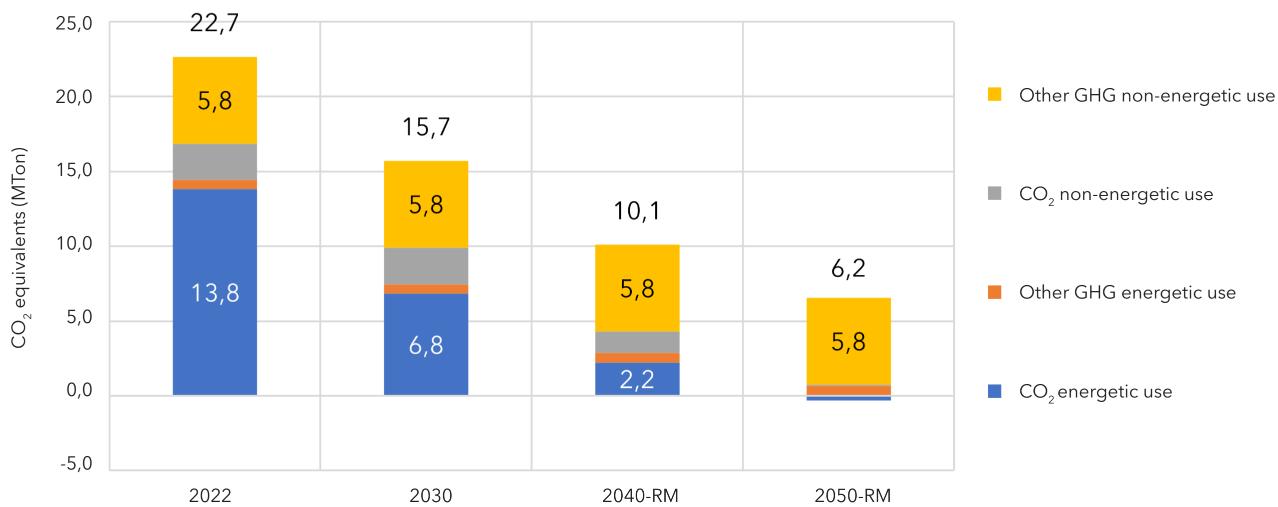


FIGURE 5-47

CO_2 and other GHG emission outlook



5.9 Performance

Table 5-3 provides an overview of the outcomes of the Roadmap scenario for selected key performance indicators.

Note that:
- Electricity dependency equals annual electricity imports/ final electricity demand
- Energy dependency equals annual net imports/total primary energy supply (incl. non-energetic)
- Zero Carbon products export includes fertiliser products and synthetic fuels
- Energy system costs cover all costs (CAPEX, OPEX, Energy carriers) and relate to total primary energy supply (in TWh) from 2022 to 2050
- Energy system costs are discounted to Net Present Value of 2022 at a Weighted Average Cost of Capital (WACC) of 4%.

5.10 Sensitivity analysis

Based on the Roadmap scenario, DNV analysed several sensitivities, where different parameters have been altered. In order to study the robustness of the Roadmap scenario and how it can respond to changes in some of the assumptions, the approach for the implementation of the sensitivities followed the variation of one of the input assumptions at a time, i.e. each sensitivity only considers the variation in one parameter. DNV has considered the sensitivities presented in Table 5-4, which are described in the following sections. For most of the sensitivities a low and a high case have been simulated. The year 2050 is used as the year to model the sensitivities, except for the sensitivity on SMR availability which is also modelled in 2040, and for Energy Hub availability, where it is assumed that it is not to be built at all.

TABLE 5-3

Roadmap's performance for key performance indicators (KPIs)

SCENARIO KPI	UNIT	2022	RM-2050
Energy dependency	%	73%	30%
Electricity dependency	%	67%	0%
CO_2 emissions	Mton	15	0
GHG emissions	Mton	22	6.2
Hydrogen exports	TWh	0	1.4
Zero carbon product exports	TWh	0	9.1
Totel energy system costs (2022-2050, in Net Present Value 2022)	BEUR (EUR/MWh)	NA	118 (39.4)
Total infrastructure capital costs (2022-2050) (non-discounted)	BEUR	NA	71
Annual energy system operating costs (energy carriers and O&M)	EUR/MWh	75	12.5

TABLE 5-4

Summary of sensitivities performed on Roadmap scenario

SENSITIVITY ON:	PARAMETER CHANGED FROM ROADMAP VALUE - LOW CASE	PARAMETER CHANGED FROM ROADMAP VALUE - HIGH CASE
Fuel prices	50% decrease	50% increase
SMR availability	SMR not included	-
Electrolyser willingness to pay[32]	-	100% increase
Hydrogen price[33]	50% decrease	50% increase
Interconnector capacity	700 MW decrease Nordics interconnector	500 MW increase Central Europe interconnector
Energy Hub availability	EI not included. Offshore wind and H2 moved to radial connection and onshore location, respectively	-
Central Europe - Lithuania price difference	15% decrease in Central Europe average wholesale electricity price	15% increase in Central Europe average wholesale electricity price
Industry size (vs 2050 RM size)	-20%	+20%

[32] This is an indicator of the maximum price that electrolysers are ready to pay for electricity to produce hydrogen. In other words, it is a price ceiling below which a profit-maximising electrolyser will run and produce hydrogen.
[33] This is an indicator of the price at which hydrogen is sold (if exported) or bought (if imported).

The sensitivity analysis shows that the most influential factors in the future Lithuanian energy system are the presence of SMR and hydrogen electrolysers willingness to pay for electricity, both factors affecting energy and electricity dependence and the level of electricity prices in the country. In contrast, fuel prices and the hydrogen price have very little impact. The other factors, namely, interconnector availability, energy hub availability, and electricity price difference between Central Europe and Lithuania have a moderate effect. In fact, SMR and electrolysers are complimentary as SMR reduces electricity prices for Lithuania and therefore leads to lower costs of electricity for the electrolysers, while electrolysers increase electricity demand maintaining electricity prices for SMR, thereby acting as a natural hedge. In summary, the following are the key observations presented as "sensitivity – outcomes" based on the modelling performed in this study[34]:

Increasing electrolysers willingness to pay for electricity
- Increases average wholesale electricity prices, at annual level as well as for the Dunkelflaute period
- Increases energy dependency and electricity dependency
- Increases exports of hydrogen and its derivatives

Price difference between the Central Europe and Lithuania (Central Europe price is above Lithuanian on average)
- Limited impact on average wholesale electricity prices, at annual level as well as for the Dunkeflaute period, when price difference increases
- Sizeable decrease in Lithuanian wholesale electricity prices when price difference decreases
- Reduces exports of hydrogen and derivative products in case the Central European price increases

Industry size difference
- Relevant impact on average wholesale electricity prices, at annual level as well as for the Dunkelflaute period. Industry size decrease, decreases electricity prices and industry size increase, increases electricity prices.
- Demand decrease in industry significantly increases export of hydrogen that is not consumed by industry. Vice versa in case of an increase in industry demand, the need for import of hydrogen arises.
- Energy and electricity dependency slightly increases or decreases with higher or lower industry demand respectively.
- Higher and lower demand also is present at Dunkelflaute moments, while only a small percentage of industry demand is flexible (and with a high activation price). Therefore, reliance on interconnectors for adequacy is affected, with higher reliance in case of greater industry size, and lower reliance in case of smaller size.

Removing SMR
- Increases average wholesale electricity prices, at annual level as well as for the Dunkelflaute period
- Decreases energy dependency and increases electricity dependency
- Reduces exports of hydrogen and its derivatives, potentially leading to imports of hydrogen
- Decreases total energy system costs
- Reduces adequacy and therefore results in a higher reliance on interconnectors during supply shortage periods

The other sensitivity tests have not shown any notable impacts on the assessed KPIs.

[34] Other impacts are likely to have place but these are not assessed within this study.

TABLE 5-5

Summary of key sensitivity outcomes

SENSITIVITY	AVERAGE ANNUAL PRICE	DUNKELFLAUTE PERIOD PRICE	EXPORTS OF HYDROGEN AND DERIVATES	ENERGY DEPENDENCY	ELECTRICITY DEPENDENCY	TOTAL SYSTEM COSTS	RELIANCE ON IC'S FOR ADEQUACY
Fuel prices -50% / +50%	<1% / <1%	<1% / <1%	-0.2 TWh	<1%	<1%	<5% / <5%	<1%
Removing SMR	+22%	+6.8%	-4 TWh	-22%	+8%	-3.7 blnEUR	+27%
Increased electrolyser willingness to pay	+27%	+18.5%	+8 TWh	+2%	+14%	-	-
Hydrogen price -50% / +50%	-2% / +2%	-4% / <1%	<0.2 Twh / <0.2 Twh	<1%	<1%	<1%	<1%
IC Nordics capacity decrease	-4.2%	-3.1%	-0.4 TWh	<1%	<1%	<1%	-
IC Central EU capacity increase	+8.8%	+3.6%	-1 Twh	<1%	<1%	<1%	-
Energy Hub availability	<2%	<2%	<0.2 Twh	<2%	<2%	<1%	-
Price difference with Central Europe increase / decrease	+1% / -5%	+1.8% / -9.3%	-2 TWh / +1 TWh	-	-3% / +2%	<1% / <1%	-
Industry size -20% / +20% vs RM	-5.3% / +5.9%	-6.7% / +0.8%	+5 Twh / -5 TWh	-2% / +3%	-2% / +2%	Not investigated	-6% / +6%

6. ROADMAP AND TRANSFORMATION PLAN

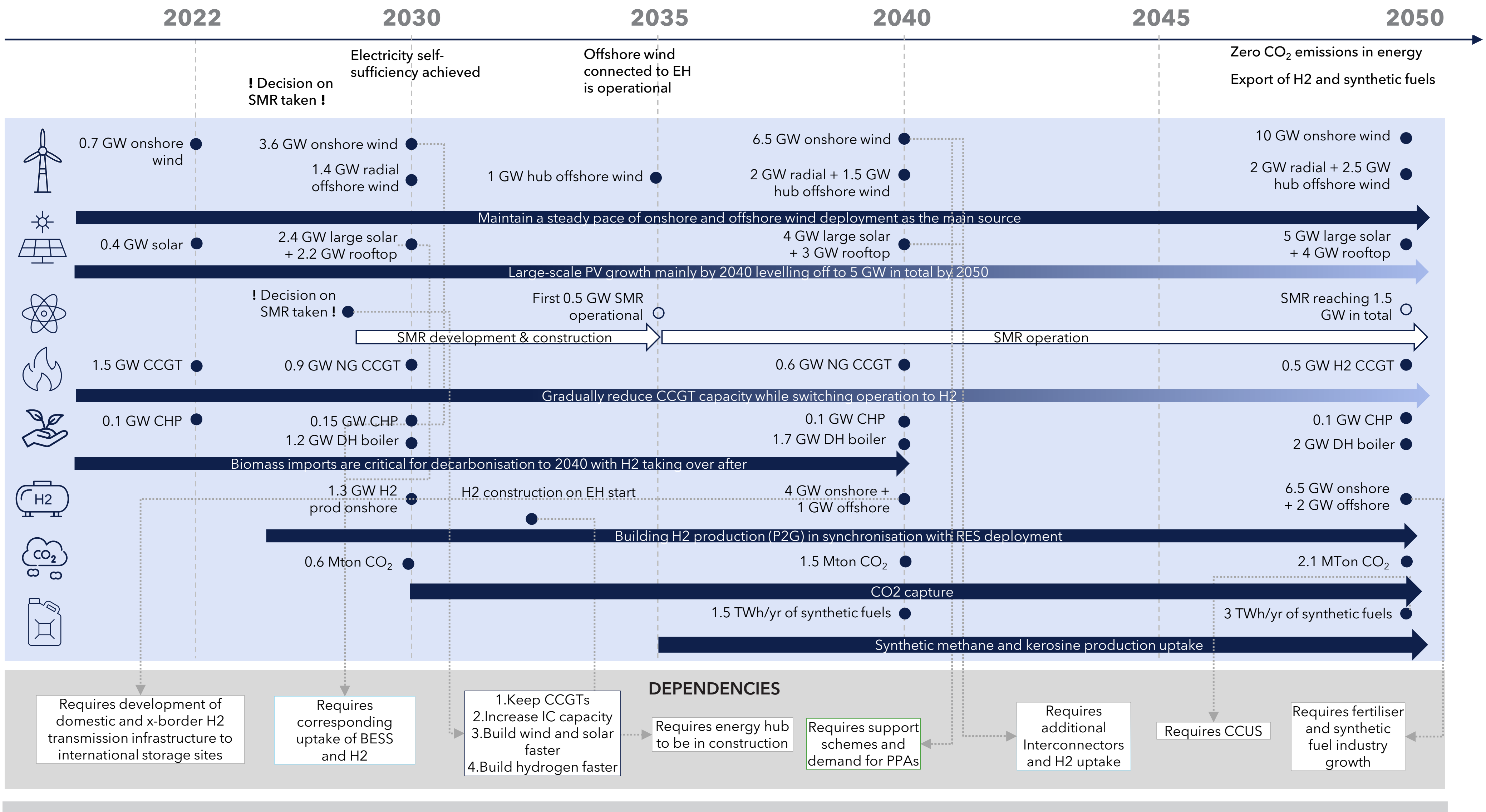
6. ROADMAP AND TRANSFORMATION PLAN

The roadmap presented in this section reflects the recommended strategic direction that the transformation of the Lithuanian energy system should take. The proposed system building blocks and development timeline are based on the results of the modelled scenarios and their performance against the strategic objectives presented earlier.

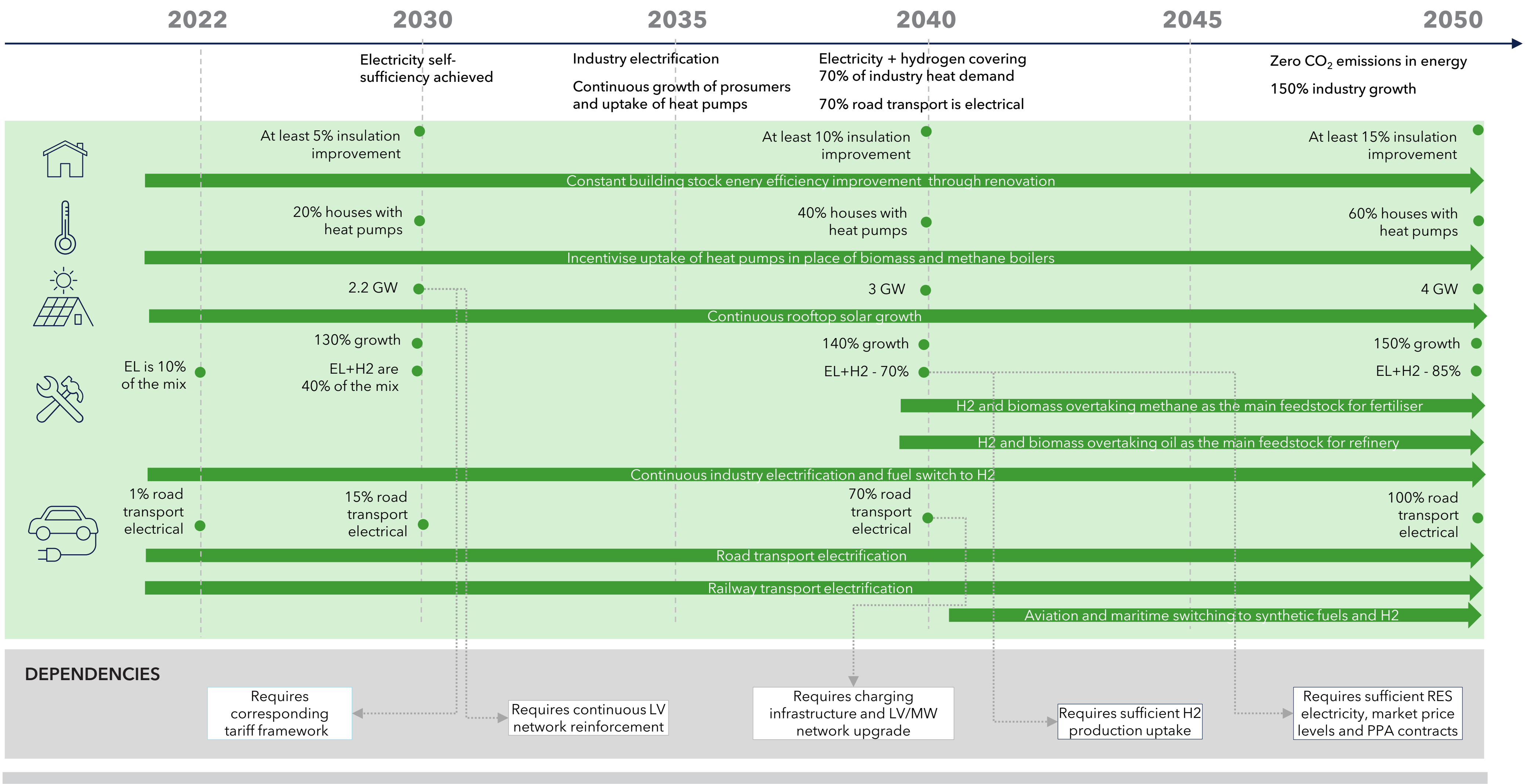
In designing the roadmap DNV attempted to balance the objectives, considered the key enablers and impediments, and aimed for an optimal energy system development pathway given the scope of this study. The roadmap merely presents the milestones, critical decisions and interdependencies. It serves as a basis for the energy strategy which is presented in the following section.

In what follows we present the energy system development pathway across Supply, Demand, Flexibility, Infrastructure and Markets & Regulation domains, and show the underlying investment calendar for the energy system.

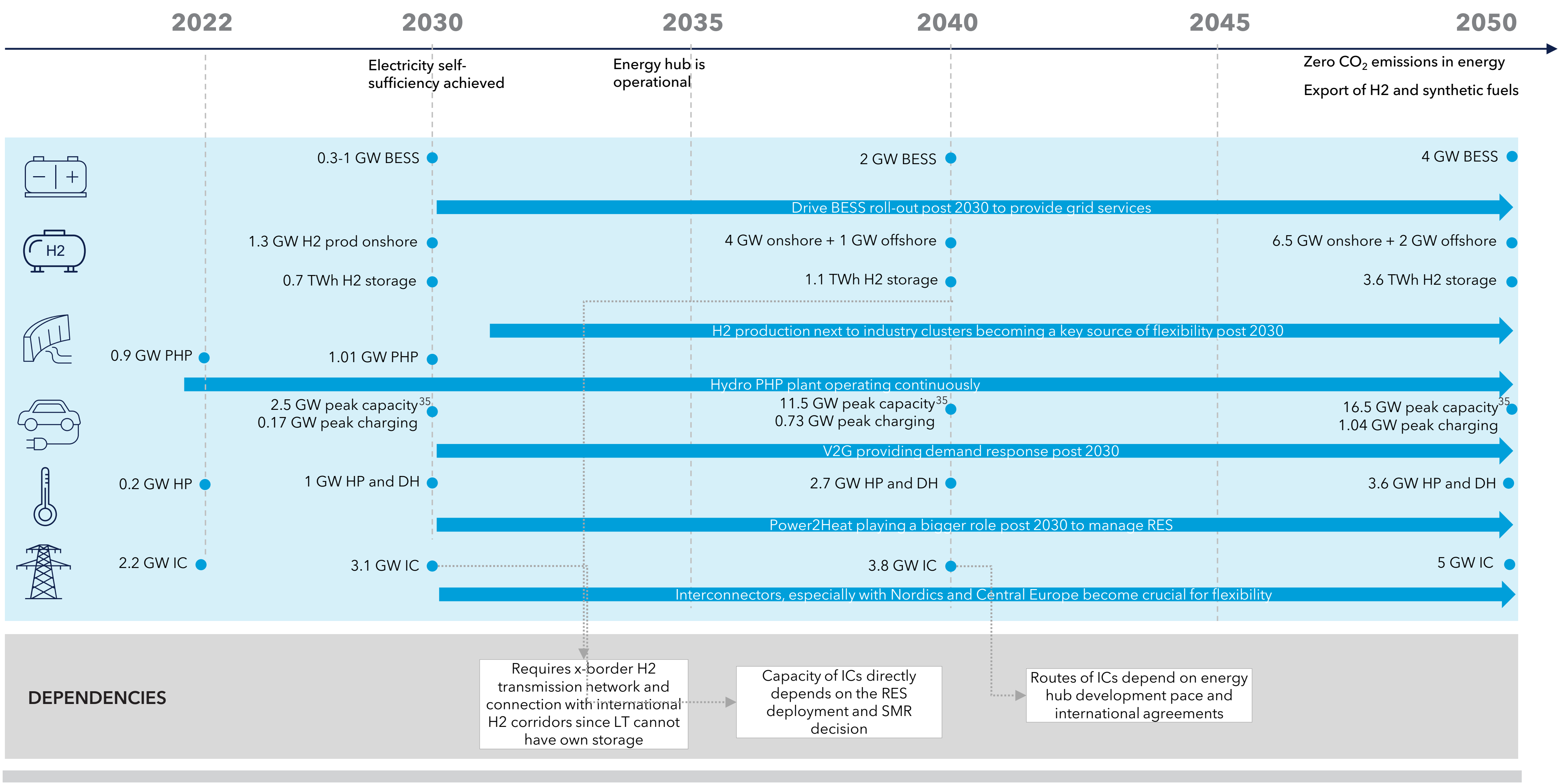
6.1 Supply


2022
2030
2035
2040
2045
2050
Electricity self-sufficiency achieved
! Decision on SMR taken !
Offshore wind connected to EH is operational
Zero CO_2 emissions in energy
Export of H2 and synthetic fuels
0.7 GW onshore wind
3.6 GW onshore wind
1.4 GW radial offshore wind
1 GW hub offshore wind
6.5 GW onshore wind
2 GW radial + 1.5 GW hub offshore wind
10 GW onshore wind
2 GW radial + 2.5 GW hub offshore wind
Maintain a steady pace of onshore and offshore wind deployment as the main source
0.4 GW solar
2.4 GW large solar + 2.2 GW rooftop
4 GW large solar + 3 GW rooftop
5 GW large solar + 4 GW rooftop
Large-scale PV growth mainly by 2040 levelling off to 5 GW in total by 2050
! Decision on SMR taken !
First 0.5 GW SMR operational
SMR reaching 1.5 GW in total
SMR development & construction
SMR operation
1.5 GW CCGT
0.9 GW NG CCGT
0.6 GW NG CCGT
0.5 GW H2 CCGT
Gradually reduce CCGT capacity while switching operation to H2
0.1 GW CHP
0.15 GW CHP
1.2 GW DH boiler
0.1 GW CHP
1.7 GW DH boiler
0.1 GW CHP
2 GW DH boiler
Biomass imports are critical for decarbonisation to 2040 with H2 taking over after
H2
1.3 GW H2 prod onshore
H2 construction on EH start
4 GW onshore + 1 GW offshore
6.5 GW onshore + 2 GW offshore
Building H2 production (P2G) in synchronisation with RES deployment
CO_2
0.6 Mton CO_2
1.5 Mton CO_2
2.1 MTon CO_2
CO2 capture
1.5 TWh/yr of synthetic fuels
3 TWh/yr of synthetic fuels
Synthetic methane and kerosine production uptake
DEPENDENCIES
Requires development of domestic and x-border H2 transmission infrastructure to international storage sites
Requires corresponding uptake of BESS and H2
1.Keep CCGTs
2.Increase IC capacity
3.Build wind and solar faster
4.Build hydrogen faster
Requires energy hub to be in construction
Requires support schemes and demand for PPAs
Requires additional Interconnectors and H2 uptake
Requires CCUS
Requires fertiliser and synthetic fuel industry growth

6.2 Demand

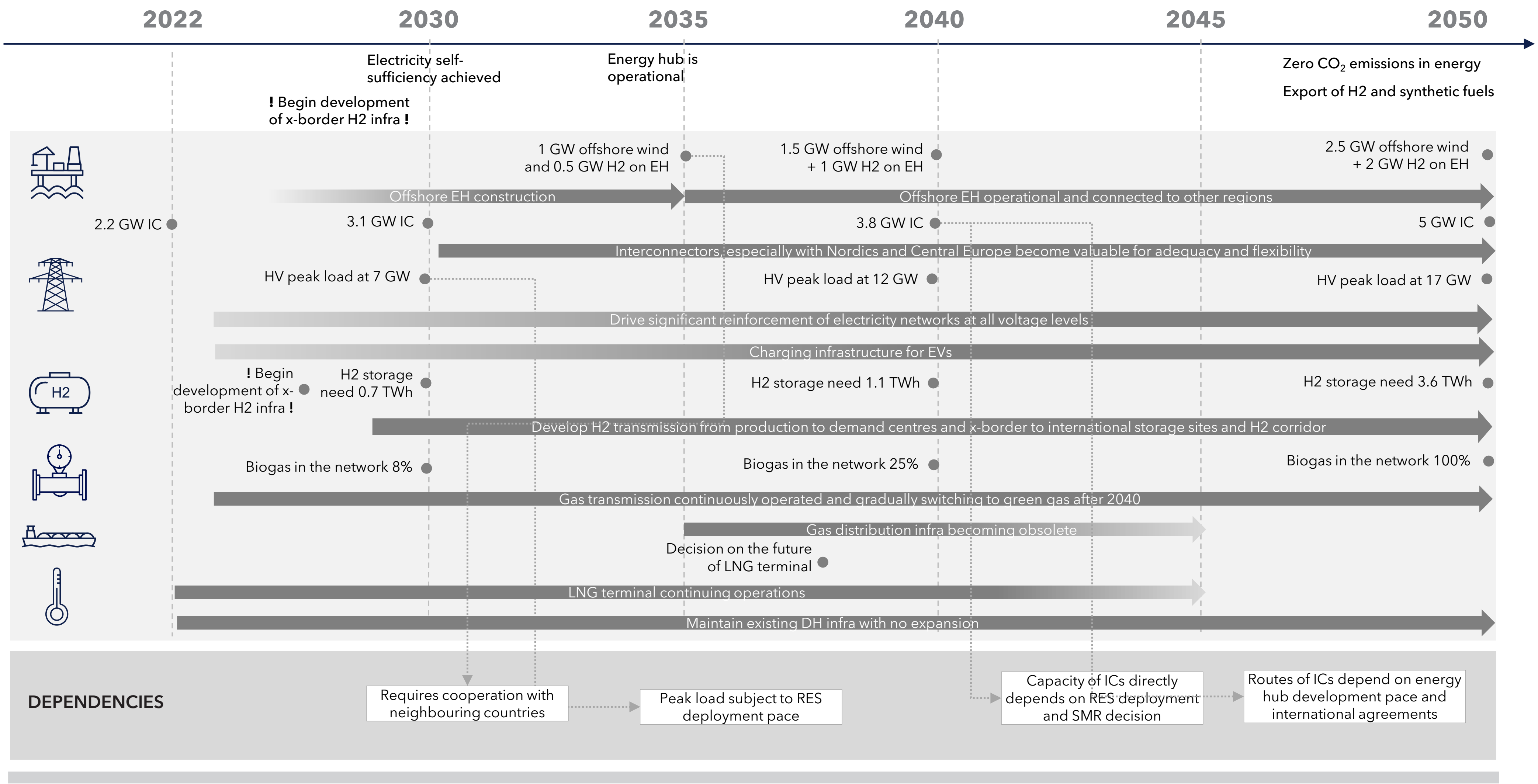

2022
2030
2035
2040
2045
2050
Electricity self-sufficiency achieved
Industry electrification
Continuous growth of prosumers and uptake of heat pumps
Electricity + hydrogen covering 70% of industry heat demand
70% road transport is electrical
Zero CO_2 emissions in energy
150% industry growth
At least 5% insulation improvement
At least 10% insulation improvement
At least 15% insulation improvement
Constant building stock enery efficiency improvement through renovation
20% houses with heat pumps
40% houses with heat pumps
60% houses with heat pumps
Incentivise uptake of heat pumps in place of biomass and methane boilers
2.2 GW
3 GW
4 GW
Continuous rooftop solar growth
130% growth
140% growth
150% growth
EL is 10% of the mix
EL+H2 are 40% of the mix
EL+H2 - 70%
EL+H2 - 85%
H2 and biomass overtaking methane as the main feedstock for fertiliser
H2 and biomass overtaking oil as the main feedstock for refinery
Continuous industry electrification and fuel switch to H2
1% road transport electrical
15% road transport electrical
70% road transport electrical
100% road transport electrical
Road transport electrification
Railway transport electrification
Aviation and maritime switching to synthetic fuels and H2
DEPENDENCIES
Requires corresponding tariff framework
Requires continuous LV network reinforcement
Requires charging infrastructure and LV/MW network upgrade
Requires sufficient H2 production uptake
Requires sufficient RES electricity, market price levels and PPA contracts

6.3 Flexibility



[35] EV peak capacity refers to the maximum theoretical potential of EVs while peak charging reflects the actual load achieved in the conducted modelling

6.4 Infrastructure



6.5 Markets & regulations

2030 | **2035** | **2040** | **2045** | **2050**

2030

Electricity self-sufficiency achieved

9.6 GW vRES
0.3-1 GW BESS
3.1 GW ICs
2.5 GW peak non-flex demand
1.3 GW H2 peak demand

2040

17 GW vRES
2 GW BESS
3.8 GW ICs
4.1 GW peak non-flex demand
5.5 GW H2 peak demand

2050

Zero CO_2 emissions in energy

23.5 GW vRES
4 GW BESS
5 GW ICs
5.4 GW peak non-flex demand
8.5 GW H2 peak demand

Markets

- 2030: Developed and liquid flexibility markets support wholesale market revenues
- 2035: PPAs between RES and industrials become large part of RES revenue
- 2040: Potential to introduce capacity markets
- 2045: vRES business model relies on a combination of PPAs, capacity payments, ancillary and wholesale market revenues

Market reform introducing alternatives to wholesale spot market only

vRES continuously driving wholesale prices downwards

Opportunity costs of electricity generation (heat and hydrogen) determine the prices

Interconnectors, especially with Nordics and Central Europe guard domestic prices from decreasing too much

Grid regulation

- Additional R&D expense allowance for TSOs and DSO to support infrastructure growth and adpatation
- 2030: Network charges to be based on multiple instead of single peak value (or other method). Discontinue net metering for prosumers or introduce standby charges
- 2035: Regular regulatory reviews by NRA to balance provision of incentives and sufficient CAPEX coverage for grid operators
- 2035: Potentially joint incentives for TSO and DSO to encourage cooperation

Increasing scale of power grid reinforcemenets and growth of supply/loads across all voltage levels

Investment

- Detailed plan for applying for EU funds, with focus on SMR, hydrogen and electrification
- Decide on mid-term approach to hydrogen support
- Announcement of tender for SMR development
- 2035: Sector coupling facilitation through partnerships, including M&A's with other infrastructure (not only energy) companies in order to realize the synergies and enable to increase the capex possibilities

DEPENDENCIES

Monitoring of business case and investment climate to ensure viable business cases and required investments for system operators and market players, through possible changes in regulatory framework, e.g. by including tariff component(s) and/ or capacity remuneration scheme(s) for recovery of (otherwise unrecovered) CAPEX costs

6.6 Investment calendar

Significant capacity additions are foreseen for electricity generation, hydrogen production, storage assets, transmission and distribution network, and for the hydrogen network.

Figure 6-2 shows the capital costs expenditures (CAPEX) for electricity and heat generation plants. The system growth as foreseen in the Roadmap scenario requires about 2 blnEUR of CAPEX each year, which by 2050 adds up to about 50 blnEUR CAPEX (real prices, basis 2023 price levels) for electricity and heat generation plants.

The figure shows that after 2030, there is significantly less investment foreseen in biomass CHPs, until 2040 when there is assumed to be a need for replacement investments which have been
modelled to be spread between 2040 and 2042.
This explains the outlier value for the year 2040.
The annual costs presented in this section are approximate proportional costs and should be seen as representative costs over each decade: 2020-2030, 2030-2040 and 2040-2050.

FIGURE 6-1

Installed production capacity outlook

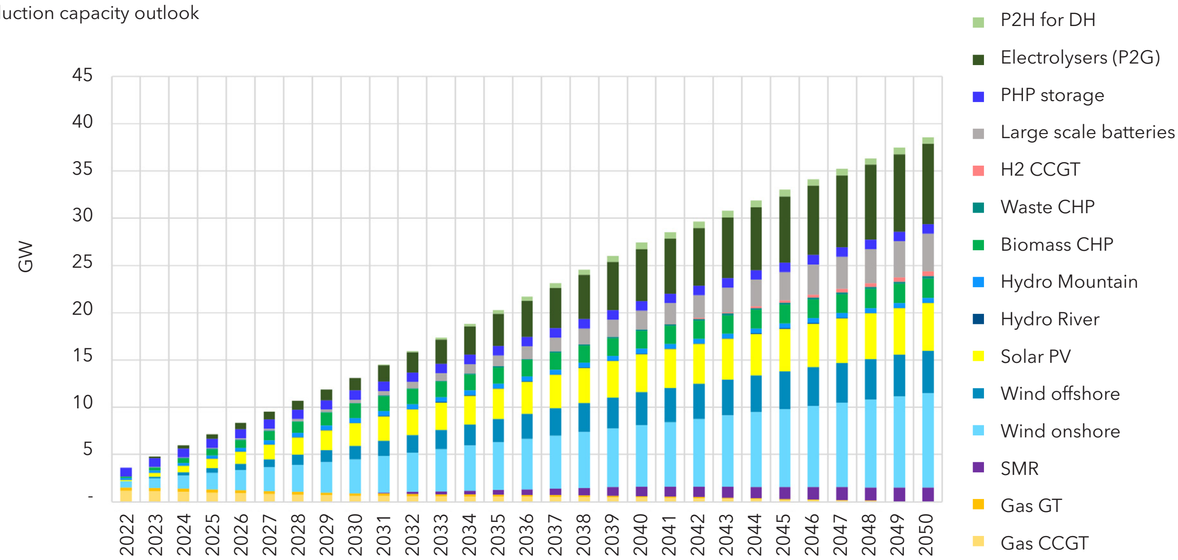


FIGURE 6-2

Capital costs expenditures (annual, real) for electricity and heat generation plants outlook

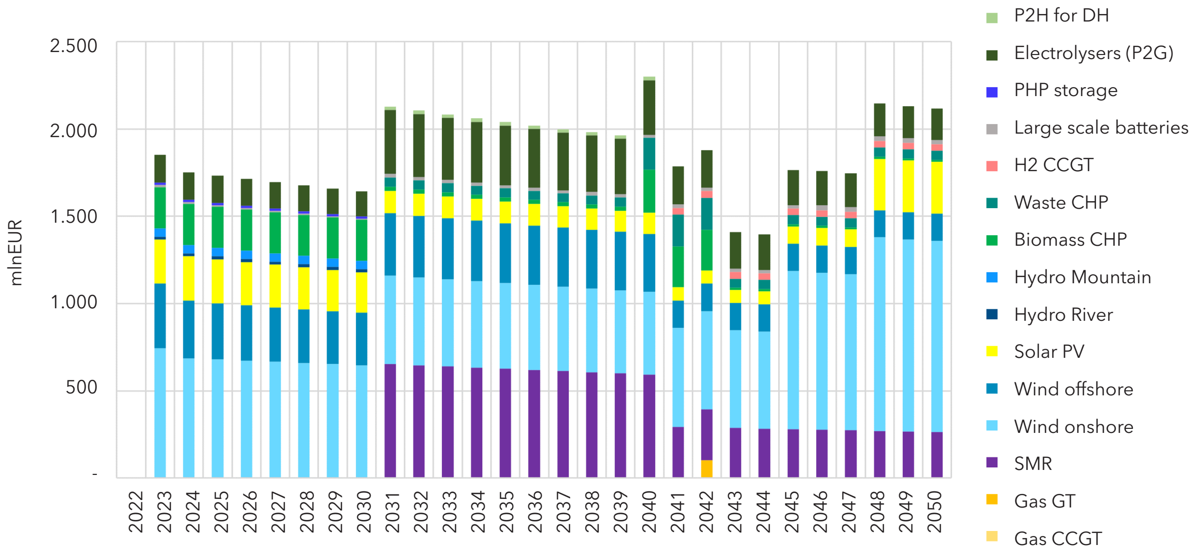


FIGURE 6-3

Power network cumulative capacity addition outlook

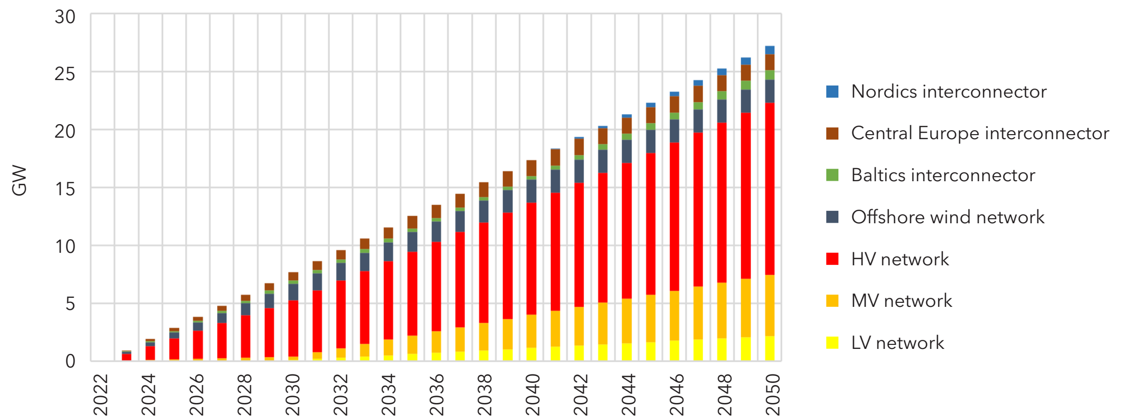
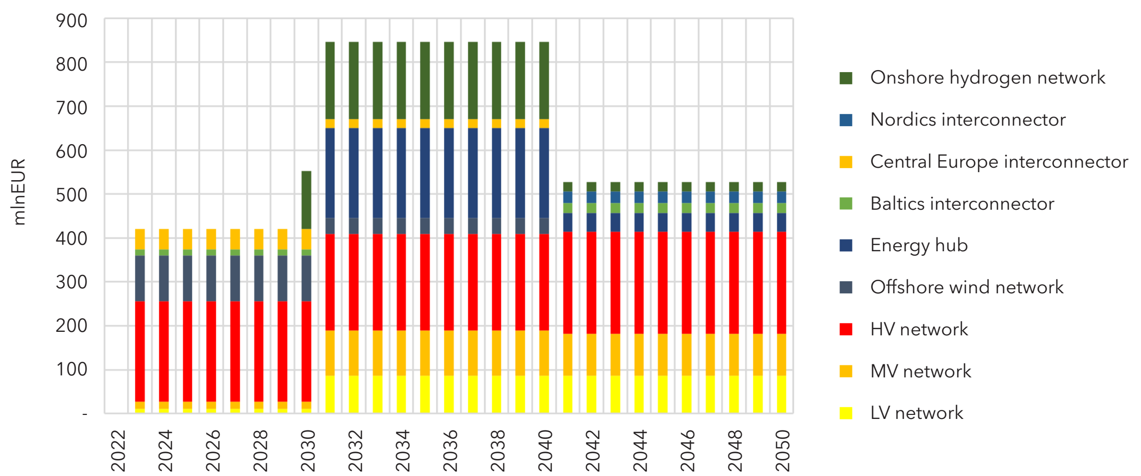


FIGURE 6-4

Capital cost expenditures (annual, real) for electricity network and offshore hub support structure outlook



To facilitate the growth of the electrical system, the electrical network needs to be expanded accordingly. The relatively high numbers for HV are due to large developments in HV connected assets (wind and solar farms, electrolysers) assumed in the scenario. Figure 6-4 shows the annual network investments from 2022 to 2050 for the transmission and distribution network in Lithuania. The chart shows that significant investments are needed in the domestic High Voltage network, followed by the Medium Voltage network. The investment requirements to connect offshore wind and the energy hub are also substantial. Annual network investments vary from 500 to 820 mlnEUR per year, which is more than 20% of the CAPEX of the electricity and heat generation plants that it supports. It is important to ensure investment and borrowing capabilities for these network operators even considering sector coupling facilitation through partnerships, including Mergers and Acquisitions (M&A) with other infrastructure (not only energy) companies in order to realize the synergies and enable to increase the CAPEX possibilities The investments in the Energy Hub cover the costs of HVDC converters, cables from the hub to Lithuania, the support structure and the hydrogen pipeline.

HV costs are relatively lower (for similar capacities) than the costs for similar expansion of LV and MV grids. This has to do with the much higher capacities that can be connected, and the much higher volumes that can be transported through a single HV connection, than through an MV or LV connection.

6.6.1 Funding sources

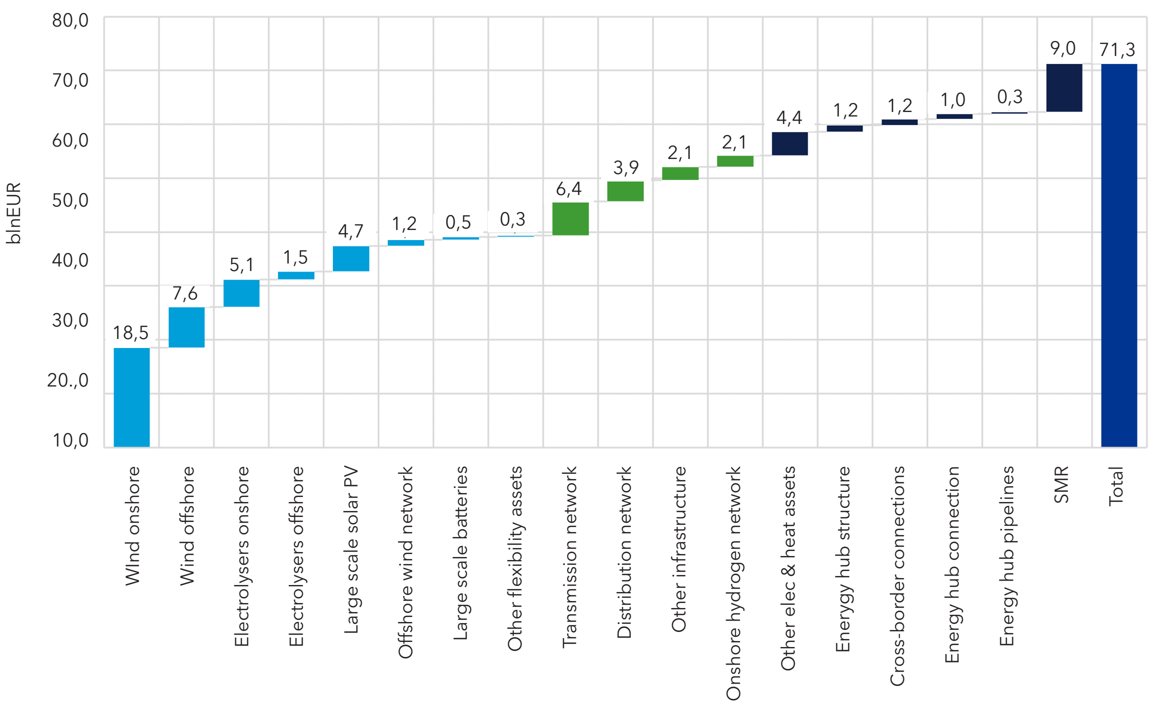
The unprecedented scale of capital investment will require mobilisation of resources from multiple funding sources. Different types of funds and investors are characterised by varying capacity to invest, desired risk profile and return on investments. Therefore, it can be useful for Lithuania to categorise the different assets into those owned solely privately and exposed to competitive markets, those that are regulated and owned by the state, and those that may exhibit features of both types and are characterized by their strategic importance for the state.

In the chart below, DNV provides an overview of the following asset groups with each having its own typical pool of funding categories:

ASSET GROUP	ASSETS INCLUDED	SUM	TYPICAL FUNDING
Market-based	• Renewable electricity generating assets • Batteries • Electrolysers • Offshore wind network	39.4 blnEUR	EU, private companies, banks, investment funds, pension funds
Regulated	• Transmission and distribution electricity grids • Onshore hydrogen infrastructure including pipelines and compressor stations • Heat network	14.8 blnEUR	EU, Lithuanian government, investment funds, pension funds
Strategic	• SMR • Energy hub support structure • Cross-border electricity interconnectors and connection to the hub • Offshore hydrogen pipeline to the hub	17.1 blnEUR	EU, Lithuanian government, private companies, banks, investment funds

FIGURE 6-5

CAPEX breakdown into asset class from the funding point of view (light blue – market assets; green – regulated assets; dark blue – strategic assets)[36]



[36] Other El & Heat assets include replacement and new-build capacity for electricity and heat production from gas GT, hydropower, biomass, waste, and H2 CCGT. Other infrastructure includes new-build heat and gas network investments including heat storage and biogas upgrades. Other flexibility assets include additional investment in PHP storage as well as P2H boilers and heat pumps for district heating.

6.6.2 Positioning for EU funding opportunities

To fund the energy transition Lithuania can leverage a number of available European Union funds that support the energy transition. For instance, funds focusing on renewable and gas infrastructure development and transportation electrification can provide valuable support to meet Lithuania's strategic goals. Funds that target the less developed regions and countries in the EU27 should particularly be taken advantage of, such as the European Regional Development Fund (ERDF), the Cohesion Fund (CF), and the Modernisation Fund. Table 6-1 shows a summary of the funds and the sectors they could be applied for.

Recent years show a significant increase in funding facilities supporting the energy transition. Budget allocation for countries covering different sectors and technologies exists and can be influenced. It is critical for Lithuania to early interact and drive visibility on projects and funding needs, supported by industry and partner countries, and grounded in a sound investment strategy.

TABLE 6-1

Summary of EU funding options per sector/investment type

SECTOR/INVESTMENTS	FUNDING OPTIONS
Renewable energy deployment	European Regional Development Fund, Cohesion Fund, Just Transition Fund, InvestEU, and Modernisation Fund, *Recovery and Resilience Facility*[37]
Hydrogen	LIFE Clean Energy Transition and Climate Change Mitigation and Adaptation, Horizon Europe, Modernisation Fund
Interconnections with neighbouring countries	Connecting Europe Facility Energy, Transport and Digital, EU Renewable Energy Financing Mechanism
Transport electrification and decarbonization	European Regional Development Fund, Cohesion Fund, Just Transition Fund
SMRs	Euratom Work Programme 2023-2025
Education, training, up- and reskilling	European Social Fund Plus, Just Transition Fund, *Recovery and Resilience Facility*
All energy sector investments	European Investment Bank

[37] Allocation already committed

6.7 Achieving strategic objectives

The Lithuanian Ministry of Energy has established a 2050 vision of the energy system in the framework of this study. This vision is expressed via strategic objectives of full decarbonisation and maximum self-sufficiency of the Lithuanian energy sector. The energy sector transformation should enable Lithuania to become an exporter of high value energy carriers at regional scale. The transformation should take place in an economic and cost-effective way, ensuring affordability for all consumers.

This study has identified the relevant contextual factors and ongoing initiatives. Together with the overview of the necessary system blocks, it allowed DNV to formulate an end state, i.e. 2050 view, as well as to define a roadmap with key milestones and dependencies, serving as a guideline to reach this end state.

In this section, DNV focuses on the key policy recommendations for the government and state energy companies that need to be implemented, comments on the monitoring framework and identifies the main risks and potential ways to mitigate them. Unlike the Roadmap presented in the previous section, the strategy is structured around the strategic objectives rather than the energy system domains. It is possible that some of the key actions and recommendations can be relevant for multiple strategic objectives.

6.7.1 Energy self-sufficiency

ENERGY SELF-SUFFICIENCY	DECARBONIZATION	NET EXPORTS	INDUSTRY GROWTH	AFFORDABILITY AND COST-EFFECTIVENESS

- Electricity self-sufficiency is achievable already by 2030 if currently planned projects are implemented. The possibility to become a net exporting country for electricity beyond 2030 will depend on the further evolution of supply and demand.
- Energy self-sufficiency is not achievable given that Lithuania has a lack of local resources for certain fuels, e.g. natural gas (no domestic production, although less relevant for a net zero system to be achieved in the long term), uranium (no domestic production) and biomass (domestic production but not meeting the future needs).
- Imports of domestically scarce fuels can be partially, but not fully, offset by exports of electricity, hydrogen and other zero carbon products.
- In order to reach electricity self-sufficiency while minimizing energy dependency to the largest extend possible, Lithuania has to maximise the utilisation of its domestic renewable resource potential, including solar PV (large scale and rooftop), onshore and offshore wind, and combined with sufficient P2G for balancing and storage.

6.7.2 Decarbonization

ENERGY SELF-SUFFICIENCY	**DECARBONIZATION**	NET EXPORTS	INDUSTRY GROWTH	AFFORDABILITY AND COST-EFFECTIVENESS

- The Lithuanian energy system can achieve full decarbonisation (net zero CO_2 emissions) by 2050.
- Full decarbonisation of the economy may not be possible since some types of greenhouse gasses (non-CO_2 GHG) cannot be captured. At the same time the volume of captured emissions from the energy system will not be enough to offset these. DNV therefore recommends to pursue other offset mechanisms to also achieve full decarbonisation of the economy.
- The main sectors to be targeted for the reduction of emissions are transport and industry. Particularly electrification of the road transport and industrial heat supply will have a major impact on a timely CO_2 emission reduction.
- Feedstock decarbonisation in large industries (e.g. refinery, fertilizers) will be achieved through a switch to a combination of hydrogen and biomass.
- Decarbonisation of space heating and domestic energy use will require affordable electrical heating technologies whose business case rely on sufficiently low electricity prices.

6.7.3 Net exports

ENERGY SELF-SUFFICIENCY	DECARBONIZATION	NET EXPORTS	INDUSTRY GROWTH	AFFORDABILITY AND COST-EFFECTIVENESS

- Lithuania can become a net exporter of electricity, hydrogen and zero-carbon products, such as fertilisers and synthetic fuels. Exports of electricity and hydrogen will be variable, i.e. subject to weather circumstances as the production of these energy carriers will be weather dependent.
- Lithuania does not have any domestic production of key fuels such as uranium and natural gas. Lithuania is likely to be a net importer of biomass which will continue to play a significant role in heating and also serve as a sustainable source of carbon in the long term. The import of these fuels will outweigh the exports of electricity, hydrogen and zero carbon products. This implies that Lithuania will remain a net energy importing country.
- Large scale underground hydrogen storage is not possible in Lithuania. Therefore, for the entire existence of a domestic hydrogen sector beyond 1 GW electrolysis scale (including export opportunities of domestically produced hydrogen), it is critical to develop sufficiently large cross-border hydrogen infrastructure and conclude bilateral agreements on storage with neighbouring countries.
- Interconnectors with Central Europe are required to benefit from electricity exports to higher priced countries. Connections to Baltic countries will support imports of cheap electricity for domestic hydrogen production. Interconnectors with Nordic countries can also provide further support with power system balancing.
- The offshore electricity and gas connections should be developed through an offshore energy hub in the Lithuanian EEZ which will result in economic benefits, cost savings and synergies between multiple energy infrastructure types.

6.7.4 Industry growth

ENERGY SELF-SUFFICIENCY	DECARBONIZATION	NET EXPORTS	INDUSTRY GROWTH	AFFORDABILITY AND COST-EFFECTIVENESS

- The Lithuanian electricity generation potential, if realised fully, will significantly exceed its current generation level. Moreover, the variable costs of operation will be minimal compared to current levels, given that electricity generation will be based on zero-carbon resources such as wind, solar PV and SMR. This creates opportunities to ensure supply of affordable and competitive electricity and hydrogen to enable industry growth and attract investments. Developing SMRs will also support the needs of the power system for zero-carbon dispatchable generation.
- To decarbonise the industry, while facilitating its growth, Lithuania should promote electrification of industrial heating (low and high temperature) where possible. For other applications, including non-energy use (feedstock), zero carbon energy carriers such as hydrogen and biofuels need to be available. Biofuels are expected to be in shortage domestically, hence Lithuania will rely on biofuel imports. Availability of hydrogen will be limited before 2030, until its production becomes cost-competitive, driven by the increasing occurrence of low-priced hours, and the first electrolysers are commissioned.
- Attractive business cases can be developed to allow industry to provide demand response services, thereby creating additional revenue streams for industrials and benefits for the power system at large.
- A supportive market design and regulatory framework for PPA contracts between renewable developers and industrial and corporate offtakers of zero-carbon electricity will be key to maintain long-term industry growth.
- The Lithuanian hydrogen value chain might face significant competition in the hydrogen market, requiring domestic electricity prices to be low, since many countries in the region plan development of own production facilities. Similar competition is expected in the ammonia market given that ammonia is a global commodity where producers from Spain and Middle East are likely to offer at low prices. Comparable considerations are valid for synthetic fuels and e-methanol. Lithuania should prioritise domestic utilisation of electricity and hydrogen for the production of high-value synthetic fuels and zero-carbon products.
- In order to ensure sufficient domestic synthetic fuel production, availability of carbon will be crucial. This may come mainly from biomass and partially from carbon capture in fossil power plants or industry (not sustainable).

6.7.5 Affordability and cost-effectiveness

ENERGY SELF-SUFFICIENCY	DECARBONIZATION	NET EXPORTS	INDUSTRY GROWTH	AFFORDABILITY AND COST-EFFECTIVENESS

- The transformation of the Lithuanian energy sector will be capital intensive, with some investments being public and others – private. Total energy infrastructure investment costs from 2022 to 2050 amount to about 70 blnEUR in total or 2.5 blnEUR per year, whereas investment requirements are highest from 2030 to 2040. Besides security of supply, decarbonisation and industrial growth related benefits, these investments also help to achieve energy strategy objectives with regard to competitiveness, energy system costs, and affordability.
- The investments in the energy system will lead to a very different cost structure of the energy system. By 2030 energy carrier costs still amount to over 50% of total energy system costs. By 2040 they are above 30% of total energy system costs, and by 2050 just 5% of total annual energy system costs. This implies that by 2050 the exposure of the Lithuanian energy system to global commodity markets has been significantly reduced. However, it is noted that at least until 2040 the Lithuania energy system will still be significantly exposed to for instance the price of natural gas and CO_2. It is recommended that this exposure is well monitored and managed by the government and the energy sector.
- The investment in the energy system will also support employment, given the significant expansion in resources such as renewables and the build out of a domestic infrastructure for the production and transport of hydrogen. The commissioning and maintenance of these new resources and infrastructure will create new jobs currently not existing in Lithuania.
- The foreseen significant deployment of wind and solar will have a downward impact on electricity prices and therefore driving electrification and decarbonisation of the Lithuanian energy system while maintaining affordability for consumers. However, lower electricity prices might deteriorate business cases for investments in required resources, such as renewables and SMR. It is foreseen that electricity prices will be pushed upwards by higher electricity demand in transport and industry sectors, towards 2030 increasingly supported by further electricity demand from electrolysis based hydrogen production. Moreover, further deployment of storage and demand resources can help to reduce power price volatility and improve power price predictability.
- Throughout the energy transition there is a need to monitor the functioning of electricity markets and the level of prices to support investment and profitable operation of system resources. The government and regulator of Lithuania can opt to change market design and introduce new markets, revenue streams and regulatory frameworks to facilitate investment in required resources. For instance, corporate power purchase agreements (cPPAs) can help to increase the willingness to pay for renewable energy projects. A capacity market may be introduced to drive investment in dispatchable resources supporting adequacy needs of the Lithuanian power system. And the emerging market for hydrogen and synthetic fuels can become important levers for more sustainable wholesale electricity prices and therefore business cases for investors.
- Important is that the 2050 wholesale price projections are highly uncertain due to the fact that more than 50% of the time in a year, the wholesale prices in the model are set by hydrogen electrolysers willingness to pay. In other words, unlike in today's system where prices are set by the marginal cost of electricity generation, in 2050 the prices will be set by demand, and in the case of Lithuania, by hydrogen industry specifically. As the 2050 hydrogen prices are uncertain, so is the willingness to pay for electricity. Hence, the attention should be paid not to the absolute values but rather to the fact that a single industry, relying on a single commodity, sets the electricity prices throughout a major part of a year.
- It is noted that Lithuanian industrial growth should be seen in a regional context. As Baltic countries have abundant offshore and onshore wind resources, and with comparably low domestic electricity demand compared to Lithuania, there will be a competition for the development of offshore infrastructure to create opportunities for electricity export to the Central Europe. Lithuania can gain advantage by swiftly signposting its intent to develop an offshore energy hub which would aggregate offshore wind energy generated in Lithuania, Latvia and Estonia, and provide opportunities for competitive conversion to hydrogen and transport to regional demand areas.

6.8 Sectoral recommendations for the short-term

This section provides short- and mid-term focused recommendations for individual sub-sectors of the energy system, including the main highlights, actions and decisions, and risks and dependencies.

6.8.1 Electricity generation

HIGHLIGHTS

- An 8-fold increase in installed capacity to 27GW by 2050, driven by onshore wind and solar PV, leading to an almost 18 times higher electricity generation of 74TWh by 2050, driven by onshore and offshore wind, SMRs and solar PV.
- The build out of onshore wind, offshore wind and solar PV is constraint by locational limitations (land, sea, grid). It is recommended to maintain sound and transparent processes for planning, permitting and monitoring.
- Lithuania is recommended to take a decision to build SMRs in the next years in order to achieve first commissioning by 2035. Lithuania has to timely address uncertainties including capital costs and uranium supply chain with OEMs of SMR technology. SMR is critical in maintaining relatively low power prices, improving system adequacy and facilitating availability of domestic electricity for hydrogen production.
- The existing gas fleet can be used for strategic reserve. The majority of the existing gas fleet will eventually be decommissioned by 2050.

ACTIONS AND DECISIONS

STAKEHOLDER	ACTION	DEADLINE
MoE	Adopt an updated **plan for domestic electricity generation capacity development** reflecting the ambitions set out in the Roadmap.	**2024 Q2 (for inclusion in NDP)**
MoE, Litgrid	Implement and maintain sound and transparent processes for **planning, permitting and monitoring** of onshore wind, offshore wind, and solar PV.	**2024**
MoE	Announce, prepare and carry out **renewable generation auctions** in accordance with the Roadmap.	**-**
MoE	Address uncertainties with original equipment manufacturers (OEMs) of SMR and take a **decision on SMR deployment** in Lithuania. If positive, secure uranium supplies and supply chain from abroad. Address policies for nuclear waste and decommissioning.	**2028**

DEPENDENCIES AND RISKS

RISK/DEPENDENCY	MITIGATION
Alignment of wind and solar PV deployment with electrification of demand sectors	The build out of the installed generation fleet should be **balanced with electricity demand growth**. This helps to maintain electricity prices at a sustainable level for investors, and at an affordable level for consumers. It also helps to mitigate dependency on cross-border electricity exchanges (imports, exports) and support network operability.
Market redesign and incentive schemes (CfD, PPA contacts) to support wind and solar PV growth	Introduce an option of **Contract for Differences** (CfDs) in RES auctions, while giving preference for **Power Purchase Agreements** (PPAs) between developers and offtakers to limit governmental support.
Negative decision on SMR	If SMR technology turns out not to be viable for Lithuania, there will be a need for hydrogen based generation (new or retrofitted existing CCGT units and / or gas reciprocating engines) which can be quickly developed, however will require **sufficient supply of hydrogen and at all times**, potentially requiring additional build-out of hydrogen network infrastructure including import terminal. Otherwise, system adequacy will be reduced, and Lithuania will experience higher reliance on interconnectors during supply shortage periods. In addition, volumes of domestically produced electricity might not be sufficient to fully cover the demand from hydrogen production, if SMR is not built. Either **alternative domestic generation capacities** will need to be developed (e.g. onshore wind or solar) or the **ambition of industrial and hydrogen value chain growth will need to be lowered** to prevent Lithuania from becoming net electricity importer.

6.8.2 Electricity transmission and distribution networks

HIGHLIGHTS

- The existing transmission and distribution network will have to be renovated and expanded significantly at all voltage levels. Peak loads are expected to more than triple current levels. This will require major investments in the network and at a rapid pace for development and construction.
- New cross-border interconnectors will be one of the critical measures to maintain power system security and benefit from exchanges with the neighbouring countries, notably Central Europe and the Nordics. The Roadmap foresees the growth in interconnection capacity from 2.2 GW in 2023 to 5 GW in 2050 with the majority of the new capacity targeted for Central Europe.
- Development of an offshore energy hub is seen as highly advantageous allowing to integrate offshore networks and interconnectors of the neighbouring countries and exploit synergies in offshore wind, electricity trade and hydrogen production. The energy hub with its first electrical connections can become operational as early as by 2032 and can accommodate both Lithuanian and some of the neighbouring countries' offshore wind generation capacity, as well as offshore electrolysis of up to 2 GW according to the Roadmap.

ACTIONS AND DECISIONS

STAKEHOLDER	ACTION	DEADLINE
Electricity TSO and DSO, ENTSO-E	Update **ten-year network development plans** reflecting the generation ambitions set out in the Roadmap. Continuously review and update the plans in line with the actual system development. Propose to develop a **thirty-year network development vision** at Europe level (ENTSO-E) to adequately support net-zero targets and net-zero energy system strategies of countries in Europe.	**2024**
MoE, electricity TSOs	Initiate **discussion on governmental level with the neighbouring countries on development of cross-border electricity connections**, i.e. with Poland and/or Germany in Central Europe, Latvia and/or Estonia in the Baltics and Sweden in the Nordics. Further strengthen regional network planning between the TSOs across the Baltic Sea and with a view on supporting net zero energy systems by 2050.	**2025**
MoE	For the above governmental discussions **formulate Lithuania's intention and readiness to develop an offshore energy hub in its EEZ and advocate for routing** the Baltic electrical and gas infrastructure through such a hub.	**2024**
Electricity TSO	Following the inter-governmental agreement achieved by MoE subject to NRAs approval, start **planning the development of cross-border electricity on- and offshore infrastructure with international partners** as per the Roadmap.	-

DEPENDENCIES AND RISKS

RISK/DEPENDENCY	MITIGATION
Infrastructure availability to support power system adequacy and network operability	Electricity TSOs and DSOs to deliver network development plans and measures supporting the envisaged growth for electricity for all resources (generation, storage, demand) and for all voltage levels, while addressing location specific aspects. This should include cross-border lines, domestic corridors and substations, and necessary control and monitoring equipment, and address typical aspects such as system adequacy, flexibility and reserve requirements, and grid operability.
Market frameworks for system balancing	Electricity TSO review and implement frameworks and processes to ensure sufficient resources for system balancing, i.e. provision of ancillary services and reserves, including integration of Lithuania in EU cross-border platforms for ancillary services.
Uncontrolled prosumer growth	MoE, NRA and the DSO have to develop market and tariff instruments that will maximise the usage of the currently ongoing rooftop solar PV boom. While contributing to electricity self-sufficiency, rooftop solar PV uptake can create issues for network operators and distort the market if not managed accurately by means of network tariffs and net-metering schemes. Another solution is to introduce (mandatory) regulation for the deployment of battery storage co-located with solar PV to minimize the negative impact of solar PV deployment on network operation.
Delays in the start of offshore energy hub construction	MoE needs to aim for a governmental agreement that will serve as a basis for the positioning of the Lithuania energy hub in the regional offshore infrastructure development. Potential delays should not result in changes to interconnector routing effectively leading to by-passing of the energy hub.

6.8.3 Natural gas transmission and distribution

HIGHLIGHTS

- The high-pressure natural gas network will continue to be used to transport methane and LNG, and facilitate North-South flows from the Nordics to Central Europe. The gas transmission network will mainly be used for transit flows after 2035. Until then, the volumes of gas in the network will slightly increase from the current levels as the Baltic TSOs apply various market integration measures. The high-pressure natural gas network can be used to transport biomethane. It will likely not be suitable to transport high hydrogen blending rates, for which a separate transmission network will have to be developed.
- The LNG terminal will continue to operate during the energy transition in Lithuania until 2045.
- Existing natural gas users on the distribution network will largely switch to electricity. The distribution network will no longer play a big role after 2035 with only 10 significant consumers of molecules left. As a result, it will gradually be faced out and in line with the pace of decarbonisation of consumers.

ACTIONS AND DECISIONS

STAKEHOLDER	ACTION	DEADLINE
Gas TSO	Update **ten-year network development plans** reflecting the energy mix ambitions set out in the Roadmap. Continuously review and update the plans in line with actual system development.	**2024**
MoE	Take a decision on **the future of the LNG terminal**. Review new roles such as hydrogen, methanol and synthetic fuels.	**~2035-2040**

DEPENDENCIES AND RISKS

RISK/DEPENDENCY	MITIGATION
Infrastructure availability to support gas system adequacy and operability	Gas TSOs and DSOs to deliver network development plans and measures supporting the envisaged growth for gas and gaseous fuels. This should include cross-border lines and pipelines, domestic corridors and substations, and necessary control and monitoring equipment, and address typical aspects such as system adequacy and operability.

6.8.4 District heating

HIGHLIGHTS

- The district heating sector is receiving signals to prepare for a future in which biomass might be seen as less sustainable in the long run. The district heating sector has multiple initiatives, e.g., support to insulation and energy efficiency projects, deployment of heat storage, electrification of heating (combined with heat storage), usage of waste heat, and integration of cooling technologies in district heating.
- District heating systems can provide technically feasible, energy efficient and cost-effective solutions to support integration of variable renewable generation. The economics of electrification of district heating strongly depends on the cost of the existing alternative for district heating (biomass and waste for Lithuania) as well as the (hourly) price of electricity. Low temperature heat storage can be a very cost-effective measure at still relative high electricity prices. At lower power prices installation of a Power-to-Heat (P2H) electrode boiler can become economic. Usage of a seasonal storage (such as a pit storage) would allow this type of hybrid asset to also benefit from sustained longer time intervals with low-priced hours. Deployment of electrical heat pumps typically requires a larger number of hours with low power prices compared to electrode boilers. Electrification of district heating would therefore require a significant deployment of wind and solar in Lithuania to ensure a high number of low-priced hours and for sustained longer time intervals.
- Waste heat can be an important source of energy, but its application is not straightforward. The temperature of the waste heat should thermodynamically fit with the district heating it supplies (similar temperature levels), and the distance should be minimal to reduce capital costs for its deployment. A future regulatory framework should enable new business models to emerge to facilitate commercial integration of waste heat sources in existing district heating schemes.
- The current regulatory framework in Lithuania might not be appropriate to support further investments in district heating to support integration of renewable energy and decarbonisation of the energy system, and particularly not after 2030 when further electrification of district heating is foreseen, which requires a substantial amount of investments.
- Lithuania is now transitioning from the current third-generation district heating network (3GDH), with hot-water temperatures below 100°C, to 4th generation district heating (4GDH) with hot-water temperatures in the range of 60-70°C. Moving towards a 4GDH network requires an integrated approach for strategy development and planning strategies between the energy sector and the build environment. This also includes network planning, given that district heating plants operate nearby load centres for electricity and heat. For this reason, district heating plants can also provide locational benefits through the provision of balancing and ancillary services and support secure system operation in power systems with a high amount of variable renewable energy.

ACTIONS AND DECISIONS

STAKEHOLDER	ACTION	DEADLINE
MoE	Adapt **the regulatory framework for district heating for change.** A future regulatory framework should enable new business models to emerge and facilitate commercial integration of waste heat sources in existing district heating schemes.	**2025**
MoE, MoEv, DH operators, electricity and gas TSOs and DSOs, municipalities	Develop an **integrated approach for strategy** development and planning strategies **between the energy sector and the built environment**. This also includes network planning, given that district heating plants operate nearby load centres for electricity and heat. It is recommended to also include cooling in this strategy, given the projected increase in demand for cooling until 2050.	**2025**

DEPENDENCIES AND RISKS

RISK/DEPENDENCY	MITIGATION
Electricity price development	Electrification of district heating require a significant deployment of wind and solar to ensure a high number of low-priced hours for sustained longer time intervals. Too high electricity prices can be mitigated by support schemes and incentives for electrification applications of district heating.

6.8.5 Hydrogen value chain

HIGHLIGHTS

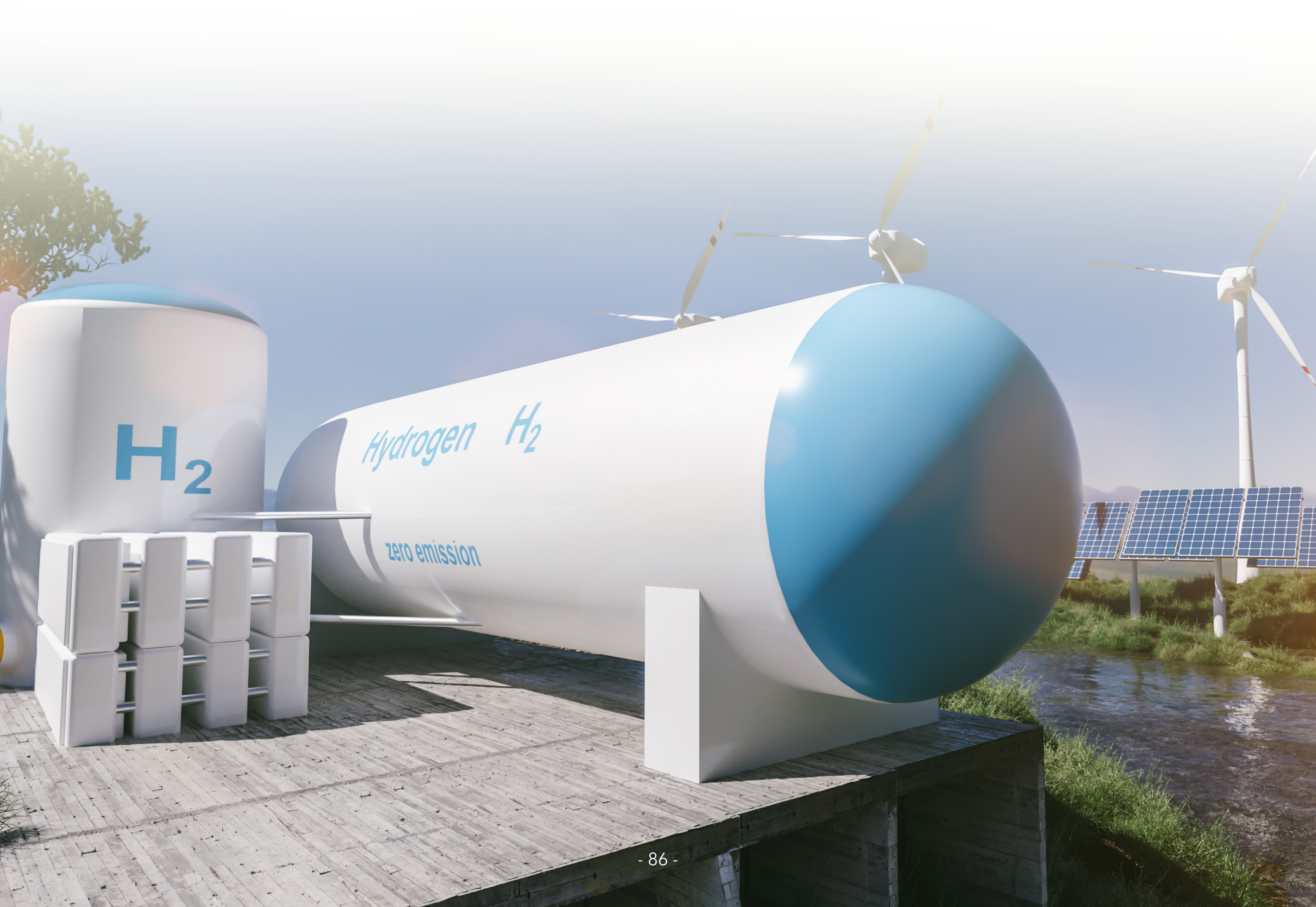
- Green hydrogen is seen as a major energy carrier for the future of the Lithuanian energy system. It will play multiple roles in decarbonising industrial heat and feedstock (fertiliser and e-fuel production), enabling the development of a domestic synthetic fuel industry, drive export to neighbouring countries and supply zero carbon gas fired power generation. According to the Roadmap scenario, the Lithuanian hydrogen sector could expand to a total installed capacity of 8.5 GW by 2050.
- Hydrogen production at a scale beyond ~1 GW requires a regional transmission network for hydrogen where the surplus or shortage of hydrogen is balanced by underground storage in connected markets such as Poland and Germany. Lithuania will need to make agreements with the respective countries for use of their storage sites so that it can scale its domestic hydrogen production. Around 3 TWh of seasonal storage is projected to be required in 2050.
- Long-term storage of hydrogen in large quantities allows for a significant increase of electricity demand beyond 2030, and support integration of variable renewable energy. It will help to increase future electricity prices, and hence improve investment conditions for renewable energy projects.
- Hydrogen transport will require development of a dedicated pipeline system for hydrogen, separate from the existing natural gas network. This system will connect the hydrogen production sites with industrial demand clusters and international transit corridors.
- Development of an offshore energy hub is seen as highly advantageous as it allows to retain the benefits from integration of offshore wind generation and offshore hydrogen production. As per Roadmap, the offshore hydrogen production on the hub can be realised by 2035-2040 reaching a total capacity of up to 2 GW. The hub could be used as a terminal connecting the Lithuanian onshore hydrogen network with the offshore Nordic-Baltic hydrogen corridor.
- Hydrogen production will become a major electricity price setting sector in Lithuania – electrolysers' willingness to pay for electricity will greatly determine the average level of wholesale electricity prices.
- Synthetic fuel production could become a significant user of hydrogen and other alternative fuels as biodiesel, bio-ethanol have a strong correlation with hydrogen in fuel choice by transport as well. The future alternative fuels market and prices are highly dependent on considerations regarding available fuels for shipping, aviation, industry, and other sectors, as well as their respective prices (see section 3-2 as well).

ACTIONS AND DECISIONS

STAKEHOLDER	ACTION	DEADLINE
MoE	Adopt an updated **plan for the development of a national hydrogen value chain** reflecting the ambitions set out in the Roadmap.	2025
MoE	Initiate **discussion on governmental level within BEMIP group on integrating the Lithuanian hydrogen infrastructure into international transmission corridors** (on- and offshore).	2024
MoE	Initiate **discussion on governmental level with Poland (or/and Germany) on utilising its underground storage potential for hydrogen.**	2024
MoE	In the above governmental discussions **formulate Lithuania's intention and readiness to develop an offshore energy hub in its EEZ and advocate for routing** electrical and gas infrastructure through such a hub.	2024
MoE	Monitor technology and **price developments** for hydrogen and its (green) alternatives **for the sectors with (prospective) large users**, to make informed choices regarding the development of production and supply infrastructure, and pricing (impacts) for and from these different sustainable alternatives.	~2030-2035
Gas TSO	Following governmental agreements achieved by MoE start **planning of the development of national hydrogen infrastructure and its interconnections with international on- and offshore hydrogen corridors** as per the Roadmap.	-
Gas TSO	Start the planning of the **development of hydrogen pipelines between hydrogen production and offtake facilities** envisaged to be operational by 2030. Integrate these pipelines with a national hydrogen transmission network.	2024

DEPENDENCIES AND RISKS

RISK/DEPENDENCY	MITIGATION
Hydrogen transmission and storage	If agreements on hydrogen transmission or storage with neighbours are delayed, the fertiliser and synthetic fuel production plants would need to be capable to operate flexible, switching between methane and green hydrogen as feedstock or varying their output. However, this measure will not make it possible to develop the hydrogen production capacities as envisaged in the Roadmap.
Delays in the start of of energy hub construction	MoE needs to aim for a governmental agreement that will serve as a basis for the positioning of the Lithuania energy hub in the regional offshore infrastructure development. Potential delays should not result in changes to pipeline corridor routing effectively leading to by-passing of the energy hub.
Industrial demand for hydrogen	It is important that MoE provides clear policy and strategy directions to the industry sector regarding the future availability of hydrogen. Supply and demand have to be developed hand-in-hand such that mismatches in production and offtake volumes are minimised. Otherwise, price volatility and supply constraints can jeopardize business cases.
Change in electrolysers' willingness to pay for electricity	Costs of building electrolysers and their potential revenue will to a great extent affect the development of wholesale electricity prices in Lithuania. Depending on the development in the hydrogen supply and offtake, the electrolysers willingness to pay for electricity will vary, thereby either leading to very low or very high wholesale electricity prices. MoE needs to constantly monitor the hydrogen industry and offtake market to ensure that proper incentives (support or taxation) for hydrogen production are introduced on time to maintain stable electricity prices.
Lock-in to a fuel (dependency) that is sub-optimal for Lithuania	Close monitoring of technology progress and (large) consumer preferences and regular alignment (e.g. 2 times/ year) between key stakeholders about options and likely sustainable commodity choices.



6.8.6 Biomass (including biofuels and waste) and biogas value chain

HIGHLIGHTS

- Since 1997 Lithuania has replaced a substantial amount of natural gas that was used in district heating and household boilers with dry biomass. The future biomass (including all types of biogenic fuels, e.g. biofuels, waste, biogas, etc.) use in Lithuania will be dependent on an assessment of the sectors which provide the highest added value for the application of biomass. In this respect, the usage of biomass to produce heat is viewed as a low value-added application of biomass. The higher value-added activities are assumed to be the production of transport fuels for shipping and aviation, the production of chemicals (including fertilisers), and the provision of high temperature heat – sectors with limited zero-carbon alternatives.
- If a high value for the domestic biomass potential is assumed (i.e. in range of 50 TWh of primary energy), domestic biomass will cover a major share (~85%) of the total demand for biomass in 2050. Yet, this will be difficult in 2030 and 2040, where biomass will have a large role in decarbonisation when green hydrogen is still not available at sufficient scale – domestic biomass covers only 60% of demand in 2030 and 70% in 2040.
- The biorefinery is the first major use-case for biomass. The potential for sustainable woody biomass can be converted into advanced biofuels that can be used in the aviation or maritime sector. Liquid fuels will play an important role in the decarbonisation of these sectors. This process can be combined with the decarbonisation of the existing refinery and will reduce the dependency of Lithuania on foreign crude oil and oil products.
- Fertiliser is the second potential major use-case for biomass, where biomass will compete with domestic hydrogen. Besides the substantial secondary forest residues, also the agricultural by-products and industrial waste represent a significant part of the biomass potential in Lithuania. These latter two biomass streams are well suited for conversion by Anaerobic Digestion (AD). This process produces biogas (which can be upgraded to biomethane and biogenic CO2) and digestate. In the absence of suitable hydrogen storage locations, baseload biomethane (in combination with some renewable hydrogen) could be a decarbonisation solution for fertilisers. Biomethane can provide the biogenic CO_2 that is necessary for the production of urea. Besides the production of renewable fertilisers, the digestate of the AD plants could also be used as an organic fertiliser.
- Thus, with proper processing and treatment, biogas can be a viable alternative to natural gas in many applications. Biogas can be used for electricity generation, which is a mature technology, but installations are still rare in Lithuania. Projects and initiatives exist to feed biomethane into the gas network.
- The used modelling shows a very high demand for biomass by 2030 from biofuels, biomass CHP's (electricity and heat) and industry. After 2030 electrification and hydrogen likely will supply a significant part of this demand. If the ambitious goals of these sectors to biomass or electrification is delayed, energy dependency on oil will remain for a longer time.

ACTIONS AND DECISIONS

STAKEHOLDER	ACTION	DEADLINE
MoE	Develop policies focussing on **phasing-out low-value biomass applications** such as heat (in housing and industry) after 2030 and avoiding potential lock-in effects blocking other renewable alternatives such as electric boilers and heat pumps.	**2025**
MoE	Develop policies promoting the **uptake of biomass in high-value energy value chains**, such as refinery, synthetic/ biofuel production and fertilisers.	**2025**
MoE	Investigate and support innovative technology uptake **enabling the usage of biogas and electricity to produce high-value products** such as synthetic fuel.	**2026**

DEPENDENCIES AND RISKS

RISK/DEPENDENCY	MITIGATION
Availability of domestic green hydrogen for fertilizers	Depending on the growth of the domestic hydrogen sector, the demand for biomass coming from the fertilisers will vary. If the hydrogen uptake is slower than foreseen by the Roadmap, **biomass will be used as a substitute** which will require even higher volumes of biomass imports in 2030-2040.

6.8.7 CCS and synthetic fuels value chain

HIGHLIGHTS

- The main sources of CO_2 that can be captured and stored or reused in Lithuania will be from the combustion of natural gas and waste, the upgrading of biogas to biomethane and industry clusters. In Lithuania there are four major central source-point CO_2 emitters. These are the refinery (Orlen; 1.6 MT), the ammonia production plant (Achema; 2.5 MT), the cement factory (Akmenes cement; 0.96 MT) and a district heating plant (Vilniaus šilumos tinklai; 0.6 MT). These represent around 65% of the industrial CO_2 emissions. The future potential of the capture of CO_2 from these installations is largely dependent on the decarbonisation pathways and the technologies deployed but it is clear that it will decline due to decarbonisation. In the future, another source will emerge – during the upgrading process to biomethane the biogenic CO_2 can relatively easily be captured. Considering the announced prohibition in the EU of the use of fossil CO_2 after 2036 for power generation (or 2041 for industry), biogenic CO_2 can play an important role to supply an alternative source of CO_2 to produce renewable fuels.
- Lithuania has a limited potential to store CO_2. The underground storage potential is mainly comprised of a couple of deep saline aquifers through structural trapping and oil fields used for the enhanced recovery of oil. Due to the limited storage potential any project in Lithuania would likely be limited to the domestic capture of CO_2. Alternative to the domestic storage of CO_2 Lithuania could connect to other European storage projects. In this case, either an export facility for shipping or piping infrastructure of CO_2 needs to be established. The transport of CO_2 can be done via three different modes - by pipeline, by ship or by truck. The choice will depend among others on the location of the end-user and the volume that needs to be transported.
- The potential reuse of CO_2 is currently mainly limited to the provision of CO_2 to beverage producers. In the future, starting already around 2030 and scaling up towards 2050, the usage in the refining of synthetic gas (like hydrogen) into higher value-added fuels like synthetic methanol or kerosene will become the primary end use with the highest potential value added. This will be an area where synergies between the production of biogas and the development of hydrogen production will emerge and create opportunities for Lithuania to export these fuels to the region (at least 3 TWh in 2050, according to the Roadmap).[38]
- Another emerging application could be in the production of CO_2-cured concrete. In case of Lithuania the capture of CO_2 at cement plants could be used into building materials, again reducing its carbon footprint.

ACTIONS AND DECISIONS

STAKEHOLDER	ACTION	DEADLINE
MoE	Together with the industry and energy production utilities associations **develop a detailed strategy for the domestic CCS and synthetic fuel value chain** sector based on a dedicated analysis of the full potential of CO_2 capture, storage and use in Lithuania.	**2025**
MoE	Based on the findings of the analysis and the developed strategy, **promote the development of industrial clusters** in Lithuania, where **synergies between hydrogen production, CO_2 emission and capture, and the production of synthetic fuels** would be exploited at full. Consider the needs for storage and transport of CO_2.	**2027**

DEPENDENCIES AND RISKS

RISK/DEPENDENCY	MITIGATION
Legislation for CO_2 capture including research and development, CO_2 transport and CO_2 storage	Determine changes to the current CO_2 legislation to support development of a strategy for the domestic CCUS and synthetic fuel value chain, and support development of business cases, e.g. for CO_2 capture in industrial clusters. Drive acceptance for CO_2 capture, transport, storage and usage in Lithuania.
Potential shortage of non-fossil based carbon	The production of zero carbon products and fuels will not only require sufficient amount of green hydrogen, but also non-fossil based carbon. It is recommended to conduct a future needs and sourcing assessment of non-fossil based carbon and develop strategies for implementation to support future increase of zero carbon products and fuels.

[38] The employed model has limited functionality around CCS, hence a more detailed study is recommended. It is clear however, that the potential to produce synthetic fuels for exports is significant.

6.8.8 System flexibility

HIGHLIGHTS

- Flexibility at different timescales, from hourly to monthly, will be a major requirement for secure and economic operation of the future Lithuanian energy system. By 2050 installed vRES capacity will reach 23.5 GW (19.5 GW peak output), while peak non-flexible demand will be only 5.4 GW.
- Primarily hydrogen electrolysers, BESS systems, power to heat in district heating networks and in industry, DSR, hydrogen powered CCGTs and interconnectors will play a role in delivering short-term flexibility and adequacy. The Roadmap entails the total of 20 GW (peak) of dispatchable flexibility sources – 6.5 GW of electrolysis, 5 GW of interconnectors, 4 GW of BESS, 1.5 GW of SMRs, 1 GW PHS plant and a few other minor assets. In 2040 the total will be at just below 14 GW. In fact, all these assets have a high utilisation rate assuming that there will likely be more opportunities for assets like BESS which can be scaled quickly and modularly.
- Hour-to-hour system ramps in residual load (vRES output less non-dispatchable demand) will reach 5 GW in 2050, more than the peak capacity of generation today. The annual average change of residual load every 12 hours will be 5.5 GW in 2050. This means increased reserve requirements for the TSO and a critical role for well-functioning flexibility markets to enable respective flexibility resources to economically support secure system operation and support electricity prices.
- The modelling shows that the significant increase of flexible resources as foreseen by the Roadmap is sufficient for the system to not have any wind or solar PV generation curtailments or hours with energy not served, assuming that electrolysers can be operated flexibly. While interconnectors have a large role in system balancing as they are the most cost-effective source with the highest availability, a 100% availability is not critical even in a period of a so-called "Dunkelflaute". In fact, in the analysis conducted within this study, the availability of interconnectors in the periods of sustained RES generation would have to get as low as 17% for some energy to not be served. The main domestic sources for the provision of system adequacy will be SMRs, hydrogen CCGT, biomass and waste CHP, PHS plant, heat storage in heat networks, and batteries.
- DSR in residential, commercial and industrial sectors will play a varying role in system flexibility. On short timescales, prosumers will provide system support by shifting their flexible loads such as EVs (including those with V2G capability) or rooftop solar PV output. This requires price signals and operational flexible contracts for prosumers. On mid- to long timescale, industrials will be able to provide some level of flexibility by shifting their loads if sustained periods of undersupply are predictable and forecasted well in advance. The ability to shift load will vary for different industry types, with some requiring firm supply at all times, and others pursuing flexibility provisions for the system as part of their business cases.
- Digitalisation, smart tariffs and incentives via real-time price signals will be key to unlock provisions of system flexibility, especially among stakeholders who do not directly participate in wholesale markets.

ACTIONS AND DECISIONS

STAKEHOLDER	ACTION	DEADLINE
Electricity TSO	**Conduct state-of-the-art adequacy and reserves studies** to assess power network needs at different timescales until 2035 given the energy mix and locational system changes as foreseen by the Roadmap. Include similar network analysis until 2050 to ensure that Roadmap targets for 2050 can be met. It is recommended to apply hourly energy system modelling, and state-of-art power market and network modelling techniques.	2025
MoE	Adopt a **plan for domestic flexibility capacity development** reflecting the needs evaluated by the TSO. Empower and support the TSO in securing the required capacities of different flexibility resources where the market may not deliver these on time. This may include introducing new market mechanisms for capacity, flexibility and reserves, or specific incentives such as tenders.	2025
Electricity TSO with support from NRA and MoE	Support the development of a liquid and transparent wholesale electricity market with significant participation of **different type of wholesale market actors, covering generation, storage and demand resources,** including BESS and P2G electrolysis operators and industrial and residential participants. **Conduct pilots with different customer types** to show-case the technical feasibility and economic benefits of flexibility provision.	2028

DEPENDENCIES AND RISKS

RISK/DEPENDENCY	MITIGATION
Market conditions for deployment and retaining flexibility from BESS, P2G and interconnectors	Ensure supportive market conditions for the deployment and dispatch of key flexibility resources such as BESS, P2G and interconnectors throughout the energy transition to meet Roadmap goals and targets. Drive cooperation and alignment between all market participants in Lithuania, including a further strengthening of cross-border cooperation between TSOs across the Baltic Sea.

6.8.9 Transport sector

HIGHLIGHTS

- The plan of Lithuania for switching fuels in the transportation sector is set in the National Energy Independence Strategy. This strategy sets the goal of achieving a 15% RES share in the transport sector in 2030 and a 50% RES share in 2050.This strategy is in line with The Law on Alternative Fuels and the National Climate Change Management Agenda.
- As Lithuania is an EU member, the regulation on EVs will request Lithuania to have a higher share of electrical cars than the global average. Therefore, a more realistic forecast for Lithuania will be to account for a 70-75% share of electricity in transport, with a 25-30% share largely fullfilled by hydrogen, and the remaining small share by synthetic fuels or biofuels.
- The Ministry of Transport has put forward an objective of growing the fleet of EVs from the current ~13,000 to 240,000 by 2030 which would constitute approximately 20% of the total passenger car fleet. It is important to mention that 58.3% of Lithuanian residents live in multi-apartment buildings. For these households, there are no legal or technical provisions to install charging stations near the property. Therefore, the development of the use of electric cars by this part of the population is only possible if the municipalities develop a particularly dense network of charging stations, and electricity suppliers offer competitive pricing for electricity.
- Lighter transport is by 2040 largely electrified. Heavier transport will be electrified to a significant amount as well, but hydrogen fuel cells will also be introduced that benefit from a higher application efficiency compared to internal combustion engines.
- The Ministry of Transport has also set a goal to have 5% of all new vehicles powered with hydrogen by 2030. This would imply ~2,000 passenger cars, 30-50 buses and ~100 heavy-duty vehicles. In parallel, the objective is to have ten hydrogen refuelling stations by 2030.
- Biomethane production development will be supported by incentive schemes, but biomethane will not make a significant contribution in the transport sector.
- Biofuels will likely be used as a transition fuel in domestic transport. Ambitious goals of biodiesel and bio-ethanol usage are set in the model for 2030. Enough biomass feedstock needs to be available for this. Current offtake has to drastically change to limit use of fossil oil. After 2030 domestic transport is expected to be electrified or use hydrogen more. However, a role for biofuels is seen in international and heavy transport for the period after 2030.

ACTIONS AND DECISIONS

STAKEHOLDER	ACTION	DEADLINE
MoT and MoE	Continuously **support road transport electrification** through incentives for EV purchase.	-
MoT and municipalities, DSO	Ensure **sufficient charging infrastructure availability** to increase attractiveness of EVs among the society. Investigate the potential of V2G technology and potentially introduce additional incentives for EVs capable of supplying power back into grid.	-
MoT and electricity TSOs	Exploit possibilities for **joint heavy-duty fast charging and electricity system development opportunities for optimal planning** of charging infrastructure connection points for the main highways with potential of land reservations to provide connection infrastructure.	2026
MoE	Assess options to ensure availability of sufficient biomass for required fuel production.	2024
MoE	Support construction of hydrogen fuelling stations, mainly for vans, busses, heavy vehicles and international transport.	~2030-2035
MoT and MoE	Develop a strategy for the production of synthetic fuels, with a view on a strategy to resource energy carriers (e.g. electricity, hydrogen, biomass, and biogenic CO_2 (from CCUS), including transport and conversion, and a strategy to market synthetic fuels for domestic and international customers.	2030

DEPENDENCIES AND RISKS

RISK/DEPENDENCY	MITIGATION
Delayed fuel switch in industry or transport	Fuel switching should be driven by market forces, i.e. low electricity price signals and affordable transport vehicles. MoE has to align the build out of RES generation with the deployment of EVs, as per Roadmap timeline, to ensure that electricity prices will be competitive and drive a market based switch from fuel to electricity based transport.
Transport electrification increase loads on LV and MV networks	Electricity TSO and DSO should factor the growth of EVs in their network development plans to be able to handle increased electricity demand. They should develop market mechanisms for EVs to provide ancillary services and congestion management for network operation from vehicle-to-grid technology deployment. They should also support market redesign mechanisms focused on the provision of demand response to wholesale and intraday markets.
Insufficient biomass for biofuels and remain dependent on oil-based fuels	Assessing options, building (international) supply lines to ensure the timely availability of sufficient biomass.
Market for synthetic fuels	Although an early mover advantage can be foreseen to enter the market for synthetic fuels, the market(s) for synthetic fuels (fuel types, volumes, customers, prices) are still highly uncertain. It is therefore recommended to better assess the market for synthetic fuels and address its potential impact on resource requirements.

6.8.10 Industry sector

HIGHLIGHTS

- The largest consumers of energy in the Lithuanian industry are the refinery, fertiliser and chemical industries. Lithuania does not have a metallurgical industry, and its paper and food industry are modest in their energy use.
- Energy-intensive industries will significantly change in the next years as they transition to less-carbon intensive operations. In the future, Lithuania can make use of CO_2 produced from bioenergy resources (biogenic CO_2) combined with green hydrogen to produce sustainable fertilisers. In the refinery sector Lithuania will face increasing pressure since the energy transition will reduce demand for its oil-based products as the transport sector decarbonises. The Lithuania refinery feedstock in 2050 will feature a mix of green hydrogen and biogenic origin CO_2 in order to produce synthetic fuels. Biomass can be used as a feedstock for biofuels and synthetic fuels production. Other low-carbon feedstocks can be used as well, such as various residues from plastics and waste.
- Biomass is playing a significant role in 2030 and 2040. By 2050 the biomass demand has decreased as industry sectors are increasingly using electricity or hydrogen to fullfil their heat demand. However, biomass will still be significantly used for industry feedstock. Biomethane will play a key role in the next 5-15 years as a source of heat in industry, gradually replaced with electric boilers, heat pumps (low temperature heat) and hydrogen towards 2050.
- Hydrogen will be primarily used for the production of derivative products, in order to meet the zero-carbon EU targets in end-use sectors. It will also be used for high-value end use products or applications that cannot be abated through direct electrification. Post 2030 a synthetic fuel industry will emerge based on the usage of hydrogen and carbon for high-value fuel products, potentially leveraging existing refinery capabilities in Lithuania.

ACTIONS AND DECISIONS

STAKEHOLDER	ACTION	DEADLINE
MoE and MoEc	**Evaluate the need for explicit CO_2 taxation or alternative financial incentives** for the end-use sectors, especially industry, additional to the EU ETS system, to promote faster fuel switching and electrification.	**2025**
MoE	Initiate a dialog with the refinery industry as major stakeholder in Lithuania to make a decision on the **strategic direction of future refinery development** in a world with a diminishing demand for oil products.	**2030**
MoE	Develop a strategy for the production of synthetic fuels, with a view on a strategy to resource energy carriers (e.g. electricity, hydrogen, biomass, and biogenic CO_2 (from CCUS), including transport and conversion, and a strategy to market synthetic fuels for domestic and international customers.	**2030**

DEPENDENCIES AND RISKS

RISK/DEPENDENCY	MITIGATION
Competitiveness of industrials	Enable the supply of low-cost electricity and hydrogen to industrials, ensuring a cost-effective decarbonisation of industrials towards 2050. Drive a significant uptake of renewable energy generation and P2G as indicated in the Roadmap.
Market for synthetic fuels	Although an early mover advantage can be foreseen to enter the market for synthetic fuels, the market for synthetic fuels (fuel types, volumes, customers, prices) are still highly uncertain. It is therefore recommended to better assess the market for synthetic fuels, and also address its potential impact on resource requirements.

6.8.11 Residential and commercial sectors

HIGHLIGHTS

- Improving energy efficiency in the built environment sector will be the major driver of declining energy demand in the residential and commercial sector. This will be mainly driven by insulation improvements and fuel switching.
- A country average of at least 15% insulation improvement in buildings compared to 2023 should be achieved by 2050, although higher values can be possible.
- Decarbonisation of residential and commercial sectors will be mainly driven by electrification. Other energy carriers will not play a major role in these sectors. District heating provides the majority of residential energy demand. By 2050 electricity will become a major source of energy for district heating, complemented by shares of biomass, waste and residual (waste) heat. The share of houses connected to the district heating network will reduce to at least 40% with the remainder being equipped with electrical heat pump installations.

ACTIONS AND DECISIONS

STAKEHOLDER	ACTION	DEADLINE
MoE	Develop and implement an action plan to drive **energy efficiency improvements, electrification of heating and rooftop PV development in residential and commercial sectors** to achieve the milestones set out in the Roadmap.	**2023**
MoE	Start a campaign promoting the topic of decarbonisation and sustainability among citizens to create **demand for sustainable products and stimulate the commercial sector through changing customer demand patterns**.	**2026**

DEPENDENCIES AND RISKS

RISK/DEPENDENCY	MITIGATION
Slow uptake of low-carbon technologies such as EVs, rooftop solar, heat pumps and insulation improvements	MoE to monitor the progress and to introduce incentives (e.g. tax deductions, grants) aimed at consumers to stimulate transformations in the residential and commercial sectors.

6.8.12 Markets & regulations

HIGHLIGHTS

- Decarbonisation of the energy system can be achieved through deployment of zero carbon generation resources and electrification of demand sectors such as industry, transport, households and commercial buildings. Well-designed electricity markets and support schemes are crucial to maintain a level playing field for the required investments and economic operation of electricity generation, storage and demand resources, while ensuring adequate and secure system operation in the transition towards a zero-carbon energy system.
- Wholesale power prices are foreseen to drop and to become increasingly volatile under influence of higher shares of variable renewable generation. The price setting of wholesale electricity prices will change from generation marginal costs based to willingness to pay (opportunity cost) of electricity generation, i.e. revenues from electricity generation for the production of hydrogen or revenues from dispatch of demand resources for the production of heat. By 2050, in more than 50% of hourly time intervals, the hourly wholesale price can be set by the willingness to pay for hydrogen production.
- Alongside increasing shares of variable renewable generation, the Lithuanian government and regulator can opt to change market design by introducing new markets and create a level playing field for instance for the provision of flexibility and capacity, and for PPA schemes and contracts supported by corporate PPA off-takers pursuing decarbonisation strategies for their industrial operations. The focus areas for Lithuania will be facilitating alternative revenue opportunities for wind and solar PV developers, supporting network operators in network reinforcement and expansion, designing proper charges and tariffs for end customers and providing support instruments for technologies which are not yet mature. While Lithuania already has multiple support instruments to drive decarbonisation, these will likely be insufficient given the projected scale of growth and investment required at all levels. DNV has estimated that, although continuous cost declines are expected for solar PV, onshore wind, offshore wind and SMR (after 2040), the foreseen drop in wholesale market prices require additional revenue streams in the magnitude order of 50% to 70% of total required revenues to ensure economic viability of investments until 2050. These amounts are fluctuating over time due to predicted changes in power price forecasts, whereas the highest amounts are foreseen by 2050. For mature RES technologies, competitive auctions with contracts for difference are likely to remain the best choice for the next few years, with gradually changing success criteria to favour developers with pre-agreed PPAs. A well-functioning PPA market will require a liquid wholesale power market providing sufficient hedging opportunities for participants to risk manage their PPA contracts. For the emerging technologies such as hydrogen and SMRs, new support and funding instruments may need to be established. In this context Lithuania will need to make use of different EU funds which promote these and other technologies in the decarbonisation area.
- Significantly increasing network loads will require large electricity network reinforcements at all voltage levels. TSO and DSOs should therefore have sufficient resources available to enable this growth (CAPEX coverage, R&D costs, etc). Coordination between TSO and DSOs will be key to unlock synergies in network planning and innovations.
- The existing network charges and electricity tariffs are not fit-for-purpose to ensure economic efficiency, cost recovery and fairness among end customers in the future system. The NRA will have to review the current approaches which worked well until now but will provide distorted signal in the future energy system – network charges shall be based on multiple instead of single peak values; location-agnostic net-metering will need to be discontinued or replaced by alternative schemes to promote prosumer growth.
- It is recommended that in order to assess the development of network charges, further detailed analysis is required taking into account the expected developments. For example, the network pricing regime can be further developed to consider adjustment of the definitions of chargeable peak demand, the integration of prosumers and flexibility services which are to be expected in Lithuania.
- One important aspect to consider is streamlining flexibility services focusing on upscaling the number of potential flexibility prosumers willing to maximise their revenue by actively participating in flexibility markets. Simplifying and standardising flexibility services, transparency can improve value stacking of flexibility services enabling access to wider range of flexibility markets that prosumers can take part in (reactive power, frequency response). Systems such as contracting platform where flexibility prosumers can visualise all the types of flexibility services, with estimated earnings, detail requirements and customer journey to qualify as flexibility service provider can bring immense value. Contracting platforms integrated with the energy network planning and operation leveraging grid automation, digital technologies and communication systems, can effectively support prosumers on their journey.

- Energy system transformation will require unprecedented level of investment (71 blnEUR) by 2050, which will have to come from various sources. The Lithuanian government will need to engage with a range of private and public entities within and outside the country to communicate the strategy and attract financing.
- The price difference with Central Europe might to a great extent affect Lithuanian electricity prices. If the prices in Central Europe decrease, Lithuania will likely see domestic prices to drop as well. This will have knock-on effects on other economy sectors through sector coupling and due to end-use electrification. Notably, the effect from increase in Central European prices will be limited given that Lithuania has sufficient domestic generation capacities.
- In relation to the labour market: High-skilled workforce to help realize necessary transformations is in very high demand throughout the world. Strategies need to be developed to help ensure the availability of sufficient staff and relevant skillsets to realize these transitions on time.

ACTIONS AND DECISIONS

STAKEHOLDER	ACTION	DEADLINE
NRA	Throughout the energy transition **set up a process and agree on methods to monitor the functioning of electricity markets** and price signals for investment and profitable operation of system resources.	2025
MoE	Develop and assign a **sector coordination role to drive the energy transition** aims in coordinated and synergies exploiting manner.	2025
MoE	Develop a **comprehensive strategy for market design, regulation and funding to support the energy transition** – investment requirements, business cases, ownership schemes, auction design and schedule, support volume, tax and other incentives, eligibility, etc. Support introduction of new markets and revenue streams for generation, storage and demand resources, and create a level playing field for instance for the provision of flexibility and capacity, and for PPA schemes and contracts supported by corporate PPA off-takers pursuing decarbonisation strategies for their industrial operations. Monitor existing support schemes for the next few years, while developing long-term outlook on which instruments will be in place to facilitate required investment for the energy transition. Align strategy and funding instruments with EU, especially for capital heavy strategic assets such as SMRs, hydrogen value chain and energy hub.	2025
MoE and electricity TSO	Consider **eligibility requirements, need and access for all resources including RES for ancillary service provision**.	2028
MoE	Evaluate for system operators and **considering sector coupling facilitation** through partnerships, including M&A with other infrastructure (not only energy) companies to increase equity base and borrowing capabilities.	2025
NRA	Review and update **incentive mechanisms for the TSO and DSO** aiming at facilitation of the foreseen electricity generation and demand growth in line with the Roadmap.	2026
NRA	Review existing **network charges and electricity tariffs** for end consumers in context of the system growth foreseen by the Roadmap.	2026
Electricity TSO and DSO	To develop a **strategy for network development and system operation in mid- and long-term**, when the system will expand by several times and today's norms, rules and procedures will become inadequate.	2026
Joint stakeholders	To develop a **strategy for attracting/ developing the required workforce** to realise the transitions	2024

DEPENDENCIES AND RISKS

RISK/DEPENDENCY	MITIGATION
Changing market conditions to incentivize RES growth	Introduce an option of CfDs in RES auctions, at the same time giving preference for applicants with PPA contracts, which are not requesting governmental support. Monitoring of business case and investment climate to ensure viable business cases and required investments for system operators and market players, through possible changes in regulatory framework, e.g. by including tariff component(s) and/ or capacity remuneration scheme(s) for recovery of (otherwise unrecovered) CAPEX costs.
Insufficient workforce to establish transitions	Broad (sectoral) alignment between all actors involved in/ affected by the required transitions to develop a strategy aimed at attracting and upskilling workers that are required to realise these transitions.

FIGURE 6-6

Top five strategic actions for enabling energy system transformation

6.9 Key actions, risks and implementation

The top five immediate and most critical actions to work on are summarised in Figure 6-6. These should be prioritised by the Lithuanian Ministry of Energy as the main strategic actions of work in order to realise the transformation.

In the first place, the energy system transformation requires immediate focus on renewable energy deployment to drive decarbonisation of electricity and put a downward pressure on electricity prices. Deployment of wind and solar would then go hand in hand with electrification of transport, which is the sector with the largest electrification potential. Hydrogen storage will be critical to provide energy system flexibility. The Lithuania government is therefore advised to initiate a dialogue with Poland and / or Germany on usage of seasonal storage. It will be critical to support the industry in Lithuania with the transformation towards the production of zero carbon products once sufficient supply of hydrogen is available. During the transformation a continuous focus on reinforcement of the electricity networks, at all voltage levels, is required to enable the transformation.

In this study the long-term objectives for the Lithuanian energy system have been reassessed, and a roadmap has been formulated to drive the fundamental transformation changes in the energy system. The Roadmap takes a view on the potential impact, implementation and benefits of critical "building blocks" driving transformational change, such as onshore and offshore wind, solar PV, and hydrogen. Figure 6-7 shows a mapping of these building blocks along the dimensions of energy system benefits and risks. It can be seen that most required energy system resources are no-regret options and have high positive impact at moderate to low risk.

FIGURE 6-7

Mapping of energy system building blocks along dimensions benefit and risks

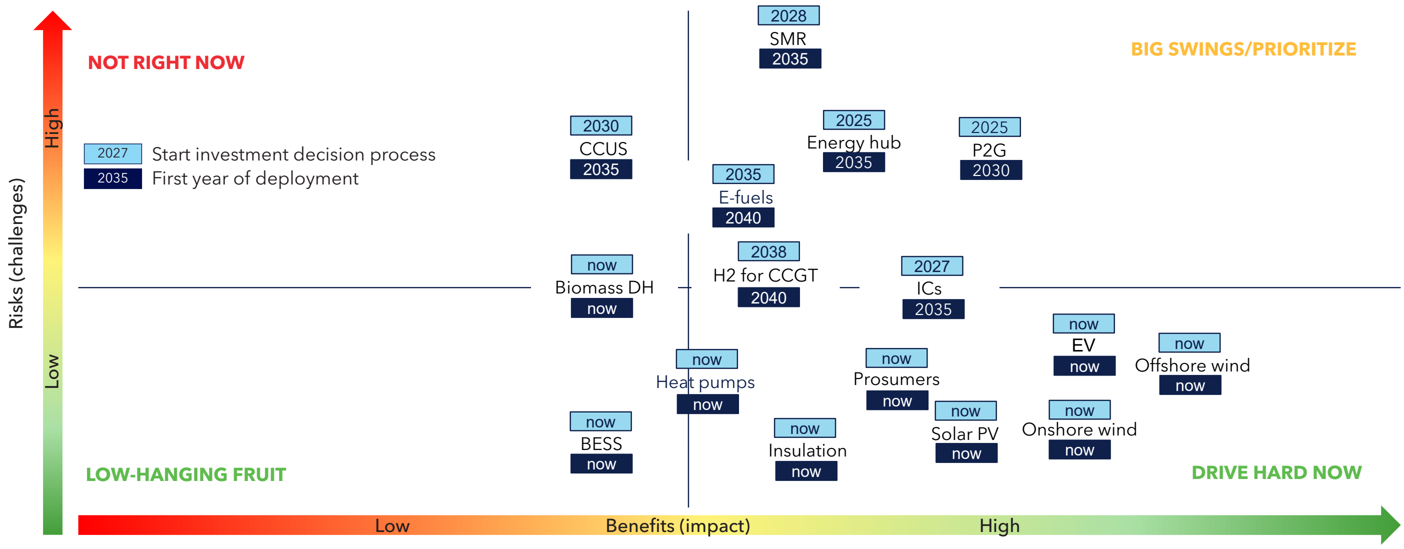


FIGURE 6-8

Risks (R) and benefits (B) of energy system building blocks

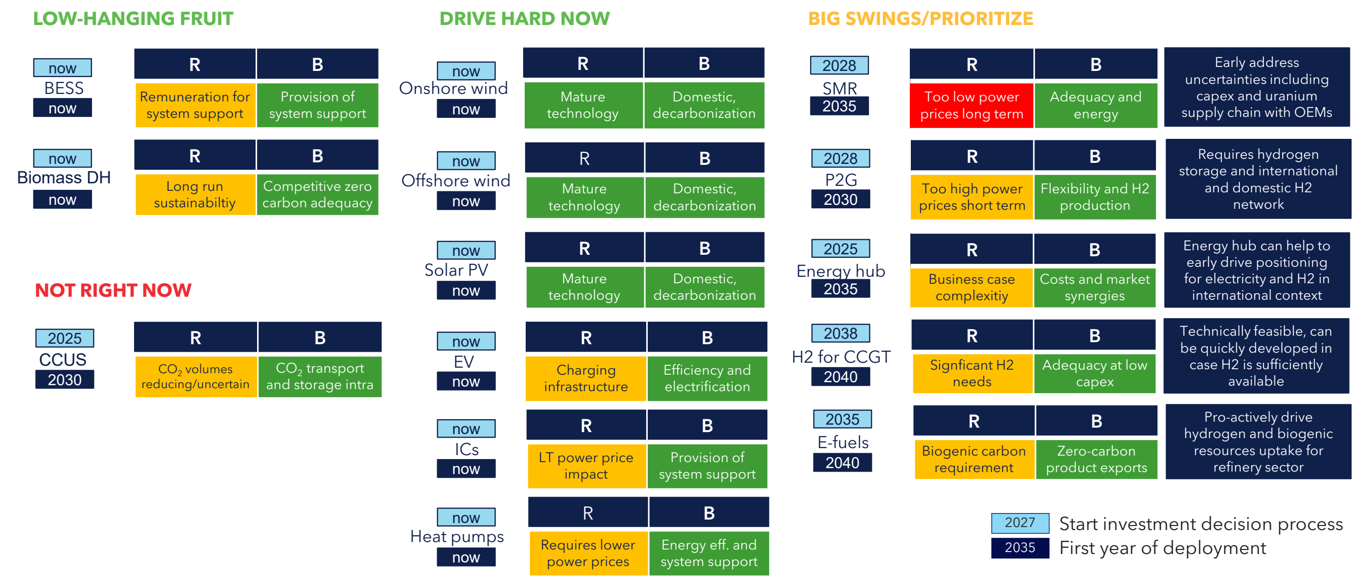


Figure 6-8 shows the prioritization of these building blocks and address the key risks (R) and the key benefits (B), as well as key measures for the so-called "big swings" which can have a significant impact to a positive outcome but require additional mitigation measures particularly to manage risk.

The here presented risk assessment is merely qualitative and based on insights from the applied modelling and interactions with stakeholders. It is recommended that a further quantification will be developed to quantify energy system benefits and risks, and determine specific monitoring actions to measure progress. The risks presented here are specific to the identified building blocks and not necessarily applicable for the whole system.

From an energy strategy point of view, the following insights and recommendations for the Ministry of Energy are noted:

- Investment requirements amount to about 2.5BEUR/year. Investments are immediately required and are recognized to be at unprecedented level for Lithuania. Investment requirements are highest between 2030 and 2040, when the build out of the energy system is most significant.
- A sound level playing field for these investments must be in place, integrating aspects such as attraction of funding, supporting the setting up and operation of viable business cases for stakeholders, and ensuring that a fit for purpose market design and regulatory framework is in place during the transition.
- It is critical to balance investments in electricity resources with end-use electrification, initially of the transport sector, and at an increasing pace also for the production of hydrogen. Wholesale electricity prices should be monitored, not only for the shorter term (5 years ahead) but also with a view on the longer term (5-25 years ahead), in order to be prepared for potential changes to market design and implementation of incentives to support investments in resources (existing and new). During the transformation a continuous focus on reinforcement of the electricity networks, at all voltage levels, is required to enable the transformation.
- It is recommended to further strengthen the cooperation with partner countries in the region, i.e. in the Baltics, Nordics and Central Europe. Cooperation requires acknowledgement of synergies between the partner countries, and a common understanding of benefits and risks. Governments can play a vital role to communicate intentions and work with the industry to realize energy strategies across the region.

From an implementation point of view, the following insights and recommendations for the Ministry of Energy are noted:

- Drive an integrated and coordinated plan with all stakeholders. As there are a range of interdependencies across sectors, it will be crucial to involve all stakeholders at an early stage and achieve a mode of operation for implementation.
- The Ministry of Energy should set up a process for risk analysis, monitoring and reporting to measure performance and success. In the setting up of this process, we advise the Ministry to involve all stakeholders. It is also recommended to organize communication as a core part of this process, in order to increase knowledge, and drive engagement and acceptance among all stakeholders and citizens of Lithuania.
- Make energy strategy development a core process for the Ministry of Energy. Update the energy strategy at least every 3 years, which is similar to industry practices. Ensure that state-of-art data and tools are made available and deployed for sophisticated energy system, power market and network modelling, to ensure that insights, recommendations and actions are based on solid expertise. It is also recommended to integrate energy strategy development and economic benefit analysis, by deploying econometric and economic impact assessment methods and tools, to ensure that energy strategy development is linked to strategy development for the economy at large.

Figure 6-9 provides an overview of the key insights and recommendations for the Ministry of Energy.

FIGURE 6-9

Key insights and recommendations for the Ministry of Energy

ENERGY STRATEGY FOR LITHUANIA

Investment requirements (~2.5 bEUR/year) immediate and unprecedented (highest between 2030 and 2040)

Level playing field for investments - funding, business cases, market design, regulatory framework

Balance supply investments with end-use electrification

- Drive electrification and deployment of hydrogen
- Monitor long-term wholesale electricity prices
- Prepare mechanisms for incentives and interventions
- Ensure build out of supporting network infrastructure

Strengthen cooperation across Baltic, Central and Northern Europe

- Acknowledge synergies, benefits and risks with partner countries
- Connect governmental intentions with industry requirements

IMPLEMENTATION AND REALIZATION

1. Drive **integrated and coordinated action plan** with all stakeholders
2. Lead **risk assessment, monitoring and reporting** process
   - Set up process for risk analysis, monitoring and reporting to measure performance and success
   - Involve all stakeholders in setting up this process
   - Organize communication to increase knowledge, and drive engagement and acceptance
3. **Make energy strategy development a core process**
   - Update the energy strategy every 3 years at least
   - Ensure state-of-art data and tools for energy system, power market and network modelling
   - Integrate energy strategy development and economic benefit analysis

The Ministry of Energy is the main stakeholder responsible for the realisation of the energy system transformation strategy and hence should lead the risk assessment and monitoring approach, in alignment with the regulator. As a basis, the monitoring and reporting framework for measuring the performance and success of the Lithuanian energy system transformation will include the following blocks:

DATA COLLECTION

Identifying the data sources and methods and regularly collecting relevant data. This may include operational data, consultations, etc. The following KPIs should be monitored at minimum:

- Energy transition progress: pace of RES, electrification, hydrogen, industry growth
- Rate of electricity demand growth across sectors, as a proxy for the rate of electrification across transport, industry, residential and commercial sectors
- Electricity market functioning: electricity price development, participation, transparency
- Cross-border exchanges: import/export balance, dependency assessments
- Network investments: resource availability, planning and permitting processes

FREQUENCY

Determining how frequently the data will be collected and reported. While this depends on the nature of specific KPI, DNV recommends monthly data collection where possible.

DATA ANALYSIS AND REPORTING

1) Analysing the collected data to derive insights and assess the performance against the defined KPIs – this can involve statistical analysis, trend analysis, benchmarking, or other relevant analytical techniques.
2) Preparing reports that present the performance results in a clear and concise manner – the reports should aid understanding and decision-making for all sector stakeholders. DNV recommends annual reviews and reporting.

COMMUNICATION

Sharing the performance reports with relevant stakeholders, such as senior management of state and private energy companies, industry association, municipalities and other Ministries. This can be done through presentations, meetings, or electronic platforms for easy access and distribution. DNV recommends opting for one common publicly opened meeting and a set of targeted engagements with representatives of RES developers, hydrogen industry, other industries, municipalities, the Ministry of Transport and their stakeholders, network operators/owners, supply chain, etc.

EVALUATION AND ACTION

Reviewing the performance results, identifying areas of improvement or areas where targets are not being met, and taking appropriate actions to address any issues or capitalise on opportunities. DNV recommends that the success of energy system transformation against the strategy should be externally evaluated every 2-4 years with possibility to update the strategy.

The monitoring and reporting framework should be designed to provide timely, accurate, and actionable information to support decision-making, track progress, and facilitate continuous improvement throughout the implementation of the strategy.

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CLIENT PROJECT TEAM

EPSO-G

- Paulius Butkus
- Ieva Kuodė
- Viktorija Valikonė
- Modestas Pocius

Litgrid

- Liutauras Varanavičius
- Ramūnas Bikulčius
- Aistė Krasauskienė
- Kristina Kilpė
- Audrius Baranauskas
- Birutė Linkevičiūtė
- Andrius Maneikis

Amber Grid

- Danas Janulionis

DNV PROJECT TEAM

- Bart Stoffer
- Maksym Semenyuk
- Sander Scheper
- Maria Miranda Castillo
- Juan-Jose Diaz Gonzalez
- Ekaterina Florez
- Thijs Slot

ABOUT DNV

DNV is an independent assurance and risk management provider, operating in more than 100 countries, with the purpose of safeguarding life, property, and the environment. Whether assessing a new ship design, qualifying technology for a floating wind farm, analysing sensor data from a gas pipeline or certifying a food company's supply chain, DNV enables its customers and their stakeholders to manage technological and regulatory complexity with confidence. As a trusted voice for many of the world's most successful organizations, we use our broad experience and deep expertise to advance safety and sustainable performance, set industry standards, and inspire and invent solutions.

In the energy industry

We provide assurance to the entire energy value chain through our advisory, monitoring, verification, and certification services. As the world's leading resource of independent energy experts and technical advisors, we help industries and governments to navigate the many complex, interrelated transitions taking place globally and regionally, in the energy industry. We are committed to realizing the goals of the Paris Agreement, and support our customers to transition faster to a deeply decarbonized energy system.

DNV Netherlands B.V.
Utrechtseweg 310-B50
6812 AR Arnhem, the Netherlands
Tel: +31 26 3569111
Email: contact.energysystems@dnv.com
www.dnv.com