Baltic-Nordic Roadmap for Co-operation on Clean Energy Technologies

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Marton Leander Vølstad and Kevin Johnsen at Nordic Energy Research were the project coordinators.

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Team at Nordic Energy Research

Marton Leander Vølstad
Adviser
marton.leander.volstad@nordicenergy.org

Kevin Johnsen
Senior Adviser

Research and consultant team

CIT Industriell Energi AB
Stefan Heyne, Project Manager
Ingrid Nyström, Project Manager

Tallinn University of Technology
Anna Volkova, Researcher – Expert consultant on Baltic states' energy research

Steering group and funding body
The work was guided by a steering group, composed of:

Daumantas Kerezis – Ministry of Energy of the Republic of Lithuania
Helena Sarén – Business Finland
Irje Möldre – Ministry of Economic Affairs and Communications, Estonia
Līna Kundziņa – Ministry of Economics, Latvia
Signe Gerinoviča – Department of Energy Efficiency and Crisis Management, Latvia

The individuals and organisations that contributed to this study are not responsible for any opinions or judgements contained in this study.

Contact
Comments and questions are welcome and should be addressed to:
Marton Leander Vølstad, Nordic Energy Research, e-mail:
marton.leander.volstad@nordicenergy.org

For enquiries regarding the presentation of results or distribution of the report, please contact Nordic Energy Research.

Additional materials, press coverage, presentations etc. can be found at nordicenergy.org

Republic of Estonia
Ministry of Economic Affairs and Communications

Ministry of Economics
Republic of Latvia

Ministry of Energy
of the Republic of Lithuania

Nordic Energy Research

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Executive summary

The Baltic and Nordic countries need to identify high-priority clean energy-related technologies (CETs) and associated research and innovation (R&I) activities to invest in over the coming years, which can contribute to the decarbonisation targets of the individual countries, the Baltic-Nordic region, and the European Union. The objective of the present study is thus to determine which CETs are most relevant for the Baltic and Nordic countries and for Baltic-Nordic co-operation, in terms of synergies and development potential, from now to 2030, 2050 and beyond. The results of the study have been framed into a Baltic-Nordic Roadmap for co-operation on CETs.

The entire range of CETs needed for the transition to a decarbonised energy system have, in this report, been grouped into six CET categories, which form the main framework for the roadmap development: integrated power and energy systems; zero emission power generation technologies; low emission transport systems; industrial energy systems; urban and built environments; and cross-cutting technologies. Within these categories, the most relevant CETs for the Baltic countries and Baltic-Nordic R&I collaboration have been filtered out based on challenges and needs, current R&I and most active stakeholders.

In the Baltic-Nordic collaboration roadmap developed, three different types of actions are included:

A. Continued and further strengthening of already initiated collaborations.

B. Initiation of new collaboration areas, advancing the development of the CET.

C. Exploratory actions, aiming at further defining the potential of the CET in the Baltic context.

Furthermore, the proposed roadmap is directly impacted by the societal development towards continuously increasing integration between sectors and strategies for increasing sustainability (such as energy system development, climate strategies, resource efficiency and circular economy), which results in collaboration areas that are subsequently broader and more complex in nature.

Consequently, central areas for Baltic-Nordic R&I collaboration throughout the time span include:

- Development of the power system, starting with R&I on power system integration, then increasing focus on solutions for the integration of high shares of zero emission power production and storage, prosumers and demand-side through increased digitalisation.
- The potential role of hydrogen, from a system perspective, in the developments above and for use in transport and industry sectors.
- Development of sustainable urban areas, initially focusing on building renovation strategies and more efficient district heating, moving towards zero/positive energy buildings and smart cities, by strengthening the inclusion of solutions based on digitalisation.
- Decarbonisation of industry, with an initial focus on efficient waste heat utilisation in district heating, then increasingly divert R&I towards new processes and electrification of industry.
- Advanced utilisation of biomass for energy and bio-products, increasing the integration of the energy and bioeconomy systems.
- Studies of the potential for system integration of CCS/CCU/BECCS[1], initially primarily linked to the oil shale industry in Estonia, but with an increasing focus on areas such as electrofuel production.
- Electrification of transport, starting with a focus on strategies for developing charging infrastructure, then turning the focus on aspects of heavy transport, maritime transport and battery recycling.

In the long-term – 2050 and beyond – the collaboration opportunities will heavily depend on the choices and decisions made until then and are thus less detailed. However, broad A-actions related to a zero emission transport system and a hydrogen society are outlined, together with B-actions based on the results of earlier explorative actions.

In summary, by building on the strengths and systems characteristics of the respective countries and regions, co-operative R&I actions related to the development of CETs should be designed to contribute efficiently to the transition to a zero greenhouse gas (GHG) emission and sustainable society.

A simplified graphic representation of the roadmap is given in a separate factsheet accompanying the present report.

https://pub.norden.org/nordicenergyresearch2022-03/BalticNordicRoadmap_JBNERP_2022.pdf

1 Carbon capture and storage (CCS), carbon capture and utilisation (CCU), and bioenergy with carbon capture and storage (BECCS).

Chapter 1

Introduction

PHOTOS: PEXELS.COM

1.1 Background and objective

The Baltic and Nordic countries need to identify high-priority clean energy-related technologies and associated research, development, demonstration and innovation activities to invest in over the coming years, both individually and collectively, that could mature towards 2030, 2050 and beyond, and contribute to the decarbonisation targets of the individual countries, the Baltic-Nordic region and the EU. Nordic Energy Research has therefore, on behalf of the Joint Baltic-Nordic Energy Research Programme, initiated a study to increase the insight into the status of clean energy-related technologies in the Baltic countries, as well as European and worldwide tendencies, regarding research, development, demonstration/pilot and innovation activities, and with respect to their strengths, limitations and potential applications.

The objective of the present study is thus to determine which clean energy-related technologies, identified in a range of Nordic Energy Research, European and Nordic studies and initiatives, are most relevant for the Baltic and Nordic countries and for Baltic-Nordic co-operation, in terms of synergies and development potential, from now to 2030, 2050 and beyond.

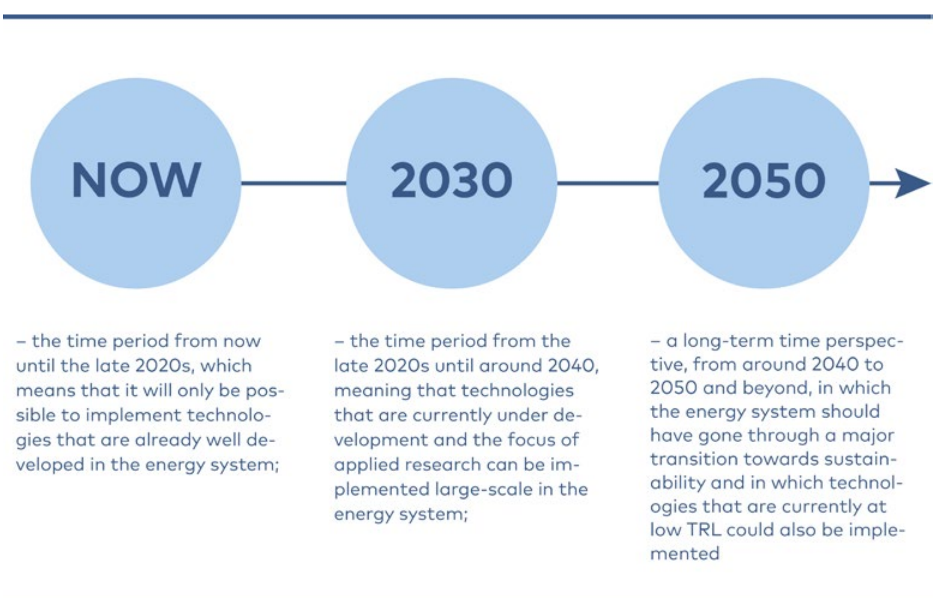
This objective is met by the development of a roadmap for Baltic-Nordic collaboration on clean energy-related technologies (CETs). The roadmap is intended as a support for the Baltic (and Nordic) countries for timely establishment and/or reinforcement of Baltic-Nordic collaborations, in order to effectively contribute to the Baltic, Nordic and European targets for decarbonisation, as set out by the EU National energy and climate plans (NECPs) and current climate and energy targets at the EU level.

The study has a very broad perspective on clean energy-related technologies and covers all parts of the energy system, from energy demand to supply, as well as cross-cutting technologies. This means that CETs related to the supply systems for power, heating, cooling and fuel production, technologies related to energy networks and distribution systems, and demand-oriented technologies for buildings, industry and transport are included. Therefore, a detailed assessment or description of specific technologies is clearly outside the scope of the study. Further, the focus is on the collaboration related to CETs from a technology-oriented perspective, not including development of, for instance, policy and communication measures.

1.2 Method

The roadmap that has been developed in this study covers the period from now to 2050 and beyond. In order to simplify the presentation, this extended period has been divided into three different time perspectives, which are denoted as Now, 2030 and 2050. Since the study does not include any quantitative modelling or analysis for specific years, these time perspectives should be interpreted more loosely, as the period around the specific years. More specifically, the three perspectives can be defined as:

- **Now** – the time period from now until the late 2020s, which means that it will only be possible to implement technologies that are already well developed in the energy system;
- **2030** – the time period from the late 2020s until around 2040, meaning that technologies that are currently under development and the focus of applied research can be implemented at scale in the energy system;
- **2050** – a long-term time perspective, from around 2040 to 2050 and beyond, in which the energy system should have gone through a major transition towards sustainability and in which technologies that are currently at low technology readiness level (TRL) could also be implemented.



The Baltic-Nordic Roadmap for Co-operation on CETs has been developed based on a five-step approach as outlined below (see also Figure 1)

1

International and EU CET overview

- Relevant CETs on a general level have been identified based on a screening of up-to-date clean energy-related technology studies and initiatives, primarily at the Nordic and EU levels. The aim of this screening was to generate a broad overview of the spectrum of available CETs that are potentially relevant in the context of Baltic-Nordic collaboration.

2

Assessing needs for CETs from the perspective of Baltic energy systems

- Based on existing scenario studies of the climate and energy system development, and on the NECPs of the Baltic states, the key CET needs in the Baltic states for the time perspectives Now, 2030 and 2050 have been identified.

3

Baltic CET stakeholder overview

- Based on an analysis of literature and stakeholder information from the Baltic countries, in combination with input from the interviews and survey (see below), the current stakeholder situation and primary research and innovation activities in the Baltic countries have been broadly mapped.

4

Technology-needs matrices

- By combining needs and stakeholder data for each of the Baltic countries, CETs from the first screening have been narrowed down to the CETs most relevant in a Baltic context and technology-needs matrices for the different time frames were developed. The matrices outline the most relevant CETs, the drivers and challenges for CET development and key barriers with respect to the Baltic countries.

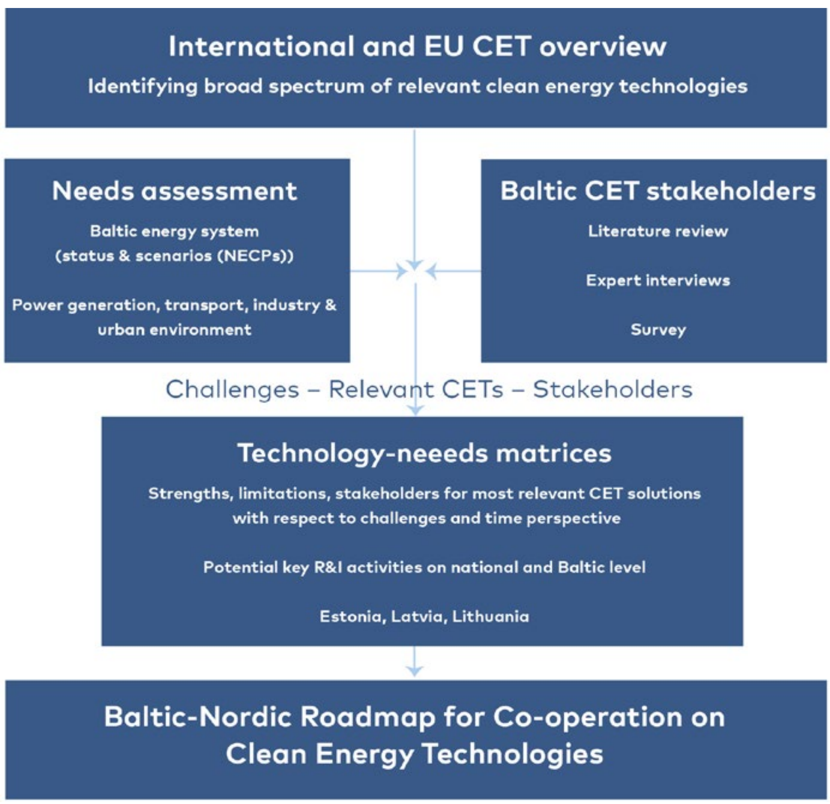
5

Roadmap development for Baltic-Nordic co-operation on CETs

- In a final step, a roadmap identifying key areas for Baltic-Nordic collaboration for the time frames Now, 2030 and 2050 was developed. To establish the basis for this roadmap, an overview of the Nordic energy perspective is included and combined with the technology-needs matrices for the Baltic countries.

The analysis carried out in this five-step approach relied on input from literature, a series of interviews with selected energy experts within the Baltic and Nordic countries, and from a survey on the relevance of different CETs directed towards a broader range of Baltic stakeholders. Information collected via interviews and the survey is primarily fed into step 3 but contributes to the analytical process as a whole.

Figure 1. Schematic overview of methodology for the development of the Baltic-Nordic Roadmap for Co-operation on CETs.



The entire study is in relation to the ambitious targets for both climate emission reductions and energy systems transition for the Baltic and Nordic countries, and under the assumption that strong measures will be taken to achieve those ambitions. This is mirrored by the needs described and the choice of referenced scenario studies, when applicable.

These overarching assumptions are thus considered to be in alignment with the European Green Deal (Fit for 55) and the climate strategies of all three Baltic countries and of the Nordics.

1.3 Report structure

The report is – apart from this introduction – divided into five chapters, each corresponding to one of the five main steps described above. Details related to the interviews and the survey are presented in separate appendices, but their main input is also integrated into the report chapters. For Chapters 2 to 4, "key findings" are presented, summing up the most important facts and forming the basis for the technology-needs matrices and the final roadmap, presented in Chapters 5 and 6, respectively. Appendix D provides a more detailed presentation of the CETs that are most relevant for each of the Baltic states from the perspective of energy systems needs, where there is a potential for Baltic-Nordic collaboration and with respect to the different time frames. The report is accompanied by a fact sheet, illustrating the approach, major results, as well as an overview of the roadmap developed.

https://pub.norden.org/nordicenergyresearch2022-03/BalticNordicRoadmap_JBNERP_2022.pdf

Chapter 2

International, EU and Nordic CET background


PHOTOS: UNSPLASH.COM / JOHANNES JANSSON, NORDEN.ORG

Key findings

Achieving GHG emission reductions in line with the Paris Agreement and fit-for-55 targets will for all regions require a broad range of transitional and strongly interlinked actions, such as:

- A move towards **zero emission technologies**, and not only emission reduction, meaning radical increases of solar and wind power.
- **Electrification** of transport, industry and heat supply (through e.g. heat pumps). In the Nordic Clean Energy Scenarios (2020) study, direct electrification forms the core of all scenarios.
- **Carbon capture**, utilisation and storage (CCUS), including CCS from bioenergy (BECCS), which could make it possible to achieve negative emissions, and the production of hydrogen, electrofuels, and materials via power-to-X (PtX).
- A focus on sustainable use of **bioenergy**, which is expected to be used increasingly in hard-to-abate sectors such as heavy transport (road and maritime), aviation, steel and cement, rather than for the production of heat and electricity.
- Production and use of **hydrogen** and hydrogen-based fuels, as a means of electricity storage and for use as a fuel in industry and transport.
- Radical measures to decarbonise **heavy industry**, including steel and cement, via bioenergy, CCUS, hydrogen and electrification.
- **Electricity storage** and the development of smart power systems and integrated grid solutions, in order to accommodate increasing shares of intermittent power and new areas for electricity use (e.g. in transport).

In this report, the CETs in focus have thus been grouped into ***six CET categories*** forming the main framework for the roadmap development:

- **Integrated power and energy systems**
- **Zero emission power generation technologies**
- **Low emission transport systems**
- **Industrial energy systems**
- **Urban and built environments**
- **Cross-cutting technologies**

2.1 Introduction

The main developments in energy systems that are expected to be necessary to reach climate targets at the Nordic and EU level form an important background to the specific needs of the Baltic states. This chapter "sets the scene" for the future development of the Baltic energy systems, presenting, at a general level, international trends and developments, and an overview and categorisation of available clean energy-related technology solutions to address the need for energy system transitions. The broad spectrum of clean energy-related technologies presented in this chapter forms the basis for the analysis of the subsequent chapters and for the survey developed.

2.2 General challenges and CET categories from an international and EU perspective

To reduce GHG emissions in line with the Paris Agreement and Fit for 55 targets, all types of measures will be needed. These include continuous energy and material efficiency improvements across the demand sectors and a shift towards renewable energy sources for the production of electricity, heat and transport fuels. Further, the key challenges identified by the clean energy transition partnership (CETP) focus on the importance of developing a sustainable energy system through an efficient integration of different measures and solutions in the various sub-systems and in the energy system as a whole.[1]

A comprehensive list of CET categories has been drawn up (see Figure 2), based on a review of literature, R&I programmes and innovation challenges, specifying key CETs for a transition towards sustainability from an international (e.g. IEA Energy Technology Perspectives) and a European (e.g. Horizon Europe and CETP) perspective.

In its Sustainable Development and Faster Innovation scenarios[2], the IEA identifies four main technology value chains that contribute to half of the cumulative global greenhouse gas savings:

- technologies needed to electrify end-use sectors (e.g. batteries)
- carbon capture, utilisation and storage (linked to both the power and industry sectors)
- hydrogen and hydrogen-related fuels for use in hard-to-abate sectors such as long-distance transport, chemicals and iron and steel production
- bioenergy for transport biofuels, power and heat generation and – in combination with CCUS – for negative emissions

1 Clean Energy Transition Partnership (2020). Strategic Research and Innovation Agenda. 61p. https://eranet-smartenergysystems.eu/global/images/cms/CETP/CETP_SRIA_v1.0_endorsed.pdf. Accessed 2021-08-18.

2 International Energy Agency (2020). Energy Technology Perspectives 2020. OECD Publishing, Paris. 400p. https://doi.org/10.1787/d07136f0-en

In addition, technologies for low emission power production, energy and material efficiency improvements, strengthening of electricity networks and storage solutions, low-carbon heating systems in buildings and district heating and cooling are identified as central to the developments.

On an international scale, the Mission Innovation[3] – a global initiative of 22 countries and the European Commission – specifies eight different innovation challenges: smart grids; off-grid access to electricity; carbon capture; sustainable biofuels; converting sunlight into storable solar fuels; clean energy materials (for use in advanced batteries, solar cells, semiconductors, catalysts etc); affordable heating and cooling of buildings; and renewable and clean hydrogen.

The clean energy transition partnership (CETP) identifies eight key challenges in its CETP strategic research agenda[4]:

1. Optimised integrated European net zero emissions energy system, focusing on electricity distribution and transmission grids, with a high level of integration among all energy carrier networks, by e.g. coupling electricity networks with gas, heating and cooling networks.
2. Enhanced zero emission power technologies, focusing on increasing conversion efficiency, decreasing production costs and improving system integration properties and impact.
3. Enabling climate neutrality with storage technologies, renewable fuels and carbon capture utilisation and storage (CCU/CCS), focusing on development and deployment of energy storage, renewable-based fuels and CCU/CCS.
4. Efficient zero emission heating and cooling solutions, focusing on optimisation of efficiency, lowering costs and providing solutions for heating and cooling peak demand.
5. Integrated regional energy systems, focusing on integrating regional and local energy systems, with high shares of renewables and tailor-made to meet local requirements.
6. Integrated industrial energy systems, focusing on developing and demonstrating integrated industrial power, heating and cooling systems, hybrid solutions and novel technologies for efficient carbon-neutral production.
7. Integration in the built environment, focusing on providing enhanced capability to produce, store and efficiently use energy in existing and new buildings of all types.
8. Cross-cutting dimensions, including transition pathways, regulations, circularity, digitalisation as well as policy and social aspects.

3 Mission Innovation (2020). MI Innovation Challenges – Impact Report. 32p. http://mission-innovation.net/wp-content/uploads/2020/09/2.-IC-Impact-Report-Final.pdf. Accessed 2021-08-18.

4 Clean Energy Transition Partnership (2020). Strategic Research and Innovation Agenda. 61p. https://eranet-smartenergysystems.eu/global/images/cms/CETP/CETP_SRIA_v1.0_endorsed.pdf. Accessed 2021-08-18.

Horizon Europe is the EU research and innovation framework programme for 2021–2027. Energy-related research is concentrated to the Cluster 5: Climate, Energy and Mobility of the Horizon Europe's second pillar: Global Challenges and European Industrial Competitiveness. The European Partnerships within Cluster 5 indicate the priorities for future developments. These are highly focused on research areas linked to electrification and transport (including partnership areas on clean aviation, Europe's Rail, connected and automated mobility, batteries and zero emission waterborne and road transport). Other areas include urban transitions and energy in the built environment (Built4People, Driving Urban Transitions to a Sustainable Future). Finally, the energy system transitions that make these developments possible are included in the two remaining areas: Clean Hydrogen and Clean Energy Transition (which include activities in the areas of renewable energy, energy system, grids, storage and CCUS).[5] [6]

The first Cluster 5 work programme (2021–2022) was launched in 2021.[7] It is very broad and includes calls related to all the CET areas mentioned above. Specified areas include:

- Cross-sectoral solutions for the climate transition
    - Competitive and sustainable European battery value chain (e.g. battery research for electromobility, materials, manufacture, recycling, digitalisation);
    - Emerging breakthrough technologies and climate solutions (e.g. methane cracking, non-CO_2 GHG removal, direct air capture).

- Sustainable, secure and competitive energy supply
    - Energy systems, grids and storage (e.g. high-voltage direct current (HVDC), increased reliability and resilience, advanced power electronics, thermal and power storage solutions);
    - Global leadership in renewable energy (e.g. wave energy, photovoltaics, carbon-negative biofuels and biofuels from waste and algae, wind energy in deep waters, innovative biomethane production, geothermal energy, renewable energy in industry);
    - Carbon capture, utilisation and storage, CCUS (cost reduction, decarbonising industry).

5 European Commission, Directorate-General for Research and Innovation (2021). Horizon Europe, the EU research and innovation programme (2021–27): for a green, healthy, digital and inclusive Europe. Publications Office. https://data.europa.eu/doi/10.2777/601756.

6 European Commission (2021). Horizon Europe Work Programme 2021–2022, 8. Climate, Energy and Mobility. https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/horizon/wp-call/2021-2022/wp-8-climate-energy-and-mobility_horizon-2021-2022_en.pdf. Accessed 2021-08-18.

7 European Commission (2021). Horizon Europe Work Programme 2021–2022, 8. Climate, Energy and Mobility. https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/horizon/wp-call/2021-2022/wp-8-climate-energy-and-mobility_horizon-2021-2022_en.pdf. Accessed 2021-08-18.

- Efficient, sustainable and inclusive energy use
  - Highly energy efficient and climate neutral EU building stock (e.g. renovation strategies, energy positive homes, smarter buildings, designs and materials);
  - Industrial facilities in the energy transition (e.g. heat upgrade technologies, organic Rankine cycles, high temperature thermal storage).

- Clean and competitive solutions for all transport modes
  - Zero emission road transport (e.g. next generation zero emission vehicles, multi-powertrain systems (battery electric vehicles (BEVs) and fully electric vehicle (FEVs)), urban transport systems);
  - Aviation (e.g. GHG emission reduction technologies, aircraft design and manufacturing, silent aircrafts);
  - Enabling climate neutral, clean, smart and competitive waterborne transport (e.g. on-board storage of ammonia and hydrogen, high power fuels cells in ships, battery charging, ammonia marine engine, on-board energy storage).

For calls directly concerning the development of novel technological solutions, there seems to be a certain focus on photovoltaics and other solar energy solutions, batteries, CCUS and, to some extent, biofuel production from advanced raw materials such as waste and algae. A substantial share of the programme is also dedicated to calls on cross-cutting and analytical aspects, such as the integration of different technologies, energy systems analysis, digital solutions, strengthening of circular processes, and market development support. Especially within the area of sustainable transport, a whole call area ("destination") is dedicated to safe, resilient transport and smart mobility services for passengers and goods, which focus on issues such as safety, logistics and human behaviour.

Consequently, the sources used generally agree on overall relevant categories, and the differences between them at this level are small. However, the terminology and grouping of technologies and measures differ. The top-level categorisation below is primarily inspired by the clean energy transition partnership (CETP) challenges identified in the CETP strategic research agenda. The list of specific technologies within each category is primarily based on descriptions of status, value chains and global market analyses of CETs on a technology-specific level, in the reports from the commission on clean energy transition and competitiveness.[8] [9] These reports describe the status, value chains and global market situation for a broad range of CETs.

8 European Commission (2020). Clean Energy Transitions – Technologies and Innovations. SWD (2020) 953 final. Brussels, Belgium. 364p. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020SC0953. Accessed 2021-08-18.

9 European Commission (2020). Report from the Commission to the European Parliament and the Council on Progress of Clean Energy Competitiveness. COM(2020) 953 final. Brussels, Belgium. 33p. https://ec.europa.eu/energy/sites/ener/files/report_on_clean_energy_competitiveness_com_2020_953.pdf. Accessed 2021-08-18.

Figure 2. General CET categories, based on an overall EU perspective.

Integrated power and energy systems
Production, distribution and storage

- Renewable hydrogen
- Carbon Capture and Storage (CCS)
- Carbon Capture and Utilisation (CCU)/ Power-to-X (P2X)
- Energy storage (batteries, hydropumping, etc) for use in energy systems
- Electricity distribution and transmission grids, such as HVDC, smart grids and power hubs

Zero emission power generation technologies

- Offshore wind
- Onshore wind
- Hydropower
- Solar power
- Nuclear energy
- Offshore ocean
- Other zero and low-emission power production

Low emission transport systems

- Batteries for transport
- Renewable fuels for transport, including biofuels, hydrogen and electrofuels
- Electrification of transport sector, smart-charging etc.

Industrial energy systems

- Industrial heat recovery
- Clean industrial process technologies
- Electrification of industrial processes
- Bio-based industrial processes

Urban and built environments

- Smart city solutions
- Building energy efficiency
- District heating and cooling
- Heat pumps
- Solar heat
- Geothermal energy
- Biobased heating solutions

Cross-cutting technologies

- System integration and energy & material efficiency improvements
- Energy linkages from development of circular and bioeconomy
- Digital energy technologies

Some clear key energy technologies and solutions specified include offshore renewables, solar photovoltaics, renewable hydrogen production, batteries and smart electricity grids, together with increasing energy efficiency throughout the energy supply chain. This list has then been complemented, based on input from other sources, leading to the categorisation described in Figure 5 for the purposes of this report. Energy efficiency improvements are included implicitly in all these CET categories, since many of the technology developments needed (such as, for instance, electrification of transport) contribute to increasing the system efficiency. Energy efficiency improvements as explicit CETs are primarily pointed out for the demand sectors (such as industry and buildings). The specification has been made from a technology-oriented perspective, not including development of e.g. policy and communication measures.

All the CET categories listed in Figure 2 include a mixture of mature and less mature CETs. The category which has the largest share of technologies that are already commercial or at high TRLs, is urban and built environment. The category low emission transport systems, on the other hand, contains many technological solutions at low TRL, especially linked to battery development.

In addition, each of the CETs specified under the general CET categories represent in general a group of CETs that can be at varying (TRLs). For instance, solar power includes conventional silicon PV modules that are commercially available, thin-film perovskite solar cells that are currently moving from the lab stage towards demonstration (TRL 4–6) and building-integrated solar cells utilising new materials such as graphene (TRL 2–3). Another example is renewable hydrogen, which can be produced both via electrolysis with renewable power (high TRL) and via technologies at a lower TRL, such as from marine algae, from direct solar water splitting or from pyrolysis processes with solid carbon as a side product.

Some examples of low TRL technologies that the IEA covered in its recent CET guide include perovskite solar cells, airborne wind energy systems, floating energy platforms for offshore sites, hydrothermal liquefaction of biomass, new battery solutions and hydrogen and carbon storage technologies.[10]

2.3 CETs in a Nordic context

The current status and expected development of different CETs in a Nordic context is extensively described in the Nordic Clean Energy Scenarios[11] (NCES). The report identifies five solution tracks, proposing a number of "no-regret" actions to address in the medium term, as well as long-term actions for three different scenarios. The report also elaborates on the potential for collaboration on clean energy technologies among the Nordic countries. It is used as major input to the roadmap for Baltic-Nordic collaboration with respect to CET development in the Nordic countries (see Chapter 6). A very brief summary of NCES is given here, while a somewhat more extensive description of the Nordic context is provided in Appendix D.

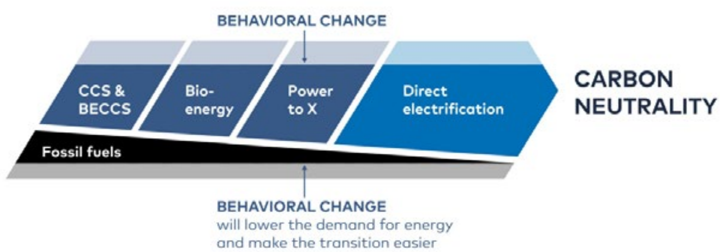
10 International Energy Agency (2021). ETP Clean Energy Technology Guide. Paris Cedex, France. https://www.iea.org/articles/etp-clean-energy-technology-guide. Accessed 2021-12-06.

11 Nordic Energy Research (2021). Nordic Clean Energy Scenarios – Solutions for Carbon Neutrality. Nordic Council of Ministers. Copenhagen, Denmark. http://doi.org/10.6027/NER2021-01.

Within NCES, three different scenarios are investigated for achieving carbon neutrality, with all scenarios basically following the same five solution tracks – as illustrated in Figure 1 – for the sustainable energy transition of the Nordic countries (in a European/global context):

- **Direct electrification** is the core of all scenarios and is complemented by three other technology tracks:
    - PtX
    - Bioenergy
    - CCS technologies (including BECCS)
- **Behavioural change** will influence any pathway chosen

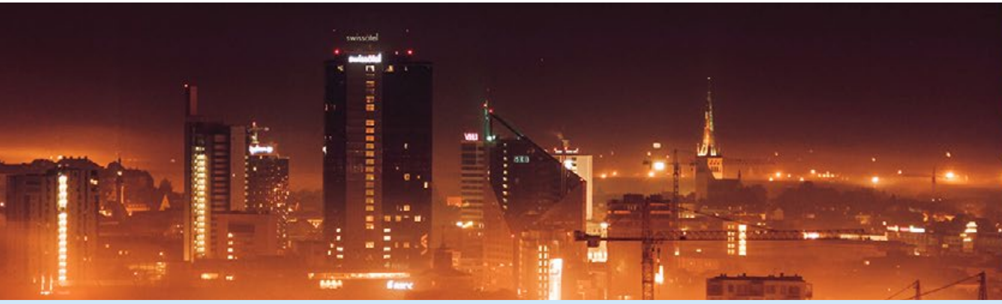
Figure 3. The five solution tracks identified by NCES



For all solution tracks, several "no-regret" actions are proposed, which are expected to provide a strong foundation for achieving carbon neutrality when being implemented in the near term. These near-term actions are highly relevant for Baltic-Nordic collaborations on CETs and therefore constitute important input to the roadmaps. As the focus of this report is technology solutions, behavioural change has not been addressed in detail. A description of the major tracks relevant for Baltic-Nordic collaboration are presented in Chapter 6.3, forming the basis for the collaboration roadmap.

Chapter 3

Challenges and needs of the Baltic states




PHOTOS: UNSPLASH.COM

Key findings

The challenges and needs of the Baltic countries are similar in most respects. In the near term, all three countries aim at:

- Increasing energy independence and interconnections within the Baltics, with Finland and with the EU for both electricity and natural gas systems.
- Increasing production and use of renewable energy for electricity, district heating and transport.
- Increasing energy efficiency in all sectors of the energy system.

Estonia has still, even if renewable power production has increased remarkedly, a specific challenge in decreasing the reliance of electricity from oil shale. For Latvia, the transition of the transport sector - due to the large amount of international freight transport - as well as the relatively high dependence on natural gas are especially challenging. Lithuania puts a specific focus on increasing the energy independence and thus the share of domestic power production, and on further reducing the use of natural gas.

For the 2030 time perspective, all the challenges above will still be highly relevant, but shift in focus towards the realisation of more radical system transitions and towards measures in hard-to-abate sectors such as transport and some industrial sectors. Examples include increased share of advanced biofuels in the transport sector, with particularly good opportunities for biogas and hydrogen in Latvia and Lithuania and carbon capture and storage/utilisation, which would be most relevant for Estonia.

For the long term, up to 2050 and beyond, the following key developments are expected:

- Continued and strong electrification of the energy system, that together with increasing demand for energy services, requires a largeincrease in renewable power production.
- Integration of variable renewable power production (e.g. from off-shore wind energy hubs in the Baltic sea) in the power system, and thus a need for storage solutions.
- Development of hydrogen for energy storage, as a stabiliser for the power system, and for the production of electrofuels.
- Cross-sectorial integration, smart production and demand side control across all sectors to unlock potential energy efficiency synergies between sectors.

The assessment of needs for changes within the energy system for the Baltic states is mainly based on the EU's Fit-for-55 scenarios, the Baltic Energy Technology Scenarios (BENTE), as well as the national climate and energy plans (NECPs).

3.1 Introduction

The purpose of this chapter is to identify the main needs over time in each of the Baltic states from a climate strategy and energy systems perspective and in relation to the CETs. The time perspectives are the same as for the study as a whole: Now (roughly until late 2020s); 2030 (roughly late 2020s towards 2040); and 2050 and beyond (thereafter). However, it should be noted that, in this section, we primarily highlight the needs for changes in the energy system in a certain time perspective. This means that actions need to be taken earlier – often decades before – to realise those changes.

The overview is primarily based on existing scenario studies of developments in climate and energy systems, and on the national energy and climate plans of the Baltic states. The scenario studies used are partly the recently developed policy scenarios until 2030 for delivering the European Green Deal (the Fit for 55 scenarios), which present data for all member states, partly the Baltic Energy Technology Scenarios (BENTE). The three core scenarios used in Fit for 55 have, despite significant differences in policy assumptions, similar outcomes in terms of energy systems transitions. The scenario used is the MIX scenario, relying on both carbon price signal extension to road transport and buildings and strong intensification of energy and transport policies to reach the 55 per cent reduction target in 2030.[12] The BENTE study includes considerably more detailed information about and analysis of the Baltic states, and a longer time perspective (until 2050).[13] When referring to this study, the 2DS scenario has been used. This is an ambitious scenario in which the EU is assumed to contribute to the global two-degree scenario (with 80 per cent reduction by 2050). In addition, relevant input from interviews and the survey (see Appendix C) has been taken into account.

Note that the purpose is not to give a complete picture of the scenario development for the energy systems transition in the Baltic states, but to draw conclusions from these studies based on the expected main needs for clean energy-related technologies and technology areas. In many respects, the types of transformational needs and related technologies are similar between the countries. However, there are also clear differences, due to differing energy systems and political targets. Further, the relative importance and detailed role may of course differ depending on the study and scenarios used, but the detailed share or size is not essential to this study.

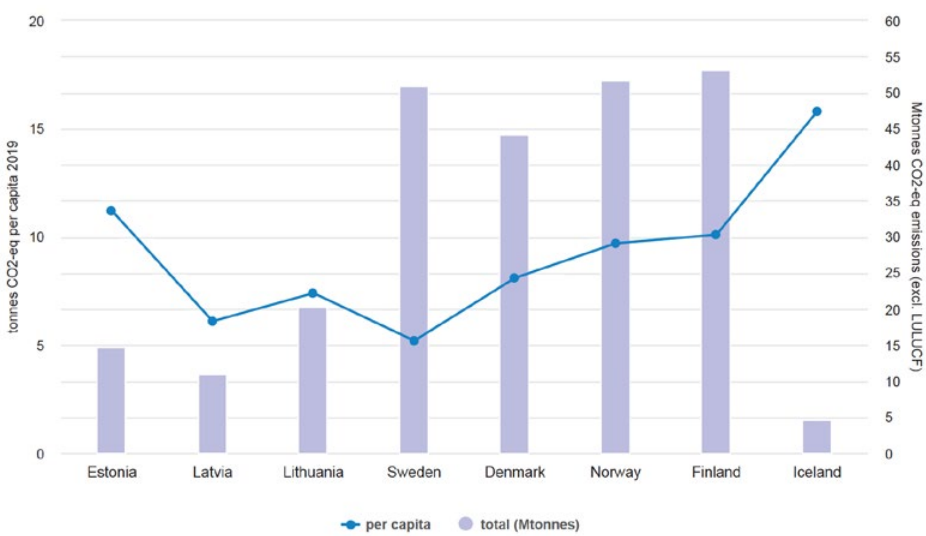
12 European Commission (2021). Policy scenarios for delivering the European Green Deal. https://ec.europa.eu/energy/data-analysis/energy-modelling/policy-scenarios-delivering-european-green-deal_en. Accessed 2021-11-03.

13 Lindroos T.J., Lehtilä A., Koljonen T., Kofoed-Wiuff A., Hethey J., Dupont, N. et al. (2018). Baltic Energy Technology Scenarios 2018. TemaNord 2018:515. Nordic Energy Research. Oslo, Norway. 164p. https://www.nordicenergy.org/project/bente/. Accessed 2021-08-18.

3.2 Baltic climate and energy status and targets

The Baltic governments have set both medium- and long-term climate and energy targets. These are described in their national energy and climate plans (see Table 1). In all the Baltic states, emissions have already decreased substantially since 1990. From around the year 2000, emissions started to increase again, but peaked in 2010 and have subsequently decreased slightly again.[14]

Figure 4. Total GHG emissions in 2019 in the Baltic countries (with figures for Nordic countries for comparison).



In **Estonia**, the emissions were in 1990 slightly over 41 Mt/yr. In 2019, they were almost 15 Mt CO2-eq, after a large drop from the 2018 figure of 20 Mt, while the current target for 2030 corresponds to about 12 Mt CO2-eq (see Table 1). In the Fit for 55 scenarios, a level of 8.5 Mt CO2-eq is reached by 2030.[15] Targets are also set for the share of renewable energy and energy efficiency improvements. Further, Estonia has committed to developing a circular economy strategic document and action plan, originally planned for 2021. The aim of security of supply is not quantified in the NECP, but the Transmission system operator (TSO) aims at keeping a strategic reserve corresponding

14 United Nations. Greenhouse Gas Inventory Data – Time Series – Annex I – GHG total without LULUCF. https://di.unfccc.int/time_series. Accessed 2021-11-03.

15 European Commission (2021). Policy scenarios for delivering the European Green Deal – Excel files for MIX scenario. https://energy.ec.europa.eu/publications-new/excel-files-mix-scenario_en. Accessed 2021-11-08.

to 1000 megawatts (MW) generation capacity..[16] According to the strategy "Estonia 2035", adopted by the Estonian parliament in May 2021, Estonia will be climate neutral by 2050.[17]

In **Latvia**, the emissions in 2019 (about 11 Mt CO2-eq) were already 57 per cent lower than in 1990, which means that they have already met the target for 2030. In the Fit for 55 scenarios, a level of 9.8 Mt CO2-eq is reached by 2030. The Latvian government has not yet defined any quantitative targets for the year 2050 (see Table 1).

In **Lithuania**, the target for reducing total GHG emissions (in 2019, about 20 Mt CO2-eq) is linked to the (former) EU level target. There are also more ambitious, but indicative, targets in the medium and long term (70 and 80 per cent reduction, respectively, including LULUCF). There is a greater focus on increasing efficiency and the share of renewable energy sources (RES). Notably, the high dependency on imported electricity in Lithuania has also spurred specific targets for increasing domestic electricity production.

16 Elering (2021). Security of supply guaranteed for the short and long term despite uncertainty. https://elering.ee/en/security-supply-guaranteed-short-and-long-term-despite-uncertainty. Accessed 2022-01-04

17 Estonian Government Office (2021). Estonia 2035. https://www.valitsus.ee/en/node/31. Accessed 2021-11-08.

Table 1. Climate and energy targets in the Baltic states, according to current NECPs[18] [19] [20] [21]

National energy and climate plans	Estonia	Latvia	Lithuania
Until 2030	Reduction of GHG emissions by 70%*	Reduction of GHG emissions by 55%*	Reduction of GHG emissions by at least 40%* (EU level target) 9% reduction outside EU EU Emissions Trading System (ETS)**
	RES share in final energy consumption (FEC) 42%	RRES share in FEC 45%)	RES share in FEC 45% (of which 45% in electricity and 90% in DH)
	Energy savings of 14.7 terawatt hours (TWh), so that FEC must be at 32–33 TWh/yr	Cumulative FE savings of 1.71 Mtoe	Reduction of primary and final energy intensity by 1.5 times
	Ensuring security of supply	Specific heat use in buildings at 100 kWh/m²/yr	Increase of domestic share in electricity from 35 to 70% 30% self-generation of electricity by consumers
	RES share in transport sector 14%		RES share in transport sector 15%
Until 2050	Reduction of GHG emissions by 80% (NECP)*	No targets set	RES share in FEC 80% (electricity and DH 100% fossil free)
			Reduction of primary and final energy intensity by 2.4 times

* Compared to 1990; ** Compared to 2005

Currently, final energy demand in the Baltic states is divided between roughly 30 per cent each in transport and the residential sectors, 20 per cent in industry, and the remaining 20 per cent in public, commercial and agriculture sectors. The only country that significantly differs from this distribution pattern is Latvia,

18 Volkova A., Pieper H., Koduvere H, Lepiksaar K. and Siirde A. (2021). Heat pump potential in the Baltic states. Nordic Energy Research. Oslo, Norway. https://doi.org/10.6027/NER2021-02.

19 Ministry of Economic Affairs and Communication (2019). Estonia's 2030 National Energy and Climate Plan (NECP 2030). https://ec.europa.eu/energy/sites/ener/files/documents/ee_final_necp_main_en.pdf. Accessed 2021-11-08

20 Ministry of Economics – Republic of Latvia (2019). Latvia's National Energy and Climate Plan 2021–2030. https://ec.europa.eu/energy/sites/ener/files/documents/lv_final_necp_main_en.pdf. Accessed 2021-11-08.

21 Ministry of Energy of the Republic of Lithuania (2019). National Energy and Climate Action Plan of the Republic of Lithuania for 2021-2030. https://ec.europa.eu/energy/sites/ener/files/documents/lt_final_necp_main_en.pdf. Accessed 2021-11-08.

in which the share for transport is higher (about 36 per cent), due to the large amount of international road freight transport.[22]

In all countries, the share of energy-intensive industry is relatively low, but still accounts for between 60 per cent and 80 per cent of total final industrial energy demand. In Estonia, important industrial sectors from an energy perspective (based on their shares of primary energy consumption) are the chemical industry, cement production, refineries and wood processing. In Latvia, wood processing strongly dominates primary energy use in industry, together with cement production. In Lithuania, the chemical industry accounts for almost 80 per cent of primary energy use.[23]

In terms of energy supply systems, the differences between the states are larger. The **Estonian** energy system stands out, in both a Baltic and Nordic perspective, by its large reliance on oil shale-based power production – about 53 per cent of total electricity generation in 2020[24] – although the proportion of bio-based and wind power has increased since 2005.[25] Further, the oil shale industry contributes with the production of shale oil, which is used for maritime purposes and to a large extent exported. About half of district heating is supplied by bioenergy, a quarter from natural gas and a substantial share from oil shale-based combined heat and power. This also means that the majority of GHG emissions (67 per cent in 2019) can be linked to the production of electricity and heat, and thus to the ETS sector. The next sectors, in relation to GHG emissions, are transport (16 per cent) and agriculture (10 per cent).

In **Latvia**, the primary energy supply has been divided fairly equally between bioenergy and waste, natural gas and oil. However, during recent years, the use of renewables has increased and natural gas use has decreased, reaching a level of about 23 per cent in 2017. Further, dependency on imported energy has decreased from 64 per cent in 2005 to 47 per cent in 2016. In 2019, 91 per cent of electricity was produced domestically. Latvian power production is dominated by hydropower and natural gas CHP.[26] [27]The Latvian ETS sector accounts for only 20 per cent of total GHG emissions. The majority of emissions can instead be linked to transport (25 per cent), agriculture (21 per cent) and small-scale energy use in the various demand sectors.

22 Lindroos T.J., Lehtilä A., Koljonen T., Kofoed-Wiuff A., Hethey J., Dupont, N. et al. (2018). Baltic Energy Technology Scenarios 2018. TemaNord 2018:515. Nordic Energy Research. Oslo, Norway. 164p. https://www.nordicenergy.org/project/bente/. Accessed 2021-08-18.

23 Volkova A., Pieper H., Koduvere H, Lepiksaar K. and Siirde A. (2021). Heat pump potential in the Baltic states. Nordic Energy Research. Oslo, Norway. https://doi.org/10.6027/NER2021-02.

24 Elering (2021) Production and forecast (in Estonian). https://elering.ee/toodang-ja-prognoos. Accessed 2021-11-08.

25 Volkova A., Pieper H., Koduvere H, Lepiksaar K. and Siirde A. (2021). Heat pump potential in the Baltic states. Nordic Energy Research. Oslo, Norway. https://doi.org/10.6027/NER2021-02.

26 Volkova A., Pieper H., Koduvere H, Lepiksaar K. and Siirde A. (2021). Heat pump potential in the Baltic states. Nordic Energy Research. Oslo, Norway. https://doi.org/10.6027/NER2021-02.

27 International Energy Agency (2021). Countries and Regions – Europe. https://www.iea.org/regions/europe. Accessed 2021-11-08.

Lithuania has a large dependence on imported electricity and only produced 32 per cent of final electricity consumption domestically in 2019. Electricity production has experienced a strong shift from about two-thirds natural gas and oil in 2010 to almost 80 per cent renewables (mostly wind and hydropower) in 2019.[28] [29] The Lithuanian sectors responsible for the largest individual GHG emissions are transport (26 per cent) and agriculture (23 per cent), but industry is responsible for roughly the same amount when including both energy and process-related emissions. The ETS sector accounts, in total, for about 34 per cent of GHG emissions.[30]

3.3 Key areas for energy transitions currently in focus for policy (Now)

A detailed description of climate and energy policies in each of the Baltic states is beyond the scope of this study. However, at an overview level, a few policy areas have been identified as particularly relevant for the region, and essentially common to the three countries. Below, these key areas are shortly described, with a few examples for specific countries.

Increase energy independence and the interconnections within the Baltics, with Finland and with the EU for both electricity and natural gas systems. The Baltic Energy Market Interconnection Plan (BEMIP) is an initiative to achieve an open and integrated regional electricity and gas market between EU countries in the Baltic Sea region, and the implementation of this is in focus for all states. In 2019, the countries signed, together with Poland and the EU Commission, a joint political roadmap for the synchronisation of the Baltic states´ electricity network with continental Europe by 2025.

The BEMIP also includes strengthening the natural gas network through the construction of the Gas Interconnector Poland (completed by end of 2021, expected to be operational by mid-2022[31]) and the Balticconnector as a link between Finland and Estonia (in operation), together with related renovations of the gas system in the Baltics. In Latvia, there is particular emphasis on the diversification of the natural gas supply with new interconnections, a regional LNG terminal and modernisation of the Incukalns Underground Gas Storage Facility. In 2020, the Baltic states and Finland also agreed on a process for the future integration of the regional gas markets in their respective countries.[32]

28 Volkova A., Pieper H., Koduvere H, Lepiksaar K. and Siirde A. (2021). Heat pump potential in the Baltic states. Nordic Energy Research. Oslo, Norway. https://doi.org/10.6027/NER2021-02.

29 International Energy Agency (2021). Countries and Regions – Europe. https://www.iea.org/regions/europe. Accessed 2021-11-08.

30 Lindroos T.J., Lehtilä A., Koljonen T., Kofoed-Wiuff A., Hethey J., Dupont, N. et al. (2018). Baltic Energy Technology Scenarios 2018. TemaNord 2018:515. Nordic Energy Research. Oslo, Norway. 164p. https://www.nordicenergy.org/project/bente/. Accessed 2021-08-18.

31 Ambergird (2022). Gas Interconnection Poland–Lithuania (GIPL). https://www.ambergrid.lt/en/projects/gas-interconnection-poland-lithuania-gipl. Accessed 2022-01-10.

32 European Commission (2020). Roadmap on regional gas market integration. https://ec.europa.eu/info/files/roadmap-regional-gas-market-integration_en. Accessed 2021-11-08.

Increased production and use of renewable energy for electricity, district heating and transport. The largest increase in capacity is expected in renewable electricity production, where e.g. Estonia expects to more than double the production (from 1.8 to 4.3 TWh), primarily through wind power (both onshore and offshore). Both Latvia and Lithuania have a strong focus on ensuring the greatest possible self-sufficiency in electricity production, taking into account trends towards increasing electrification. The Lithuanian state is preparing an environmental impact assessment for the construction of a 700 MW wind farm and plans an auction in 2023 to find a developer.[33] Other important areas for the implementation of renewable energy projects in e.g. the Latvian NECP include solar heat in district heating, anaerobic digestion of waste in landfills and waste-to-energy.[34] For increasing renewable fuels in transport, the Baltic states have a focus on increasing biomethane production and fostering market development. Preliminary results from the Nordic Energy Research project FasTen[35] indicate that renewables in private transport will only make up a share of about 4–5 per cent in 2030, indicating the need for more measures to comply with set climate goals.[36]

Increasing energy efficiency in all sectors of the energy system is a primary focus of all countries. In Lithuania, the prioritised sectors include industry, buildings and transport. The primary approach for efficiency improvements in buildings is to promote renovation, and in transport by renewing the vehicle fleet.[37] Experience, from for instance Latvia, show that, despite large potentials (with energy savings up to 58 per cent), renovation is only done when supported by funding.[38] The Estonian NECP specifically highlights the need for promoting the introduction of low-carbon technologies and the efficient use of resources in industrial processes. The green technology investment programme focuses on boosting start-up and scale-up of companies with "green" products that can contribute to reducing or capturing GHG emissions.[39] In Latvia, priorities include increasing energy efficiency and using local RES in district heating, industry buildings and municipal buildings, through e.g. renovation. One specific example

33 ThreeSeas (2021). Connection of offshore wind farm to the electricity transmission grid of Lithuania, https://projects.3seas.eu/projects/connection-of-offshore-wind-farm-to-the-electricity-transmission-grid-of-lithuania. Accessed 2022-01-03.

34 Ministry of Economics – Republic of Latvia (2019). Latvia's National Energy and Climate Plan 2021–2030. https://ec.europa.eu/energy/sites/ener/files/documents/lv_final_necp_main_en.pdf. Accessed 2021-11-08.

35 Nordic Energy Research (2020) Fast, flexible and secure decarbonisation of the Baltic states – possible progress in the next Ten years. Joint Baltic-Nordic Energy Research Programme. https://www.nordicenergy.org/article/jbnerp-first-call-completed/. Accessed 2021-11-08.

36 Tomi Lindroos. Personal communication. 2021-08-24.

37 Ministry of Energy of the Republic of Lithuania (2019). National Energy and Climate Action Plan of the Republic of Lithuania for 2021-2030. https://ec.europa.eu/energy/sites/ener/files/documents/lt_final_necp_main_en.pdf. Accessed 2021-11-08.

38 Silovs G. (2021). Latvian experience with energy efficiency programmes. Ministry of Economics. Presentation at Nordic-Baltic Energy conference 2021: Energy delivery in the European Green Deal. https://www.norden.ee/images/rohemajandus/Energiakonverents/Energiakonverents_2021/Gatis_Silovs.pdf. Accessed 2021-11-08.

39 Ministry of Economic Affairs and Communication (2019). Estonia's 2030 National Energy and Climate Plan (NECP 2030). https://ec.europa.eu/energy/sites/ener/files/documents/ee_final_necp_main_en.pdf. Accessed 2021-11-08

is that all new multi-flat buildings and public buildings in Latvia should be nearly zero-energy buildings from 2021 onwards.

In each country, a broad range of policies, strategic processes and documents have been developed to govern and guide the transition. A couple of examples for each country are included below.

Estonia places substantial emphasis on implementing the National Development Plan of the Energy Sector until 2030 (NDPES), which describes the objectives of Estonia's energy policy until 2030, the vision for the sector until 2050, as well as overall and specific targets and actions to meet them. The NDPES covers the electricity, heating, transport and fuel sectors (see further below).[40] Another identified area is to increase knowledge and prepare for potential transitions to hydrogen, by engaging in the Hydrogen Initiative (joined in 2018).[41]

Latvia has the ambition to further foster Baltic co-operation to reach climate and energy targets, and has identified developments in the transport sector as a primary area for such co-operation. Research priorities are outlined in the national RIS3 strategy for smart specialisation; these include research related to the bioeconomy and smart energy (energy efficiency, new materials, optimisation of production processes and use of alternative energy sources).

According to the **Lithuanian** National Energy Independence Strategy (NEIS), four priority areas have been set up: 1) reducing the impact on climate change and ambient air pollution; 2) reliability; 3) competitiveness; 4) involvement of the country's businesses in the efforts towards energy progress. The NEIS vision for 2050 is advanced energy, generating added-value for the state and the consumer, using low-GHG technologies and clean energy sources, resistant to cyber threats and climate change, and providing energy reliability at competitive prices.[42] Outside, the direct climate and energy area, Lithuania has issued a general Industrial Digitisation Roadmap until 2030 and, in connection with this, developed a national industry digitalisation platform and is working on the development of a roadmap for the transition to a circular economy.[43]

40 Ministry of Economic Affairs and Communications (2017). National Development Plan of the Energy Sector until 2030. Tallinn, Estonia. 124p. The NDPES to 2035 is currently being developed.

41 Ministry of Economic Affairs and Communication (2019). Estonia's 2030 National Energy and Climate Plan (NECP 2030). https://ec.europa.eu/energy/sites/ener/files/documents/ee_final_necp_main_en.pdf. Accessed 2021-11-08

42 Ministry of Energy of the Republic of Lithuania (2018). National Energy Independence Strategy – Energy for Lithuania's Future. (Unofficial translation from Lithuanian to English). https://enmin.lrv.lt/uploads/enmin/documents/files/National_energy_independence_strategy_2018.pdf. Accessed 2021-11-08.

43 Ministry of Energy of the Republic of Lithuania (2019). National Energy and Climate Action Plan of the Republic of Lithuania for 2021-2030. https://ec.europa.eu/energy/sites/ener/files/documents/lt_final_necp_main_en.pdf. Accessed 2021-11-08.

3.4 Needs for Baltic energy systems transition in the medium term (2030)

In the medium term, the need for energy systems transitions in the Baltic countries is in general well aligned with current policy priorities and the focus areas described above. The medium-term needs are described for each country separately, but the main needs that are common to all countries are summarised below.

The process for integration of the regional electricity and natural gas systems, and the interconnections with Finland and the EU, is already planned and expected to be finalised well in advance of 2030. It is therefore not included in the "needs description" for this time perspective.

A key area, for all states, is the need to increase renewable electricity production. Here, increasing production capacity through wind power is in focus for the medium-term perspective. In the BENTE study, wind power production is expected to almost quadruple between 2020 and 2030, and then double again until 2040. Since the cost is lower for onshore wind power, and the maximum potential (in the model) is not exhausted, almost no offshore wind power is included in the results of the BENTE study.[44] According to Wind Europe, offshore wind power by 2030 could account for between 1700 and 3200 MW by 2030.[45] However, to realise such a dramatic expansion over a relatively short time period, both onshore and offshore wind farms would most likely need to be developed. From 2030 onwards, solar power potential would also need to be expanded. The BENTE modelling results show an increasing reliance on imported electricity from the Nordic countries[46] up until 2030 (for the Baltic countries as a group), due to a lack of relevant policies in the Baltic countries (see Figure 5). This indicates that it may be of interest to the countries to further accelerate the development of domestic renewable electricity production. In the period between 2030 and 2040, model results show a strong expansion of wind and solar power. For large-scale offshore wind power to be relevant in the longer time frame, establishment of smaller-scale hubs would be needed in the medium term.[47]

Future district heating supply was analysed in detail in a recent NER study. According to this study, total district heating demand will be fairly stable over the entire time period. In the base scenario, heat provided from biomass would

44 Lindroos T.J., Lehtilä A., Koljonen T., Kofoed-Wiuff A., Hethey J., Dupont, N. et al. (2018). Baltic Energy Technology Scenarios 2018. TemaNord 2018:515. Nordic Energy Research. Oslo, Norway. 164p. https://www.nordicenergy.org/project/bente/. Accessed 2021-08-18.

45 Tardieu P. (2021). Bright future for Offshore Wind? Challenges in the Nordic-Baltic Region. WindEurope. Presentation at Nordic-Baltic Energy conference 2021: Energy delivery in the European Green Deal. https://www.norden.ee/images/rohemajandus/Energiakonverents/Energiakonverents_2021/Pierre_Tardieu.pdf. Accessed 2021-11-08.

46 The BENTE modelling results also show an increasing reliance on imported electricity from Russia up until 2030 for the Baltic countries as a group. Naturally, this does not con sider the Russian invasion of Ukraine on 24 February 2022, as well as the subsequent political crisis and ongoing energy security deliberations at the EU and national levels.

47 Matti J Koivisto. Personal communication. 2021-08-18.

increase strongly until 2030, and heat from large-scale heat pumps would expand strongly between 2030 and 2040. With specific investment support, this expansion could start as early as 2030. In this time perspective, the main heat source used for heat pumps would be sewage water. Although heat generation would be stable, total installed capacity would decrease due to the introduction of heating storage technologies from 2030 onwards.[48]

The primary focus for increasing energy efficiency until 2030 is the renovation of the building sector. In the BENTE study, a continued reduction of specific energy consumption in residential buildings is expected until 2040 (by roughly 25–40 per cent). However, total final energy demand in this sector initially increases slightly (until 2030), due to increasing building stock, before starting to decrease. In other buildings the achieved increase in efficiency is expected to be balanced by increasing building stock (especially between 2030 and 2050). Note that the modelled rates of change are lower in the Ministry of Economic Affairs and Communication's "Estonia's 2030 National Energy and Climate Plan" (2019) than in the national plans, but are still very ambitious and will not take place without concerted action. Neither the NECP documents nor the BENTE study include any particular focus on increasing energy efficiency (or reducing emissions from) industrial processes. The BENTE study points out that the potential for improvements in this sector may be underestimated.

Energy efficiency improvements will also play an important role for the transport sector in the medium time frame. This is primarily expected to take place through the replacement of vehicles and a gradual electrification. Scenarios presented in an Nordic Energy Research study by ABB, foresee an electricity share in 2030 between 3.5 and 7 per cent in Estonia and Lithuania, and between 5.5 and 11 per cent in Latvia, based on the states' NECPs (base and high estimates).[49]Decarbonisation of the sector will also need to be initiated through electrification and increased use of renewable fuels. However, according to modelling results, actual system changes are expected to be limited until 2030, but start to accelerate in the period thereafter (2030–2040). Such a development also requires a focus on development of infrastructure.

Overall electrification is not explicitly described as a strategy in the national plans, but total electricity use is in general expected to grow. In Estonia, for example, by about 20 per cent until 2030.[50] Electrification is more in focus in the BENTE study, but with a similar result in overall increase in electricity consumption until 2030 (17–27 per cent growth in the Baltics as a whole). In the period between 2030 and 2040, electrification in the residential sector

48 Volkova A., Pieper H., Koduvere H, Lepiksaar K. and Siirde A. (2021). Heat pump potential in the Baltic states. Nordic Energy Research. Oslo, Norway. https://doi.org/10.6027/NER2021-02.

49 Nordic Energy Research/ABB (2020). Transport Statistical Data and Projections in the Baltic States. Nordic Energy Research. Oslo,Norway. https://www.nordicenergy.org/wordpress/wp-content/uploads/2020/02/20200407_NER_Final-Reportupd.pdf. Accessed 2021-11-08.

50 Ministry of Economic Affairs and Communications (2017). National Development Plan of the Energy Sector until 2030. Tallinn, Estonia. 124p. The NDPES to 2035 is currently being developed.

(due to an increasing number of appliances and heat pumps) and for transport increases strongly.[51]

3.4.1 Medium-term needs in Estonia

The main challenges and potential solutions for reaching the Estonian targets in the medium term have been identified, based on the Estonian NECP and NDPES and the results of the scenario studies.[52] [53]

Increase renewable electricity production. The highest growth potential for renewable electricity production is found in onshore and offshore wind power, but also renewable electricity production from solar should increase. In this context, an important approach is to develop offshore wind farms in a regional co-operation between Estonia, Latvia and Lithuania (see above and Section 3.5).[54] The potential of wind power production is quantified at about 4300 gigawatt hours (GWh) in 2030, which is the most apparent change to the energy system. Solar power production is quantified at about 360 GWh in 2030.[55]

An area specific to Estonia, is the need to minimise GHG emissions from the oil shale industry. Here, the focus is on market-driven development and the EU ETS system, and the future is thus largely dependent on crude oil prices. A shift of oil shale industry from electricity to oil and chemical products is foreseen.[56] The reliance on oil shale is, in the BENTE study, drastically reduced already by 2025, which in the modelling was a result of introduced constraints in line with current policies. In 2025, a significant portion of the oil shale power generation units will be shut down due to environmental restrictions related to air quality, and in addition, other plants that are based on old technologies. This would mean that the shift from oil shale-based electricity and heat production should mainly take place in the shorter term "Now" perspective. However, three oil shale power generation units (total capacity 650 MW) are expected to still be running, also after 2030. By 2040, oil shale generation is reduced to less than 2 TWh, as a

51 Lindroos T.J., Lehtilä A., Koljonen T., Kofoed-Wiuff A., Hethey J., Dupont, N. et al. (2018). Baltic Energy Technology Scenarios 2018. TemaNord 2018:515. Nordic Energy Research. Oslo, Norway. 164p. https://www.nordicenergy.org/project/bente/. Accessed 2021-08-18.

52 Lindroos T.J., Lehtilä A., Koljonen T., Kofoed-Wiuff A., Hethey J., Dupont, N. et al. (2018). Baltic Energy Technology Scenarios 2018. TemaNord 2018:515. Nordic Energy Research. Oslo, Norway. 164p. https://www.nordicenergy.org/project/bente/. Accessed 2021-08-18.

53 European Commission (2021). Policy scenarios for delivering the European Green Deal – Excel files for MIX scenario. https://energy.ec.europa.eu/publications-new/excel-files-mix-scenario_en. Accessed 2021-11-08.

54 Ministry of Economic Affairs and Communication (2019). Estonia's 2030 National Energy and Climate Plan (NECP 2030). https://ec.europa.eu/energy/sites/ener/files/documents/ee_final_necp_main_en.pdf. Accessed 2021-11-08

55 European Commission (2021). Policy scenarios for delivering the European Green Deal – Excel files for MIX scenario. https://energy.ec.europa.eu/publications-new/excel-files-mix-scenario_en. Accessed 2021-11-08.

56 Ministry of Economic Affairs and Communication (2019). Estonia's 2030 National Energy and Climate Plan (NECP 2030). https://ec.europa.eu/energy/sites/ener/files/documents/ee_final_necp_main_en.pdf. Accessed 2021-11-08

result of the high CO2 price, which make it uncompetitive.[57] The research project "Climate change mitigation using CCS and CCU technologies" is highlighted as a measure that may contribute to longer-term emission reductions from oil shale production.

District heating would, according to the Nordic Energy Research heat pump study, be almost completely reliant on biomass by 2030 in the base scenario, while large-scale heat pumps could deliver about half of all generated heat by 2040 (and even more in the investment support scenario).[58]

Boosting efforts to increase energy efficiency, primarily in the built environment, by renovating existing buildings and building new, energy-efficient, ones. Other areas where energy efficiency improvements are important include transport (to mitigate increased energy use), industry (for competitiveness) and street lighting (for quality and reliability). Another strategy will be to increase the efficiency of the heating supply (for buildings) by installing heat pumps. The total use of heat from heat pumps is expected to grow by 50 per cent until 2030.[59]

The share of advanced biofuels in transport should increase, at levels corresponding to the shares mandated by the EU's Renewable Directive II (REDII). The primary strategy to reach these targets is an increasing domestic production of biomethane from anaerobic digestion, which should quadruple by 2030 (reaching a level of about 340–395 GWh), in addition to initiating electrification.[60] This development is also closely linked to the implementation of waste management practices, including landfill gas recovery, anaerobic digestion and digesters in wastewater management.[61]

Electricity use for transport should increase by 34 times until 2030 (from 21 to 729 GWh) and would then cover about 5 per cent of energy use for transport. Until 2030, there will be a special focus on electrification of railways and ferries.[62] In the Fit for 55 scenarios, electricity use in transport is expected to account for only about 1 per cent of total demand in 2030, while in the BENTE

57 Lindroos T.J., Lehtilä A., Koljonen T., Kofoed-Wiuff A., Hethey J., Dupont, N. et al. (2018). Baltic Energy Technology Scenarios 2018. TemaNord 2018:515. Nordic Energy Research. Oslo, Norway. 164p.

58 Volkova A., Pieper H., Koduvere H, Lepiksaar K. and Siirde A. (2021). Heat pump potential in the Baltic states. Nordic Energy Research. Oslo, Norway. https://doi.org/10.6027/NER2021-02.

59 Ministry of Economic Affairs and Communication (2019). Estonia's 2030 National Energy and Climate Plan (NECP 2030). https://ec.europa.eu/energy/sites/ener/files/documents/ee_final_necp_main_en.pdf. Accessed 2021-11-08

60 Ministry of Economic Affairs and Communication (2019). Estonia's 2030 National Energy and Climate Plan (NECP 2030). https://ec.europa.eu/energy/sites/ener/files/documents/ee_final_necp_main_en.pdf. Accessed 2021-11-08

61 Lindroos T.J., Lehtilä A., Koljonen T., Kofoed-Wiuff A., Hethey J., Dupont, N. et al. (2018). Baltic Energy Technology Scenarios 2018. TemaNord 2018:515. Nordic Energy Research. Oslo, Norway. 164p. https://www.nordicenergy.org/project/bente/. Accessed 2021-08-18.

62 Ministry of Economic Affairs and Communication (2019). Estonia's 2030 National Energy and Climate Plan (NECP 2030). https://ec.europa.eu/energy/sites/ener/files/documents/ee_final_necp_main_en.pdf. Accessed 2021-11-08

study, it is higher.[63] As noted above, a strong increase in electrification of transport is not expected until after 2030.

3.4.2 Medium-term needs in Latvia

The main challenges and potential solutions for reaching the Latvian targets in the medium term have been identified, based on the Latvian NECP and the results of the scenario studies.[64]

Increase renewable electricity production, primarily with onshore wind power plants until 2030, even if there is a potential also for offshore. Two specific, potential projects are the AS Latvenergo project and the Doble Win Park (about 200 MW). The Fit for 55 study quantifies a substantial potential for onshore wind (5800 GWh) and solar power (2100 GWh) until 2030. This study also shows an increase in electricity production from biomass, waste and natural gas.[65] The BENTE study shows that, without additional policies to promote renewable electricity production, the share of domestically produced electricity will be only slightly above half in 2030, and mainly consist of (existing) hydropower, with almost no additional wind power.[66] However, from 2030 until 2040, capacity would increase substantially.

Continuing and broadening efforts to increase energy efficiency. The focus areas identified in the NECP include increased energy efficiency and use of local RES in district heating and in buildings, including industrial, municipal and multi-flat buildings.[67] [68]

District heating in Latvia would, according to the NER heat pump study, increasingly rely on heat from biomass by 2030, although a substantial share of heat from natural gas would remain. In the base scenario, heat provided from heat pumps would correspond to about a quarter in 2040.[69] The national energy

63 European Commission (2021). Policy scenarios for delivering the European Green Deal – Excel files for MIX scenario. https://energy.ec.europa.eu/publications-new/excel-files-mix-scenario_en. Accessed 2021-11-08.

64 Lindroos T.J., Lehtilä A., Koljonen T., Kofoed-Wiuff A., Hethey J., Dupont, N. et al. (2018). Baltic Energy Technology Scenarios 2018. TemaNord 2018:515. Nordic Energy Research. Oslo, Norway. 164p. https://www.nordicenergy.org/project/bente/. Accessed 2021-08-18.

65 European Commission (2021). Policy scenarios for delivering the European Green Deal – Excel files for MIX scenario. https://energy.ec.europa.eu/publications-new/excel-files-mix-scenario_en. Accessed 2021-11-08.

66 Lindroos T.J., Lehtilä A., Koljonen T., Kofoed-Wiuff A., Hethey J., Dupont, N. et al. (2018). Baltic Energy Technology Scenarios 2018. TemaNord 2018:515. Nordic Energy Research. Oslo, Norway. 164p. https://www.nordicenergy.org/project/bente/. Accessed 2021-08-18.

67 Lindroos T.J., Lehtilä A., Koljonen T., Kofoed-Wiuff A., Hethey J., Dupont, N. et al. (2018). Baltic Energy Technology Scenarios 2018. TemaNord 2018:515. Nordic Energy Research. Oslo, Norway. 164p. https://www.nordicenergy.org/project/bente/. Accessed 2021-08-18.

68 Ministry of Economics – Republic of Latvia (2019). Latvia's National Energy and Climate Plan 2021–2030. https://ec.europa.eu/energy/sites/ener/files/documents/lv_final_necp_main_en.pdf. Accessed 2021-11-08.

69 Volkova A., Pieper H., Koduvere H, Lepiksaar K. and Siirde A. (2021). Heat pump potential in the Baltic states. Nordic Energy Research. Oslo, Norway. https://doi.org/10.6027/NER2021-02.

and climate plan also outlines a potential development of district cooling for use in public buildings in this time frame.[70]

Implementation of advanced biofuels for transport. Latvia is discussing increasing domestic production of both biogas and bioethanol from straw. Another focus is the implementation of infrastructure developments necessary to increase the share of renewable fuels and electricity in the transport sector. Both scenario studies foresee a limited transformation of the transport sector until 2030. However, according to the BENTE study, in the period from 2030 to 2040, domestic biofuel production would become competitive and start increasing significantly, especially in the 2DS scenario that is in focus here.

3.4.3 Medium-term needs in Lithuania

As for the other countries, the main challenges for Lithuania until 2030 have been identified based on the Lithuanian NECP, the NEIS and the scenario studies presented in BENTE and Fit for 55. Also for Lithuania, the two most important areas in this time frame are increasing the use of renewable energy, especially electricity production, and energy efficiency improvements.

Increased production of renewable electricity is especially central to Lithuania since it has ambitious targets for increasing domestic electricity generation and currently a low level of self-dependency in this respect. As for all the Baltic states, the focus until 2030 is on increasing wind energy generation (see Figure 5). According to the Fit for 55 scenarios, about 1 TWh of domestic wind power production and almost 2 TWh of solar power could be in use by 2030.[71] In the BENTE study, roughly 3 TWh of wind power is produced in Lithuania in 2030, under the 2DS scenario. Between 2030 and 2040, the expansion phase would, according to modelling results, be very strong and increase the share of renewable electricity from 40 per cent (2030) to 70 per cent (2040).[72] Another important focus area is to upgrade district heating systems, including increasing efficiency and economically rational utilisation of surplus heat, heat pumps and co-generation.[73]

As for Estonia, the NER heat pump study shows also for Lithuania an almost complete reliance on biomass for district heating in 2030. By 2040, in the base scenario, heat pumps would correspond to roughly a quarter of total demand.[74]

70 Ministry of Economics – Republic of Latvia (2019). Latvia's National Energy and Climate Plan 2021–2030. https://ec.europa.eu/energy/sites/ener/files/documents/lv_final_necp_main_en.pdf. Accessed 2021-11-08.

71 European Commission (2021). Policy scenarios for delivering the European Green Deal – Excel files for MIX scenario. https://energy.ec.europa.eu/publications-new/excel-files-mix-scenario_en. Accessed 2021-11-08.

72 Lindroos T.J., Lehtilä A., Koljonen T., Kofoed-Wiuff A., Hethey J., Dupont, N. et al. (2018). Baltic Energy Technology Scenarios 2018. TemaNord 2018:515. Nordic Energy Research. Oslo, Norway. 164p. https://www.nordicenergy.org/project/bente/. Accessed 2021-08-18.

73 Ministry of Economics – Republic of Latvia (2019). Latvia's National Energy and Climate Plan 2021–2030. https://ec.europa.eu/energy/sites/ener/files/documents/lv_final_necp_main_en.pdf. Accessed 2021-11-08.

74 Volkova A., Pieper H., Koduvere H, Lepiksaar K. and Siirde A. (2021). Heat pump potential in the Baltic states. Nordic Energy Research. Oslo, Norway. https://doi.org/10.6027/NER2021-02.

Increasing energy efficiency is one of the key priorities in the energy area until 2050, according to the NEIS. Until 2030, the need for increasing energy efficiency is primarily focused on renovating buildings, improving energy performance of businesses and increasing efficiency in the transport sector by renewing the vehicle fleet. By renovating multi-flat and public buildings, it has been estimated that 5–6 TWh can be saved by 2030. The development of energy-efficient industry focuses on deployment of state-of-the-art technologies and equipment.[75]

For the energy transition in the transport sector, there is expected to be a limited increase in advanced biofuel and electrification of the vehicle fleet and the rail system until 2030. In this context, the introduction of biogas for transport and the development of recharging infrastructure, to pave the way for increasing electrification, is prioritised.

3.5 Needs for Baltic energy systems transition in the long term (2050 and beyond)

In the longer term – by 2050 and beyond – the NECP includes little information and guidance on expected challenges and needs. However, hydrogen is mentioned as a longer-term "future" energy solution (post 2030). Also, the Fit for 55 studies cover only the period until 2030.

The BENTE study includes long-term scenarios and identifies key developments for reaching the 2050 targets. In the 2050 time perspective, results for the different Baltic states are more similar, since the energy system for all countries is expected to have developed towards increasing shares of renewable energy, increasing integration and decreasing dependency on the current, varying infrastructure. Therefore, for this long-term perspective, it makes more sense to discuss the needs for the Baltic area as a whole.

Based primarily on the BENTE study, the following key overall energy system changes needed until 2050 are:

A continued and strong **electrification** of the energy system. Modelling results indicate an increased demand for electricity by about 60–65 per cent in 2050, due to a combination of increasing demand for energy services from increasing production, floor area, transport volumes etc., and electrification of transport, buildings and large heat pumps for district heating.

Continued strong increase in **renewable electricity production**, primarily from onshore wind (according to modelling results), but also solar power and biomass-based production. According to the study, production is dominated

75 Ministry of Energy of the Republic of Lithuania (2018). National Energy Independence Strategy – Energy for Lithuania's Future. (Unofficial translation from Lithuanian to English). https://enmin.lrv.lt/uploads/enmin/documents/files/National_energy_independence_strategy_2018.pdf. Accessed 2021-11-08.

by onshore wind in Estonia, onshore wind and biomass in Lithuania and hydropower in Latvia. By 2050, in the 2DS scenario, the results show that the Baltic states are self-sufficient for electricity. This would mean a very strong expansion of wind and solar power between 2030 and 2040 continues, but at a slightly lower pace from 2040 to 2050.

An ongoing project will study the potential role of offshore wind energy hubs in the Baltic Sea for the Baltic-Nordic energy and power systems.[76] Results from similar studies of the North Sea region, show that large-scale hubs would be relevant from about 2035, but especially towards 2050. Their role depends highly on developments throughout the system with respect to electrification levels, hydrogen demand and power system integration. As noted above, path dependencies would, however, require small hubs to be in place earlier to realise such a development.[77] Expansion of offshore wind energy hubs is also high on the agenda for Baltic collaboration.

In the perspective until 2050 and beyond, hydrogen could also develop into an important part of the energy system. In interviews and reports/studies, relevant Baltic stakeholders stress the potentially important role for hydrogen in the longer term for energy storage, as a stabiliser of a power system based on renewables, and for the production of electrofuels. In the results from the BENTE study, hydrogen is also introduced until 2050, but primarily for the transport sector, through direct use in hydrogen buses and cars, and for the production of methanol for transport (together covering about 15 per cent of final energy consumption for transport in 2050).

The district heating systems in the Baltic states could, according to the base scenario of the NER heat pump study, be supplied by heat from large-scale heat pumps – using waste heat and renewable heat from seawater, rivers and lakes – at a share of about 50 per cent in 2050. In this perspective, and at such a scale of expansion, the large heat sources used would include, apart from sewage water, also sea and river water. The importance of storage capacity in the networks would also continue to grow.[78]

In the transport sector, the shift to EVs is expected to accelerate after 2030. The BENTE study indicates that the number of EV passenger cars, for instance, will increase from only a few per cent in 2030 to more than 80 per cent in 2050. However, such shifts require infrastructure investments. In addition, transport biofuels would be needed to decarbonise heavy vehicles, airplanes and shipping. The BENTE study also indicates the development of significant domestic

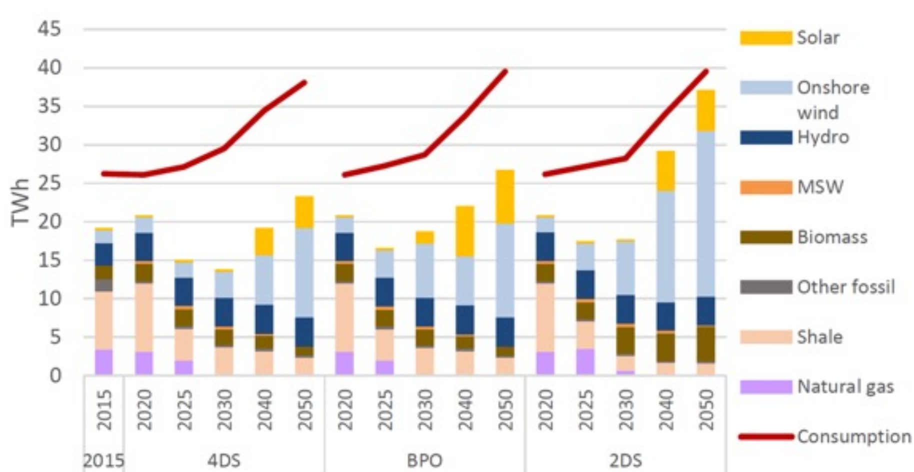
76 Koivisto M.J., Murcia Leon J.P., Sørensen P.E., Münster M., Bramstoft Pedersen R.B. (2021). Interconnecting the Baltic Sea countries via offshore energy hubs (BaltHub). Baltic-Nordic Energy Research Programme. https://orbit.dtu.dk/en/projects/interconnecting-the-baltic-sea-countries-via-offshore-energy-hubs. Accessed 2021-11-08.
77 Matti J Koivisto. Personal communication. 2021-08-18.
78 Volkova A., Pieper H., Koduvere H, Lepiksaar K. and Siirde A. (2021). Heat pump potential in the Baltic states. Nordic Energy Research. Oslo, Norway. https://doi.org/10.6027/NER2021-02.

production of transport biofuels until 2040. In the BENTE 2DS scenario, production would more than triple in 2040, compared to 2030 (and today). Between 2040 and 2050, the production would – due to continued efficiency improvements, increased electrification and increased use of synfuels – actually decrease slightly until 2050, but remain at about the same share of total final energy use (about 45 per cent).

To realise the dramatic reductions of GHG emissions needed until 2050, CCS technologies will potentially need to play a significant role in the system as well. According to the BENTE modelling results, CCS is introduced in the Baltic states until 2050, primarily for reducing GHG emissions from cement and ammonia production.

Finally, the need for continuing efforts to increase efficiency throughout the system, including buildings, transport, and industry will remain – also in the long term.

Figure 5. Development of the overall Baltic electricity generation systems (all three countries combined), according to the BENTE scenario and modelling study[79]. The 2DS scenario is considered the most relevant for this report.



79 Lindroos T.J., Lehtilä A., Koljonen T., Kofoed-Wiuff A., Hethey J., Dupont, N. et al. (2018). Baltic Energy Technology Scenarios 2018. TemaNord 2018:515. Nordic Energy Research. Oslo, Norway. 164p. https://www.nordicenergy.org/project/bente/. Accessed 2021-08-18.

Chapter 4

Overview of current R&I activities and stakeholders in the Baltic states

PHOTOS: SIGURÐUR ÓLAFSSON, NORDEN.ORG / PEXELS.COM

Key findings

From the survey conducted it is clear that most CET areas are considered highly relevant for the Baltic stakeholders. All three Baltic states also have a strong R&I profile in relation to many of the CET categories included. Three broad areas of strength across the Baltics are:

- **Energy in urban and built environment**, including energy efficient buildings, district heating and the use of heat pumps and bioenergy in district heating. Examples of activities include the Centre of Excellence for zero energy and resource efficient smart buildings and districts (ZEBE) at Taltech in Estonia; solar heat use for district heat in Salaspils in Latvia; and sustainable buildings research at VilniusTech in Lithuania.
- **Power systems, energy storage and distribution**, including efficient strategies for short-term balancing of power systems, micro and smart grids and power storage developments. Example of activities include the research projects SMAGRINET, BaltHub and Flex4RES with leading roles for research institutions such as TalTech, RTU and KTU. In this area also the active roles of transmission system operators of the power and natural gas systems and energy companies are important.
- **Renewable hydrogen** is being actively pursued by national hydrogen initiatives in all Baltic states. In Latvia (Riga) 10 hydrogen buses are in operation since 2010. In Estonia, Estiko Energia plans to develop a hydrogen valley in the vicinity of Tartu by 2030 and in Lithuania, the natural gas operator Ambergrid plans for green hydrogen production for injection into the natural gas grid starting in 2024.

A few additional examples of concrete actions that relate to the CET development include:

- In Lithuania the electricity storage facilities system project for transmission grid stabilisation by battery storage project aims at a total combined capacity of 200 MW by the end of 2022.
- In Estonia, co-combustion with bioenergy as well as CCS/CCU research is being conducted, mainly related to shale oil use.
- In Latvia, the energy supply company Latvenergo provides full digital service since 2018. In Estonia, Elering has designed and operates Estfeed, which is the first highly secure platform for exchanging private energy metering data.

CET-related areas where there seem to be relatively few stakeholders currently directly involved are primarily:

- Technological development of renewable emission power technologies, with the prominent exception of photovoltaics in Lithuania.
- Process-related development of low carbon industrial energy systems.
- R&I related to the development of a low emission transport systems, mainly due to the lack of automotive industry.

CET categories that are, by the stakeholders, not considered relevant for the Baltics include nuclear and offshore ocean technology.

4.1 Introduction

This chapter describes current R&I activities and stakeholders in the Baltic countries, addressing clean energy-related technologies (CETs). Stakeholders may be research groups that focus on development of CETs, companies that develop and/or market CETs, or public organisations that specifically focus on the use of CETs. The overview is based on interviews with Baltic energy experts (see Appendix A), an internet search of main stakeholder websites, literature review and a survey of a broad range of energy experts and stakeholders in the Baltic countries.

The full list of Baltic energy experts and stakeholders was collected systematically through existing research networks, a scientific database (SCOPUS) and databases of research projects (e.g. EU CORDIS project database). The full systematic procedure is described in Appendix B. Finally, this list was reviewed and complemented by the project board members, representing each of the Baltic states, in order to complement the list with more stakeholders that do not represent research organisations.

A survey, with the purpose of providing input on the relevance of these CETs for the different Baltic states, was then directed to individuals representing the stakeholders on this list. This survey was based on the comprehensive list of general CET categories and CETs in Figure 2. For more information about the set-up of the survey and the interpretation of results see Appendix C.

Based on this input, an overview – organised based on the same general CET categories – of relevant R&I activities by these stakeholders in the Baltic states, has been compiled and is presented in the sections below. Note that this overview is based on the systematic approach towards compiling relevant stakeholders and input described above, but primarily based on information available on the respective websites and does thus not claim to be exhaustive. The purpose is rather to give very brief information about activities and areas that are most in focus and to provide examples. It has not been possible, within the scope of this project, to go further into published research results and the like. Further, for similar reasons, the focus is entirely on applied research and activities directly related to the challenges of the energy system and not on more fundamental research which can potentially have future energy applications, but for which this is not currently explicitly in focus.

4.2 Integrated power and energy systems

The area of integrated power and energy systems includes a broad range of different research areas within quite different disciplines. What they have in common is that the technological solutions have an impact on one or more (or all) of the interconnected energy sub-systems, such as the power system or a future hydrogen network, or that they impact climate emissions from a systems level.

For this CET category, key stakeholders include the transmission system operators of the power and natural gas systems in each of the Baltic states (Elering in Estonia, AST in Latvia, Litgrid and Ambergrid in Lithuania). All of these are extensively involved in the development of integrated and synchronised power and gas markets and in all major projects and initiatives related to the area. Other highly relevant organisations are energy companies and distribution grid operators (e.g. Fortum, LatvEnergo, Ignitis Group and EPSO-G), as well as industry and interest organisations linked to the power, natural gas and hydrogen sectors (see also Appendix B).

In **Estonia**, one research group at the Department of Energy Technology at Tallinn University of Technology (TalTech), is involved in research on carbon capture and storage technologies, including carbon capture from biomass, potentially leading to negative emissions, as part of their focus on reducing climate impact from the Estonian oil shale industry.[80]

Also at TalTech, there are two research groups in the Department of Electrical and Power Engineering and Mechatronic, focusing on power system research. They investigate efficient strategies for short-term balancing of power systems and the development of micro and smart grids as part of the power system.[81] They also host a project focusing on optimising energy storage in the residential sector from a system perspective (ORBES)[82].

At the Stockholm Environment Institute (SEI) in Tallin, projects in the area focus on, for instance, analysis of opportunities for hydrogen deployment in Estonia and policy analysis.

The Estonian electricity and natural gas grid operator Elering is actively working with the de-synchronisation of the power grid from the Russian power system to synchronise with the Continental European power grid and frequency area. This project, directed towards system change, is to be finished by the end of 2025 and covers infrastructure investments in the whole Baltic-Nordic region.[83]

80 Department of Energy Technology. Tallinn University of Technology. https://taltech.ee/en/department-energy-technology. Accessed 2021-08-27.

81 Department of Electrical Power Engineering and Mechatronics. Tallinn University of Technology.

82 Department of Electrical Power Engineering and Mechatronics. Tallinn University of Technology. Optimised Residential Battery Energy Storage Systems (ORBES). https://taltech.ee/en/orbes. Accessed 2022-03-01.

83 Elering. Synchronisation with continental Europe. https://elering.ee/en/synchronization-continental-europe. Accessed 2021-10-25.

In **Latvia**, the Institute of Energy Systems and Environment (IESE) at Riga Technical University (RTU) is active in systems-oriented research, primarily through longer-term energy modelling and strategic systems analysis. Further, research focuses substantially on the role of bioenergy and biogas in the future energy system.[84] RTU also participated in the NER project Flex4RES, addressing the challenge of integrating high shares of variable renewable energy in the energy system (finalised in 2019).[85]

Given the natural gas infrastructure and the role of natural gas in power generation, greening of natural gas by biogas and blending of carbon-neutral hydrogen in the natural gas grids are options investigated more in-depth. Hydropower is used for balancing the power grid and can play a major role for integrating even higher shares of intermittent renewable power generation alternatives. Also, bio-based power generation has a long tradition.

An active hydrogen association and hydrogen buses in public transport in Riga are the first initiatives, in line with the European hydrogen initiative.

In **Lithuania**, the stakeholders involved in research on the power systems, are, for instance, the Department of Electric Power Systems at Kaunas University of Technology (KTU) and the Smart Grids and Renewable Energy Laboratory at the Lithuanian Energy Institute (LEI). One example of a large project is the Smart grid competence hub for boosting research, innovation and educational capacities for energy transition (SMAGRINET[86]), which is a Horizon 2020 project running from 2019–2021, coordinated by TalTech and with partners from Estonia (TalTech, Civitta, Union of Electricity Industries), Lithuania (KTU), Germany, France, Portugal and Slovenia.

Hydrogen is also actively pursued as a long-term solution for the energy system, with a number of projects at the Center for Hydrogen Energy Technologies at LEI. Other active organisations within hydrogen are the Lithuanian Hydrogen Platform and the natural gas operator Ambergrid, the latter recently announcing plans for green hydrogen production for injection into the natural gas grid starting in 2024.[87] Also, the electricity grid operator Litgrid has identified hydrogen as a long-term energy carrier in a recent study.[88]

84 Institute of Energy Systems and Environment. Riga Technical University. https://videszinatne.rtu.lv/en/science/project-and-research/active/. Accessed 2021-08-27.
85 Nordic Energy Research (2019). Flex4RES – Flexible Nordic Energy Systems. https://www.nordicenergy.org/flagship/flex4res/. Accessed 2022-01-04.
86 SMAGRINET. Empowering Smart Grid Expertise in Europe. https://www.smagrinet.eu/. Accessed 2021-08-27.
87 FuelCellsWorks (2021). Amber Grid – The First Green Hydrogen Production Project Is Launched in Lithuania. https://fuelcellsworks.com/news/amber-grid-the-first-green-hydrogen-production-project-is-launched-in-lithuania/. Accessed 2021-10-25.
88 Litgrid/DNV GL (2020). Scenario Building for the Evolution of Lithuanian Power Sector for 2020-2050. Report 2020-0430, https://www.litgrid.eu/uploads/files/dir564/dir28/dir1/15_0.php. Accessed 2021-10-25.

The importance of electricity storage for the development of the power system has also led to the Lithuanian electricity storage facilities system project, led by Energy Cells, which is part of the EPSO-G Group. The project should lead to the instalment and integration of four energy storage facilities (batteries) with a total combined capacity of 200 MW by the end of 2022.[89]

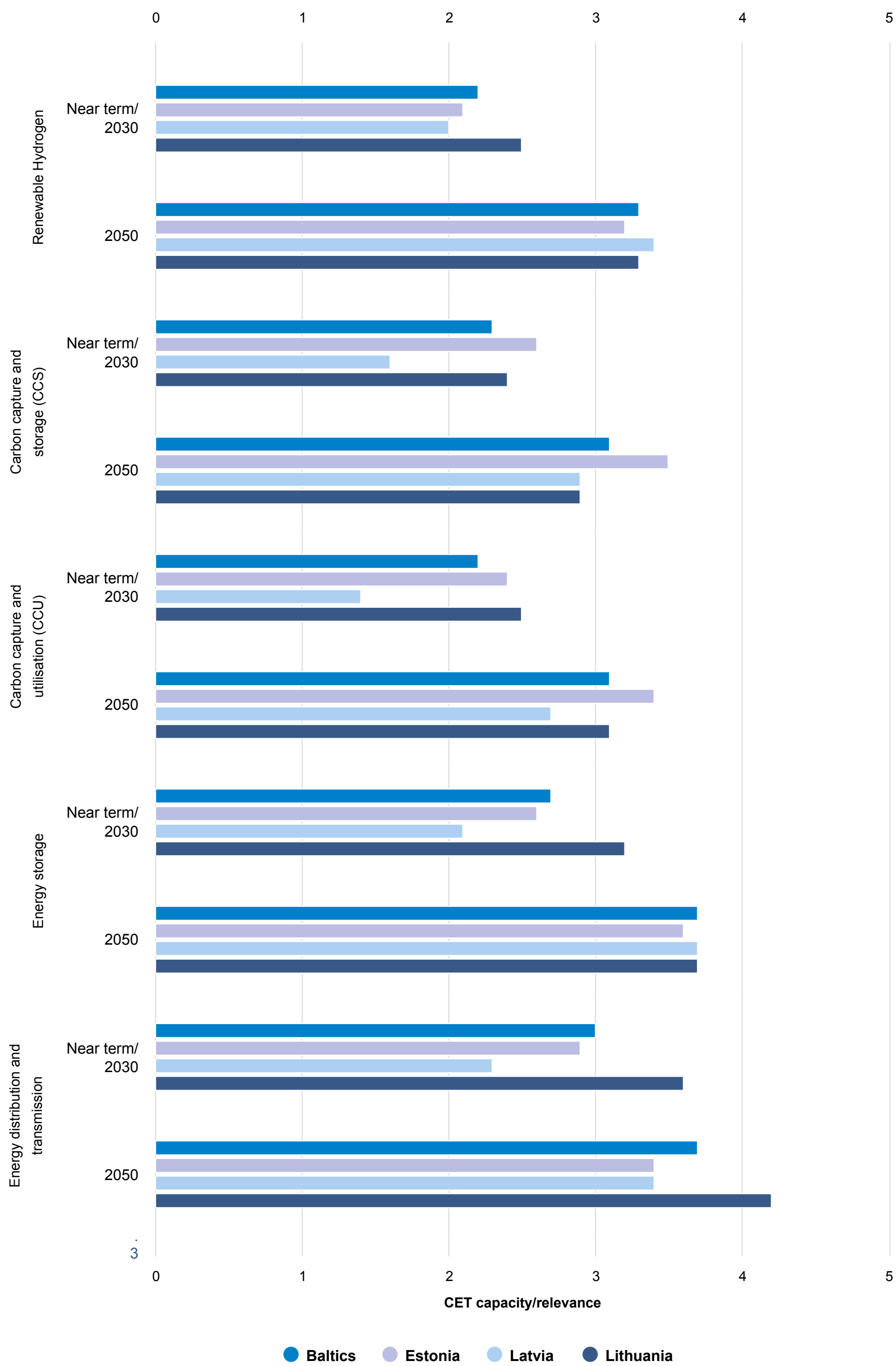
Related to the development of an interconnected and more renewable power system there are also already initiated **Baltic-Nordic** collaborations. The so called BaltHub project, financed by the Joint Baltic-Nordic Energy Research Programme, will study the potential role of large-scale offshore wind hubs in the Baltic Sea.[90] In this project, led by the Danish Technical University (DTU), KTU in Lithuania and TalTech in Estonia are partners.

The survey results illustrated in Figure 6 indicate that within the CET category *Integrated power and energy system*, energy distribution and transmission are of most relevance in the near term, closely followed by CETs for energy storage. It is also clear that both these CETs are rated as more important by stakeholders in Lithuania than in the other states. All CETs are rated as being more relevant in the longer term. This means that, towards 2050, also hydrogen and CCUS are considered relevant. The interest of CCUS is also rated somewhat higher in Estonia, than in the other countries.

89 EPSOG (2022). Lithuanian Electricity Storage Facilities System Project. https://www.epsog.lt/en/projects/lithuanian-electricity-storage-facilities-system-project. Accessed 2022-01-03.

90 Koivisto M.J., Murcia Leon J.P., Sørensen P.E., Münster M., Bramstoft Pedersen R.B. (2021). Interconnecting the Baltic Sea countries via offshore energy hubs (BaltHub). Baltic-Nordic Energy Research Programme. https://orbit.dtu.dk/en/projects/interconnecting-the-baltic-sea-countries-via-offshore-energy-hubs. Accessed 2021-11-08.

Figure 6. Survey results for the CET category Integrated power and energy system.



4.3 Zero emission power generation technologies

In relation to the development of zero emission power production capacity and integration into the power system, transmission system operators and power companies are highly relevant stakeholders. In Latvia, for example, LatvEnergo – being the main producer of electricity – is strongly involved in renewable power generation, primarily via hydropower.[91]

However, there seem to be few stakeholders directly involved in the technological development and production of zero emission power technologies, and fairly limited research activities within the Baltic states.

In **Estonia**, two examples of relevant industrial stakeholders include Elcogen, which develops and markets solid oxide fuel cells, in collaboration with, for instance, several Finnish research partners[92]; and Ubik Solutions, which is a spin-off from TalTech that markets power electronic solutions, especially for solar power installations.[93] Further, there is a focus on co-combustion with bioenergy as a means for reducing emissions from power produced from oil shale, both by improved controlled of combustion conditions, as well as other thermochemical conversion options (pyrolysis/gasification).[94]

In **Lithuania,** a number of stakeholders are involved in the development of photovoltaics. At the Kaunas University of Technology (KTU) Department of Chemistry, there is fundamental research directed towards development of perovskite photovoltaics.[95] The industrial research centre Protech focuses especially on silicon and building integrated solar cells and has several demonstration and testing laboratories.[96] Further, Lithuania is home to one of the leading European manufacturers of solar PV elements, SoliTek Group, in Vilnius, with a large share of their modules being sold in the Nordic countries. They also have research and development collaboration with KTU and institutes/universities in the Nordic region (DTU, SINTEF).[97]

In **Lithuania**, the Lithuanian Energy Institute (LEI) is extensively involved in European nuclear-related research, including for instance projects focusing on fusion, small modular reactors as well as dismantling and waste handling.[98]

91 Latvenergo. Generation. https://latvenergo.lv/en/par-mums/razosana. Accessed 2022-01-
92 Elcogen. Company profile. https://elcogen.com/company/. Accessed 2022-01-03.
93 UBIK Solutions. Company profile. https://www.ubiksolutions.eu/company. Accessed 2022-01-03.
94 Estonian Research Information System (2019) Thermal engineers consider increasing the amount of wood in fossil fuels to be a possible solution https://www.etis.ee/Portal/News/Display/c357c4b9-354e-453e-9394-4d47e10d6d04?lang=ENG. Accessed 2022-01-03.
95 KTU. Perovskite Thin-film Photovoltaics (PERTPV). Kaunas University of Technology, https://en.ktu.edu/projects/perovskite-thin-film-photovoltaics-pertpv/. Accessed 2021-08-27.
96 Protech. The Applied Research Institute for Prospective Technologies. https://protechnology.lt/. Accessed 2022-01-03.
97 SoliTek company. https://www.solitek.eu/en/company. Accessed 2021-10-25.
98 LEI. Lithuanian Energy Institute – Projects. https://www.lei.lt/projects/. Accessed 2022-01-04

This is also an area of excellence of the Center for Physical Sciences and Technology.[99]

There is ongoing fundamental research on advanced materials that can be used for development of photovoltaics, but also other CETs, such as sensors, batteries and fuel cells, in all the Baltic states. One example is the Institute of Solid State Physics at the University of Latvia, which also hosts a nanotechnology centre.[100]

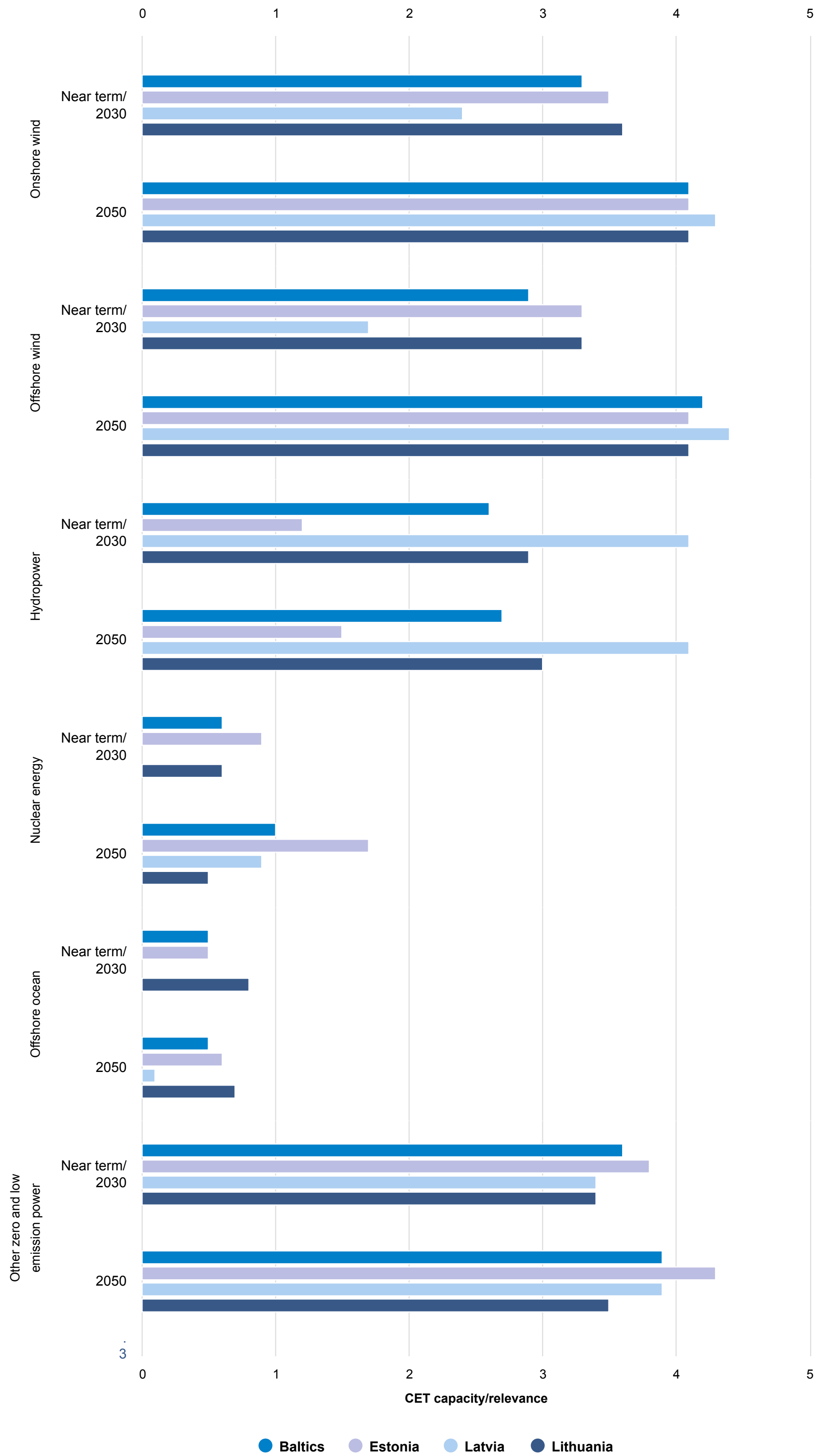
Offshore wind, pumped hydropower and bio-based power generation are also in focus in the research in several of the Baltic countries and in Baltic-Nordic collaborations, but then primarily with a focus on systems development (see above) and not on the development of the technologies as such. One project focusing specifically on optimising the potential and efficiency of offshore wind energy in the Baltic Sea Region is Baltic InteGrid, which was led by IKEM in Germany and finalised in February 2019. The project presented a roadmap for a meshed offshore grid in the Baltic Sea region, which would contribute to reducing bottlenecks for offshore wind production. Baltic partners included the Coastal Research and Planning Institute in Lithuania, the University of Tartu in Estonia, and the Latvian Association of Local and Regional Governments.[101]

The survey results for this CET category clearly show that nuclear energy and offshore ocean technologies are irrelevant to the Baltics as a whole and that hydropower is of little relevance to Estonia. Further, the relevance of hydropower as a mature technology, in general, does not increase over time. At the other end, onshore and offshore wind, as well as solar power are estimated to be highly relevant for all countries towards 2050; in Estonia and Lithuania (with less hydropower than Latvia), they are considered highly relevant in the near term. Other low emission power technologies, such as biomass-based power, are considered to be of high relevance in both time perspectives.

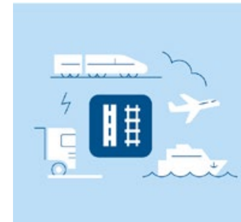
In comments provided via the survey, the high potential for wind power and biomass, which could serve as an important basis for development of green energy solutions for both domestic use and potentially export of energy carriers such as hydrogen and biofuels. Further, the importance of developments towards a more decentralised and small-scale power production system is highlighted.

99 Center for Physical Sciences and Technology. Environmental Research and energetics. https://www.ftmc.lt/environmental-research-and-energetics. Accessed 2022-01-03.
100 Institute of Solid State Physics – University of Latvia. Research topics. https://www.cfi.lu.lv/en/research/research-topics/. Accessed 2022-01-04.
101 Baltic InteGrid. Integrated Baltic Offshore Wind Electricity Grid Development. EU Interreg project. http://www.baltic-integrid.eu/. Accessed 2022-01-03.

Figure 7. Survey results for the CET category Zero emission power generation technologies.



4.4 Low emission transport systems



Within the area of low emission transport systems, there are some research stakeholders, but the extent of activities is somewhat unclear. During the interviews, a general consensus was that the Baltic countries – mainly due to the lack of an automotive industry sector – do not have a leading position in low emission transport systems, but rather "are following European and international trends".

In relation to hydrogen for transport, there are hydrogen associations in all Baltic countries (addressing hydrogen as an energy carrier in general).[102] [103] [104] In Estonia, Estiko Energia has recently published plans to develop a hydrogen valley in the vicinity of Tartu by 2030.[105] In Lithuania, there is also an operator of oil and LNG terminals (KN), which is an important stakeholder in relation to LNG and, together with other stakeholders, a part of the Lithuanian LNG Platform.[106] In addition to this, most relevant activities relate to the expansion of biogas (biomethane) for transport.

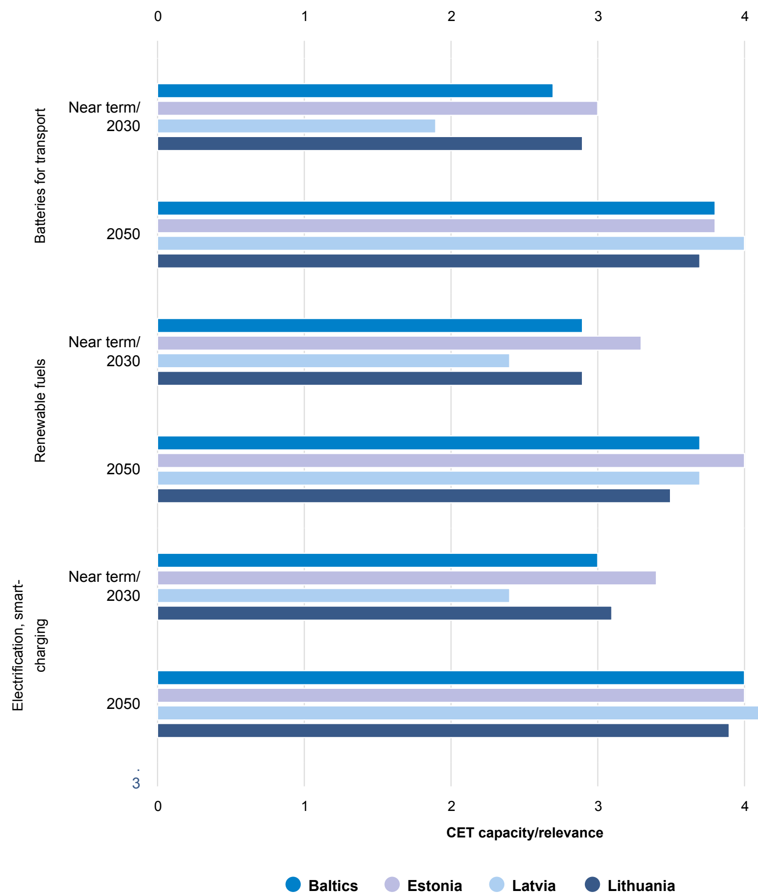
In **Estonia**, the national TSO Elering identified in 2016 the biogas potential as interesting for public transport or heavy duty transport.[107] Public transport in larger cities uses partly biomethane. In Tallin, for instance, 100 new CNG buses were delivered in 2020 and biomethane gas filling stations are being developed.[108] The biogas potential is still included as an important area for development for the future.

In **Latvia**, the IESE at RTU conducts extensive research on the production of biomethane via anaerobic digestions, directed partly towards use for transport.[109] In Riga, a fleet of 10 hydrogen fuel-cell trolly buses have been in operation since 2010, and the first hydrogen refuelling station in Latvia was installed as part of the project.

At Vilnius Gediminas Technical University (VilniusTech), in **Lithuania**, sustainable transport is one of the main research focus areas and there is a competence centre on intermodal transport and logistics. Aspects mentioned include autonomous transport, green logistics, intermodality and urban mobility, but not specifically renewable fuels or electrification.[110]

102 Estonian Hydrogen Association. https://h2est.ee/eng/. Accessed 2022-01-03.
103 Latvian Hydrogen Association. http://www.h2lv.eu/. Accessed 2022-01-03.
104 Lithuanian Hydrogen energy association. https://www.h2lt.eu/. Accessed 2022-01-03.
105 Hydrogen Valley Roadmap – Tartu. http://h2est.ee/wp-content/uploads/2021/07/4_Tartu-Hydrogen-Valley-Ain-Tammvere.pdf. Accessed 2022-01-03.
106 AB Klaipėdos nafta. https://www.kn.lt/en/. Accessed 2022-01-03.
107 Elering. Renewable energy-Green gas-Biomethane. https://elering.ee/en/biomethane. Accessed 2021-08-27.
108 Tallinn City (2020). Tallinn launched environmentally friendly compressed gas buses in the service. https://www.tallinn.ee/eng/greencapital/Uudis-Tallinn-launched-environmentally-friendly-compressed-gas-buses-in-the-service. Accessed 2021-11-08.
109 Elering. Synchronisation with continental Europe. https://elering.ee/en/synchronization-continental-europe. Accessed 2021-10-25.
110 Vilnius Gediminas Technical University. Research Focus. https://vilniustech.lt/research-and-innovation/research-focus/4819. Accessed 2022-01-03.

Figure 8. Survey results for the CET category Low emission transport systems.



The survey results for the transport CET category show similar results for all countries and a very high relevance for all CETs in the longer term. In the near term, the transport solutions are also estimated to be highly relevant, but with lower results for Latvia. In Estonia, the estimated relevance of renewable fuels and electrification is at the same level as for hydrogen long term. For Latvia, a comment points out that the lack of subsidies and policy measures supporting the introduction of BEVs is an important barrier to the development. Further, the strong focus on biogas is a driver for transforming the sector, but at the same time, risks undermining development of, for instance, hydrogen, advanced biofuels or electrofuels.

4.5 Industrial energy systems

Stakeholders and research directly related to the development of sustainable industrial energy systems, apart from Estonian research on development of the oil shale industry, seem to be fairly limited in the Baltic states.

At the Institute of Environmental Engineering at KTU, in Lithuania, cleaner production and research focusing on pollution prevention is one key area. The research does not, however, have a direct focus on energy aspects.

With respect to industrial heat recovery, there is quite some tradition in the Baltic countries. According to expert input from the interviews, the potential to feed this heat into district heating networks can be increased.

In **Estonia**, the Ministry of Economic Affairs and Communications has conducted a study on energy efficiency potential and waste heat potential from industry.[111] Industrial waste heat is also included in the recent NER study if the heat pump potential in the Baltic states, conducted by TalTech.

In **Latvia**, a Heating and cooling strategy has been developed at RTU[112] , also addressing industry heat supply and industrial waste heat potential.

In **Lithuania**, a large fertiliser company is supplying heat to the local district heating network, and in addition, generating electric power from the excess heat.[113]

The survey results indicate a high relevance for all industrial CETs – especially long term, but also in the shorter time perspective – with bio-based industrial processes rated highest of all. It should be noted that these are rated at the same level as the CETs for, for instance, wind power and electrification of the transport sector. The relevance in Latvia is ranked lower in the near term, but they are at the same level as the more interesting near-term CETs for other categories in Latvia.

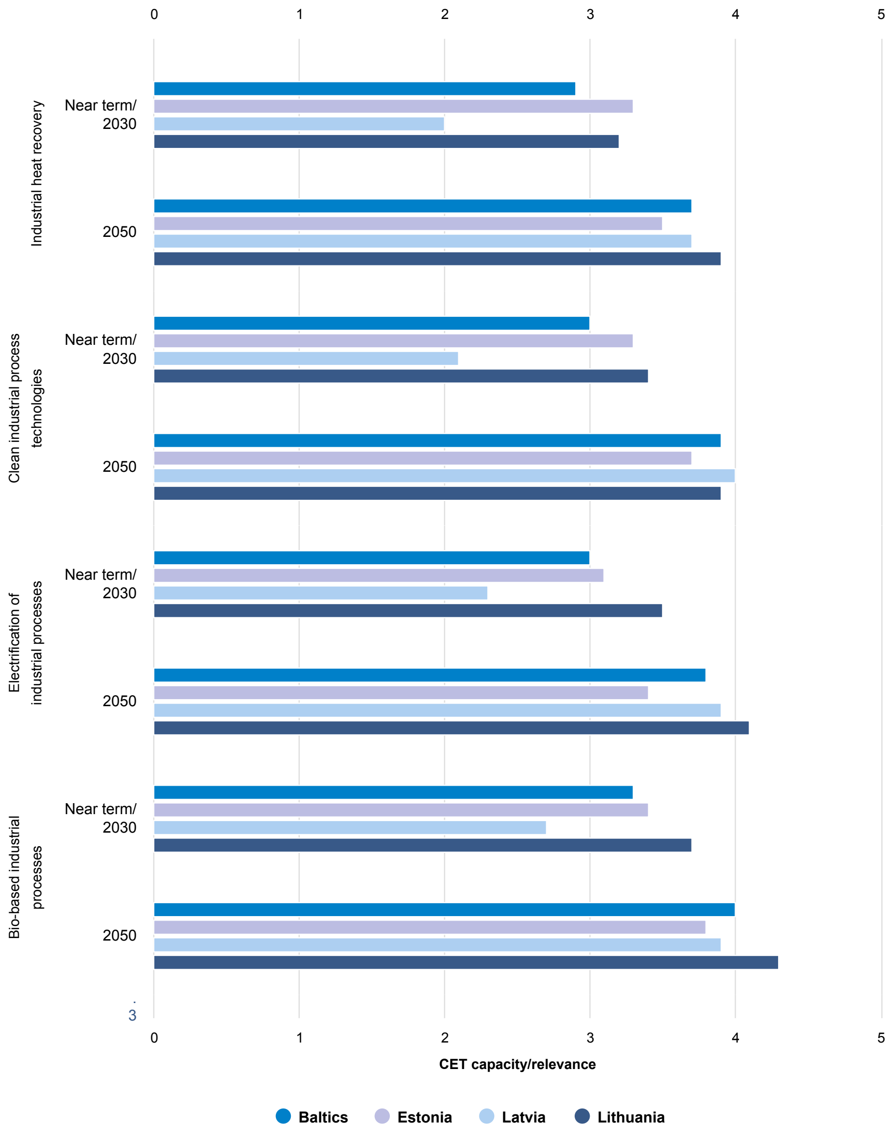
The survey comments include also references to barriers for more innovative solutions such as the lack of large industries and the fact that many existing industries are old and strongly linked to the natural gas supply.

111 Possibilities of using waste heat and exhaust cooling in the heating and/or cooling sector and assessing the potential of efficient district heating and cooling in Estonia (in Estonian). https://mkm.ee/sites/default/files/heitsoojuse_ja_-jahutuse_analuus_.zip. Accessed 2022-01-04.

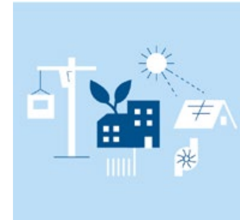
112 Determination of the Efficiency Potential of Heating and Cooling Supply in Latvia in accordance with EU Energy Efficiency Directive 2012/27/EU (in Latvian).

113 EuroChem-Lifosa. Electricity and Heat Energy. https://www.lifosa.com/en/energy-activity electricity-and-heat-energy/95. Accessed 2021-10-29.

Figure 9. Survey results for the CET category Industrial energy systems.



4.6 Urban and built environment



Within this area, there is substantial expertise and a strong focus on research in all three Baltic states. The three areas of energy efficient buildings, district heating and the use of heat pumps are especially in focus (see further below). There are also ongoing efforts to increase energy and climate planning in cities, supported e.g. via regional energy agencies.[114] [115] One example of an initiative in relation to smart city solutions, is the Estonian Smart City Cluster (ESCC), which involves members from the City of Tartu, R&D institutions and companies, and a focus on digital solutions, within several areas, including mobility and energy.[116]

Energy and resource efficient smart buildings
In **Estonia**, TalTech manages the Centre of Excellence for zero energy and resource efficient smart buildings and districts (ZEBE), which contributes to Estonian Smart Specialisation growth areas of More Efficient Use of Resources and Smart and More Efficient Construction of Buildings. The centre involves, in addition to TalTech, the Estonian University of Life Sciences and the University of Tartu and has three focus areas:

- zero energy and resource efficient smart buildings
- resource efficient wooden structures and composites
- intelligent and efficient energy management for ZEB

Based in Estonia is also the FInEst Centre for smart cities, focusing on mobility, energy and built environment.

In **Latvia**, RTU IESE has significant activities focusing on energy efficiency in buildings and sustainable development of Baltic cities, for instance through the EU projects SUNSHINE and Accelerate SUNSHINE and the regional project Act Now, focusing on energy efficiency in renovated apartment buildings and increase of municipality employee capacity, respectively.[117]

In **Lithuania**, sustainable buildings is a research focus area at VilniusTech and this research area is the focus of at least two different sections. The Civil Engineering Research Centre has a focus on building materials and technologies. The Faculty of Environmental Engineering, Dept of Building Energetics, focuses on the use of renewable energy resources in buildings, energy efficiency measures and sustainable energy planning.[118] Also, the Institute of Environmental Engineering at KTU focuses on smart sustainable cities.[119]

114 Tartu Regional Energy Agency. https://www.trea.ee/eng/. Accessed 2022-01-04.
115 Kaunas Regional Energy Agency. https://www.krea.lt/en. Accessed 2022-01-04.
116 Estonian Smart City Cluster (ESCC). http://smartcitylab.eu/en. Accessed 2022-01-03.
117 Elering. Synchronisation with continental Europe. https://elering.ee/en/synchronization-continental-europe. Accessed 2021-10-25.
118 Tallinn City (2020). Tallinn launched environmentally friendly compressed gas buses in the service. https://www.tallinn.ee/eng/greencapital/Uudis-Tallinn-launched-environmentally-friendly-compressed-gas-buses-in-the-service. Accessed 2021-11-08.
119 Institute of Environmental Engineering. Kaunas University of Technology. https://apinien.ktu.edu/. Accessed 2021-08-27.

Further, **Baltic-Nordic** collaboration is already under development through the NER project "Knowledge sharing on NZEB buildings in the Nordic-Baltic region", which is one of the first projects within the Joint Baltic-Nordic Energy Research Programme. The project is led by Aalborg University, and the Baltic partners are TalTech, KTU, and RTU.

District heating

The Department of Energy Technology at TalTech, in **Estonia**, has a research group focusing specifically on smart district heating systems. Areas in focus in the research include large-scale district heating system transitions towards 4th generation DH and development of low temperature district heating. Further, there is specific focus on the integration of large heat pumps in district heating systems. This group also led the recently finalised NER project focusing on the overall heat pump potential in the Baltic states.[120]

In **Latvia**, RTU IESE is active in research into the development of low temperature district heating, the integration of heat supply and cooling systems and various aspects related to the use of bioenergy for heating.[121] Solar heat for heat supply to the district heating system is in operation in Salaspils since 2019.

Heat pumps

No research stakeholders have been identified that focus on actual development of heat pumps, but rather on their integration in the energy system in general and especially in district heating systems. These aspects are therefore included under district heating, above.

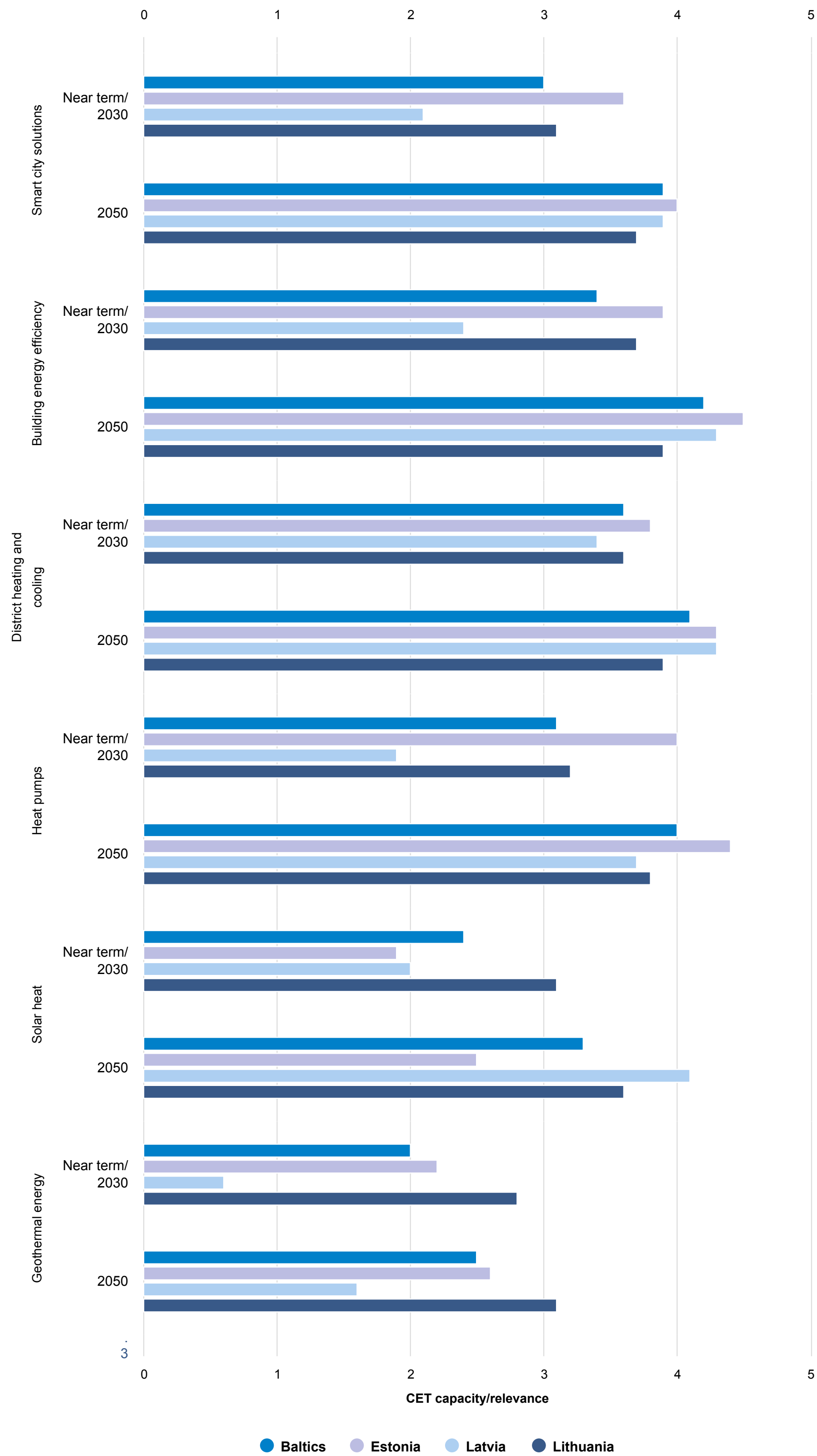
The survey results for the built environment show that the respondents consider district heating and cooling, building energy efficiency and heat pumps to be highly relevant both near term and long term, although the relevance for the latter two is increasing more between the two time perspectives. In all states, smart city solutions are also considered highly relevant for 2050, as is solar heat, although at a slightly lower level. Of the CETs specified for this category, geothermal energy is rated the lowest, in particular, it is seen as irrelevant for Latvia which is (according to survey comments) lacking a geothermal layer.

In the comments, it is also pointed out that the well-developed district heating systems are a strength for the Baltic countries, but that this, together with high electricity prices, may be a barrier to the development of heat pump technologies. The lack of citizen involvement in energy communities is also mentioned as a barrier to increasing energy efficiency.

120 Volkova A., Pieper H., Koduvere H, Lepiksaar K. and Siirde A. (2021). Heat pump potential in the Baltic states. Nordic Energy Research. Oslo, Norway. https://doi.org/10.6027/NER2021-02.

121 Elering. Synchronisation with continental Europe. https://elering.ee/en/synchronization-continental-europe. Accessed 2021-10-25.

Figure 10. Survey results for the CET category Urban and built environments.



4.7 Cross-cutting technologies

In relation to cross-cutting technologies, all three, very generalised CET technology areas identified are highly relevant to the overall development towards sustainability and there are many related ongoing initiatives in the Baltic states. These areas are important and thus included in the total picture and in the survey (see below). However, due to their broad nature, it has not been possible to map relevant stakeholder activities to the same degree as for the other areas.

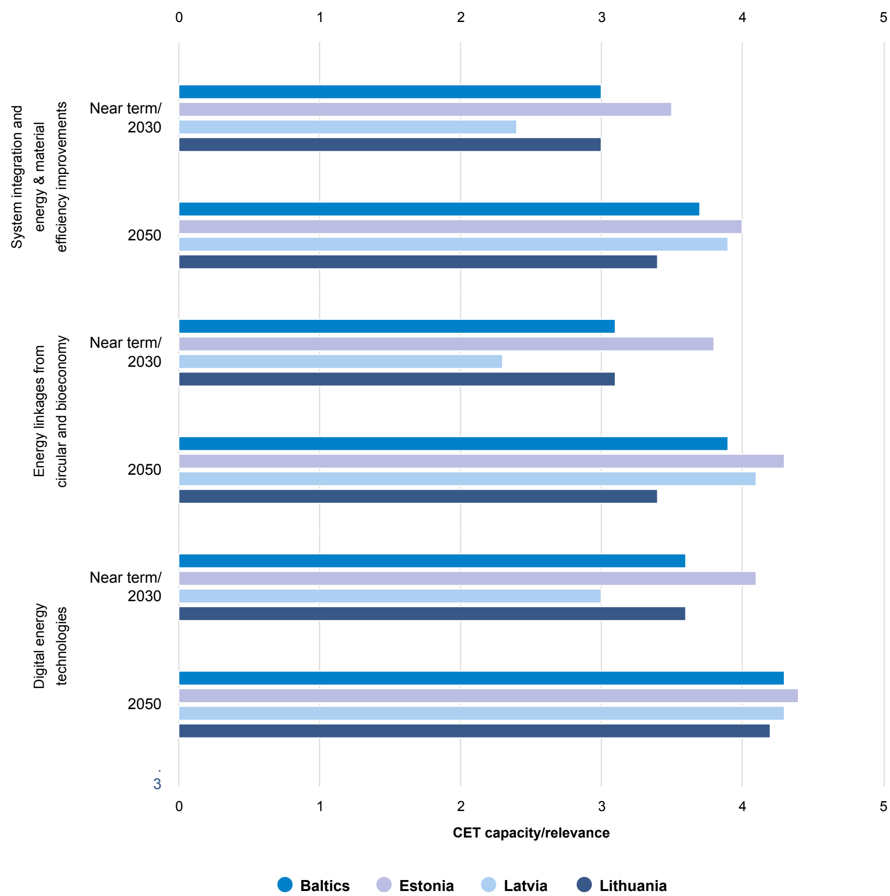
One area that is actively driven by the national TSOs relates to smart metering and digitalisation. In **Latvia**, the energy supply company Latvenergo has implemented customer service projects providing full digital service since 2018. In **Estonia**, Elering has designed and operates Estfeed, which is the first highly secure platform for exchanging private energy metering data.[122] Other aspects of digitalisation may include the potential to contribute to efficient manufacturing.[123]

There is also a strong focus and a number of recent and ongoing studies and initiatives related to the development of the bioeconomy both at a national level and in international collaboration.[124] [125]

The survey results for cross-cutting technologies indicate that all the included technology areas are estimated to be highly relevant in the longer term and show a similar pattern for all countries. Further, for both time perspectives, digital energy technologies are ranked slightly higher than the other two areas. One survey comment points out that the development of these types of cross-cutting technologies may be especially challenging for small economies, which often lack relevant industry.

122 Elering. Estfeed – Secure and legal energy data exchange. https://www.estfeed.eu/en/home. Accessed 2022-01-04.
123 Lietuvos inžinerijos ir technologijų pramonės asociacija LINPRA. https://linpra.lt/en/. Accessed 2022-01-03.
124 Tiits M., Karo.E. (2021). What will Estonia's bioeconomy look like in 2050?. Institute of Baltic Studies. https://www.ibs.ee/en/publications/what-will-estonias-bioeconomy-look-like-in-2050/. Accessed 2022-01-03.
125 BIOEASTsUP (2019). Advancing Sustainable Circular Bioeconomy in Central and Eastern European countries. Horison 2020 project. https://videszinatne.rtu.lv/en/science/project-and-research/bioeastsup/. Accessed 2022-01-03.

Figure 11: Survey results for the CET category Cross-cutting technologies.



Chapter 5

Analysis of clean energy technology challenges

PHOTOS: UNSPLASH.COM

5.1 Introduction

In this chapter, the information in Chapters 2 to 4 is summarised in terms of technology-needs matrices for the Baltic countries. The technology-needs matrices list the key relevant CET challenges that need to be addressed for transforming the energy system with respect to time frame and key national drivers and barriers, taking into account the needs and stakeholder situation described in Chapters 3 and 4. In addition, selected R&I activities that are considered most relevant for addressing the challenges in each country are included.

The R&I activities specified are used as basis for the development of the roadmap for collaborative efforts between the Baltics and the Nordic (as well as European countries), presented in Chapter 6. They are shortly described in terms of key research issues and include examples of relevant stakeholders and international R&I programmes for the activity. Note, however, that to describe the activities in detail, research expertise from each specific discipline would need to be involved.

Matrices are presented for each of the Baltic states for the time perspectives Now (roughly until late 2020s) and 2030 (roughly late 2020s towards 2040). These matrices can be found in Tables 3 to 8. Since the challenges are similar between the Baltic states (as for other regions and countries, there is also many similarities in proposed actions – and between the tables - for each respective country. To make it easier for readers with interest of one specific country, we have still chosen to include all information in each table, even though this means quite some repetition.

For the third time perspective – *2050 and beyond* – one common technology-needs matrix has been set up for all the Baltic states (Table 9). At this, more distant, point in time it is hardly feasible to define CET focus areas on a country-specific level. The energy systems in the Baltic states are expected to be more integrated by that time and, consequently, the relevant CETs and their challenges and opportunities can be expected to be similar for all three Baltic states.

For the IEA Technology Cooperation Programmes (TCP) mentioned in the tables below, the main focus has been on the ones where competence from the Baltic countries is expected to result in synergies and added value in Baltic-Nordic (or generally international) collaborations within these TCPs. In addition, TCPs that could directly help the Baltic States in addressing relevant CET challenges are mentioned.

From the Horizon Europe Work Programme on Climate, Energy and Mobility, selected already published call topics of relevance are presented to highlight focus areas to screen for future collaboration opportunities. Specific call topics that will be included in future calls are of course not known. Still, screening the funded projects within the calls could give indications on potential collaboration partners on a European level.

In the matrices, the CET focus areas have, in addition to the actual technology, been characterised by their phases of development with respect to its role in the energy system in that time period. The interpretation of the development phases is described in Table 2. Contrary to the related TRL system, the phases are meant to describe the actual deployment within the system rather than the level of technological development as such. The categorisation used covers multiple aspects of CET deployment, in a simpler way compared to the Innovation Readiness Level developed at KTH[126]. The latter describes the deployment status of innovation and covering multiple dimensions of readiness, spanning from technology, customer, IPR and business to funding readiness level.

Table 2. Development phase categorisation used in the Technology-needs matrices.

Development phase	Preparation	Establishment	Expansion	Evolution[1)]
Description	The introduction of the technology is prepared by demonstration and pilot plants, formation of industry networks and applied research.	The first installations of a technology in real life situations and at a considerable scale.	The technology has a substantial impact on the energy system, becoming large scale, and potentially replacing, or generating synergies with other technologies.	The technology is established, but regularly updated and improved, to continuously contribute to the energy system, unlocking additional synergies with new upcoming technologies.

1) The evolution phase of CETs is only mentioned in the technology-needs matrices if considered relevant for the scope of the present study. Otherwise, basically all existing CETs present at large scale at a given time would need to be categorised being in the "Evolution" phase as continuous development is expected also for mature technologies.

Please note, also, that some of the R&I activities highlighted for the time perspectives 2030 and 2050 would require actions for planning, development of collaborations and capacity building at an earlier stage.

126 KTH Innovation Readiness Level. https://kthinnovationreadinesslevel.com/. Accessed 2022-01-31.

5.2 Technology-needs matrices for Estonia (Now and 2030)

The main challenges in Estonia in the "Now" and "2030" time perspectives and CET-related R&I activities that can contribute to addressing these challenges have been identified and summed up in Tables 3 and 4, respectively. For a more extensive summary of the specific CET-related R&I actions for Estonia, please see the country annex in Appendix D. The tables are used as basis for the roadmap development and do not have the ambition to cover all aspects in detail.

Note that policy and market actions needed to accomplish the energy system transformation are not addressed, although being to some extent included as drivers (and/or barriers) for development in the tables.

In the near term, focus areas for R&I activities that are country-specific to Estonia include:

- Development and demonstration of technologies to further reduce carbon emissions from the oil shale industry, including co-combustion/pyrolysis/gasification of biomass, and studies of systems and technologies that could contribute to implementation of CCS/CCU/BECCS linked to the oil shale industry.
- Power system modelling and analysis, including the role of micro and smart grids, linked to increasing RES share in electricity production, the need for storage capacity and electricity grid integration.
- Combine focus on digitalisation, district heating/cooling and energy efficiency improvements in buildings to foster the development towards smart urban areas as part of the future integrated energy system.
- Integration of biomethane for road transport and shipping applications as well as international R&I collaboration on other advanced biofuel technologies.

For the 2030 perspective selected focus areas for R&I activities in Estonia can be:

- Integration of intermittent RES, new technologies for energy storage solutions, demand side management and distributed energy systems.
- CCU/PtX applications in connection with bioenergy and hydrogen, simultaneously unlocking potential for mitigation of emissions from remaining oil shale use and for deep decarbonisation in industry.
- Integrated local systems for energy positive buildings and built environment through increased digitalisation.
- System impact from larger scale electrification of the transport system, including charging technologies (e.g. electrical road systems) and digital solutions.

Table 3. Technology-needs matrix for Estonia for the "Now" time perspective.

Estonia – Now		
CET Focus	**Drivers and barriers**	**R&I activities**
Integrated Power and Energy Systems		
Energy distribution and transmission *Expansion* Focus on electricity and power system	+ Synchronisation with EU grid planned for 2025 + Existing and planned transmission links between Baltic and Nordic countries + TSO actively driving forward development	• Power system modelling and analysis, taking into account increasing shares of RES, including the role of micro and smart grids at Estonian and Baltic levels Competence at Taltech (project SMAGRINET), and Elering • Horizon Europe call within Energy systems, grids and storage: Energy system modelling, optimisation and planning tools; IEA The Energy Technology Systems Analysis Program (ETSAP)
Carbon Capture and Storage (CCS) *Preparation* Focus on CCS for shale oil	+ Decarbonising shale oil energy use - No domestic storage alternatives	• Efforts aiming at demonstration of technologies for implementation of CCS and CCU, especially linked to co-combustion with biomass, in the shale oil industry • Horizon Europe area Carbon capture utilisation and storage (CCUS) • Competence at Taltech, Univ. of Tartu (project ClimMIT); collaboration with SE/FI on technologies and NO on storage
Energy storage *Establishment* Focus on electricity storage	+ 500 MW pump storage plant under commissioning, + Increasing need for storage with higher RES share + Limited possible locations for hydropumping	• Applied studies on the system impact of power storage solutions, such as hydropumping. Linked to power systems R&I above • Strengthen R&I on optimised use of other decentralised storage CETs, such as batteries and hydrogen • Competence at Taltech (project ORBES)

Table 3 (continued)

Zero Emission Power Generation Technologies		
Offshore wind *Establishment* **Solar power** *Establishment* **Onshore wind** *Expansion* Focus on system integration	+ Baltic-Nordic co-operation on offshore wind initiated (BaltHub) + Reverse auctions financing subsidies for additional renewable power installation [127] + Reduce CO2 intensity in power generation - International investment projects require new agreements - Infrastructural barriers	• Applied studies of system impact from increasing shares of RES, depending on location, concentration, capacity and type of RES, based on projected capacity increase • Competence at Taltech (project BaltHub) an Univ. of Tartu (project InteGrid) • Horizon Europe area Energy systems, grids and storage • In relation technological development of RES, focus on utilisation of international development and collaborations (e.g. with Lithuania)
Other zero and low emission power production *Expansion* Focus on bioenergy applications	+ Competence, resources and infrastructure for bioenergy already established + Strong synergies in area of thermal conversion of biomass & CCS between Baltics and Nordic countries	• Applied studies of co-combustion/pyrolysis/ gasification of biomass and BECCS, linked to shale oil industry (see above) • Increase engagement in IEA TCP Bioenergy - Task 32 • Develop R&I capacity linked to Solid oxide fuel cell development (Elcogen) and demonstration activities linked to power electronics for solar power (Ubik solutions)
Low Emission Transport System		
Renewable fuels *Establishment* Focus on biomethane	+ Transport sector energy efficiency potential identified + Cohesion fund supporting biomethane use in transport + Funds from ETS supporting electric vehicles - Little to no car manufacturing industry - Competition between electrification and biogas in e.g. public transport	• R&I efforts focusing on integration of compressed and liquified biomethane in road transport and shipping, including linkages to waste handling system • Define strategic R&I focus areas in relation to other biofuel technologies and electrification of transport (see "2030" perspective) • Increased engagement in IEA TCP Bioenergy participation tasks 33, 34, 37, 39 • Relevant Horizon Europe calls: Innovative biomethane production as an energy carrier and a fuel
Electrification of transport sector *Preparation*	+ Sector most difficult to decarbonise + Transport identified as primary area for Baltic cooperation - Missing infrastructure	• System impact from larger scale electrification of the transport system, including charging technologies • Utilise extensive knowledge within digitalisation from other sectors for supporting electrification

127 Elering. Renewable Energy – Reverse auctions. https://elering.ee/en/taastuvenergia-vahempakkumine. Accessed 2022-01-03.

Table 3 (continued)

Industrial Energy Systems		
Industrial heat recovery *Expansion*	+ Industrial sector energy efficiency potential is identified - Not a primary focus of stakeholders, lack of established research infrastructure (?)	• Strengthen R&I related to Industrial heat recovery, especially in relation to processes used in chemical industry, cement production, refineries and wood processing industry • Strengthen R&I related to energy efficiency improvements in SMEs and non-energy intensive industry • Horizon Europe area Industrial facilities in the energy transition; CSA actions related to energy-efficiency in SMEs • Engage in IEA TCP on Industrial Energy-Related Technologies and Systems
Urban and Built Environments		
Building energy efficiency *Expansion* Focus on renovation processes	+Ongoing renovation wave +Strict NZEB requirements in place + ZEBE Centre of Excellence + High level of digitalisation in general - Low motivation of consumers	• Develop this national area of excellence towards zero energy and resource efficient buildings, strengthening further the focus on improving the processes for renovation of existing buildings • Competence at TalTech, Tartu and Univ of Life Sciences (ZEBE) • Horizon Europe area Highly energy efficient and climate neutral EU building stock • IEA Energy in Buildings and Communities (EBC TCP)
District heating and cooling *Evolution* **Heat Pumps** *Evolution* Focus on waste heat utilisation	+ Well-developed DH infrastructure + Bio-based CHP, but unexploited waste heat potential - High share of heat generation from biomass acts as a break for low-grade (non-fuel) heat source integration	• System oriented R&I on the use of waste heat including heat pumps by utilising the potential of 4th generation DH solutions • Competence at TalTech, DH sector • IEA TCP on District Heating and Cooling including Combined Heat and Power • IEA Heat Pumping Technology TCP
Cross-cutting Technologies		
Digital energy technologies *Establishment* Focus on digitalisation for efficiency	+ High level of digitalisation + Unlocking energy efficiency across all sectors	• Initiate R&I on the role of digitalisation for supporting total system efficiency in, e.g., a smart power system, electrification of the transport system, and energy efficient buildings • IEA TCP on International Smart Grid Action Network (ISGAN)

Table 4. Technology-needs matrix for Estonia for the 2030 time perspective.

Estonia – 2030		
CET Focus	**Drivers and barriers**	**R&I activities**
Integrated Power and Energy Systems		
Hydrogen *Establishment*	+ Increased renewable power generation - Lack of infrastructure	• Alternative technologies for hydrogen production (apart from electrolysis) • System integration of hydrogen in energy system and for energy storage • Horizon Europe, Cluster 5, Clean Hydrogen and Clean Energy Transition
Carbon capture and storage *Establishment*	+ Decarbonisation of shale oil industry and power generation necessary - No storage infrastructure for CO_2	• Development analyses related to Baltic-Nordic infrastructure for C_{O2} transport and storage • Investigating synergies between CO_2 and hydrogen in the framework of CCU, also with respect to infrastructur
Zero Emission Power Generation Technologie		
Offshore wind *Expansion* **Onshore wind** *Evolution* **Solar power** *Expansion*	+ Small energy hubs needed to realise the larger hubs in 2050 + High demand for renewable electricity from all sectors - Need for energy storage for integrating larger shares of intermittent renewables	• Solutions for integration of intermittent RES • More advanced technologies for power storage, such as batteries and hydrogen
Low Emission Transport System		
Renewable fuels *Establishment* Shift towards hydrogen & e-fuels	+ Hydrogen & CCS pushing e-fuels + Advanced biofuels technologies deployed - Lack of infrastructure	• Various biorefinery and advanced biofuel technologies, also linkages to bioeconomy • Alternative technologies for hydrogen production (apart from electrolysis) • Biofuels in transport sector hard to electrify (shipping/aviation)
Electrification of transport sector *Establishment*	+ Synergies with more flexible power system/smart charging + Energy efficiency in transport - Lack of infrastructure	• System impact from larger scale electrification of the transport system, including the charging technologies • Implementation of digitalisation efforts for supporting electrification and efficiency improvements in the transport system

Table 4 (continued)

Industrial Energy Systems		
Clean process technologies/ Electrification/ Biobased technologie*s* *Expansion*	+ Energy intensity of industries will decrease + Large fraction of waste heat potential used	• Deep decarbonisation of industrial processes, including potential CCS and CCU technologies and their linkages • Increasing efforts on electrification of industrial processes • IEA TCP on Heat Pump Technology – Industrial applications
Urban and Built Environments		
Smart city solutions *Expansion*	+ High potential for continuing the development towards low emissions in the built environment	• Integrated and digitised local systems for energy positive buildings and built environment through increased digitalisation • Continued R&I on large-scale use of heat pumps in district heating, also addressing potential use of heat pumps for electrification in industry
Cross-cutting Technologies		
Digital energy technologies *Expansion*	+ With increased renewables, demand will increase for smart digital solutions + Digitalised energy consumption measurements established, allowing for advanced demand-response control	• Integrated in other CET areas above

5.3 Technology-needs matrices for Latvia (Now and 2030)

The main challenges in Latvia in the "Now" and "2030" time perspectives and CET-related R&I activities that can contribute to addressing these challenges have been identified and summed up in Tables 5 and 6, respectively. For a more extensive summary of the specific CET-related R&I actions for Latvia, please see the country annex in Appendix D. The tables are used as basis for the roadmap development and do not have the ambition to cover all aspects in detail.

Note that policy and market actions needed to accomplish the system transformation are not addressed, although being to some extent included as drivers (and/or barriers) for development in the tables.

In the near term, focus areas for R&I activities that are country-specific to Latvia include:

- Power systems modelling and analysis, taking into account increasing shares of intermittent RES and utilisation of hydropower for balancing and storage.
- Continued R&I related to systems aspects in the natural gas system, including the role for gas storage and greening of the supply through blending with biogas, and increasing focus on the role of hydrogen in such a system.
- Integration of compressed and liquefied biomethane for use in road transport and shipping in the Latvian system and on system linkages with the waste handling system.
- Initiate R&I efforts to follow-up on the impact and experience from recent hydrogen initiatives.
- Continue and strengthen R&I focusing on energy efficiency in buildings and on the development of smart and sustainable urban environments.

For the 2030 perspective selected focus areas for R&I activities in Latvia can be:

- System and technology-oriented R&I related to the integration of hydrogen in the overall power and energy system, the transition of NG system into a zero emission gas system and the role of hydro power for balancing.
- Various biorefinery and advanced biofuel technologies, also linked to the wood processing industry and R&I on energy linkages from the development of a bioeconomy.
- System impact from larger scale electrification of the transport system, including charging technologies (e.g. electrical road systems) and digital solutions.

Table 5. Technology-needs matrix for Latvia for the "Now" time perspective.

Latvia– Now		
CET Focus	**Drivers and barriers**	**R&I activities**
Integrated Power and Energy Systems		
Energy distribution and transmission *Expansion* Focus on electricity and power system	+ Synchronisation with EU grid planned for 2025 + Hydropower capacity + Existing and planned transmission links between Baltic and Nordic/EU countries + TSO actively pushing development	• Power system modelling and analysis, taking into account increasing shares of RES and utilisation of hydropower for balancing and storage at Latvian and Baltic levels • Competence at AST, but Latvian research infrastructure in the area may need to be strengthened, e.g,. linked to IESE energy systems competence at RTU (e.g. Flex4RES project) • Horizon Europe call within Energy systems, grids and storage: Energy system modelling, optimisation and planning tools; IEA The Energy Technology Systems Analysis Program (ETSAP)
Renewable hydrogen/Energy storage *Preparation* Focus on natural gas system	+ Developed natural gas infrastructure, incl. NG underground storage and power generation + Active hydrogen association	• Studies of the role for gas storage and greening of the supply through blending with biogas in the natural gas system, including the role of hydrogen in the longer term. • Competence at RTU (IESE, incl. project Flex4RES) • Horizon Europe, Cluster 5, Clean Hydrogen and Clean Energy Transition
Zero Emission Power Generation Technologie		
Offshore wind *Establishment* **Onshore wind** *Expansion* Focus on system integration	+ Baltic-Nordic co-operation initiated - International projects requiring new agreements - Getting infrastructure in place - Latvia somewhat lagging in development in relation to other Baltic countries	• Investigate possibilities to increase involvement in applied studies of system impact from increasing shares of RES, e.g. through Baltic or Baltic-Nordic collaborations • Potential area for competence development • Horizon Europe area Energy systems, grids and storage • In relation to R&I for technological development of RES, focus on strategic actions to follow and utilise international developments, and on collaborations (e.g. with Lithuania)

Table 5 (continued)

Biomass CHP **Expansion/Evolution**	+ Large biomass potential, and long tradition of bio-based power generation + Linkages to the development of the bioeconomy, which is included in the national RIS3 strategy	• Horizon call area: Industrial facilities in the energy transition (e.g. addressing low temperature heat use in organic Rankine cycles, thermal storage etc.)
	Low Emission Transport System	
Renewable fuels *Establishment* Focus on biomethane and **the introduction of hydrogen**	+ Biogas potential, NG underground storage + H_2 buses in public transport + H_2 alternative for decarbonising railway transport system without extensive need for electricity infrastructure + Sector most difficult to decarbonise - Little to no car manufacturing industry - Competition between electrification and biogas in e.g. public transport	• R&I efforts focusing on integration of compressed and liquified biomethane and hydrogen in road transport and shipping, including linkages to waste handling system • Initiate R&I to follow up on the impact and experience from recent hydrogen initiatives • Competence at IESE at RTU • Define strategic R&I focus areas in relation to other biofuel technologies and electrification of transport (see "2030" perspective) • Increased engagement in IEA TCP Bioenergy participation tasks 33, 34, 37, 39 • Relevant Horizon Europe calls: Innovative biomethane production as an energy carrier and a fuel
Electrification of transport sector *Preparation*	+ Sector most difficult to decarbonise + Transport identified as primary area for Baltic cooperation - Missing infrastructure	• System impact from larger scale electrification of the transport system, including the charging technologies
	Industrial Energy Systems	
Industrial heat recovery *Expansion*	+ Industrial sector energy efficiency potential is identified + Heating and cooling strategy developed at RTU, also addressing industry heat supply and industrial waste heat potential - Not a primary focus of stakeholders, lack of established research infrastructure (?)	• Strengthen R&I related to Industrial heat recovery, especially in relation to processes used in wood processing and cement production • Strengthen R&I related to energy efficiency improvements in SMEs and non-energy intensive industry • Horizon Europe area Industrial facilities in the energy transition; CSA actions related to energy-efficiency in SMEs • Engage in IEA TCP on Industrial Energy-Related Technologies and Systems

Table 5 (continued)

Urban and Built Environments		
Building energy efficiency *Expansion* Focus on renovation processes	+ Ongoing renovation wave + Large focus on energy efficiency - Large amount of old multi-family buildings - Low motivation of consumers	• Continue and strengthen R&I on smart and sustainable cities and regions and on improving the processes for renovation of existing buildings • Competence at IESE at RTU (e.g. SUNSHINE projects) • Horizon Europe area Highly energy efficient and climate neutral EU building stock • IEA Energy in Buildings and Communities (EBC TCP)
District heating and cooling *Evolution* **Heat Pumps** *Evolution* Focus on waste heat utilisation	+ Well-developed DH infrastructure + Increasing share of DH from biomass expected, but unexploited waste heat potential + Solar heat to DH demo plant	• System oriented R&I on integration of solar and waste heat, including heat pumps and 4th generationDH and district cooling solutions • Competence at IESE at RTU, DH sector • IEA TCP on District Heating and Cooling including Combined Heat and Power • IEA Heat Pumping Technology TCP
Cross-cutting Technologies		
Digital energy technologies *Preparation* Focus on digitalisation for efficiency	+ TSO (Latvenergo) ongoing projects related to smart metering and digitalisation + Unlocking energy efficiency across all sectors	• Initiate R&I on the role of digitalisation for supporting total system efficiency in, e.g., a smart power system and electrification of transport • Increase R&I related to energy linkages from the development of both bio- and circular economy • IEA TCP on International Smart Grid Action Network (ISGAN)

Table 6. Technology-needs matrix for Latvia for the 2030 time perspective.

Latvia – 2030		
CET Focus	**Drivers and barriers**	**R&I activities**
	Integrated Power and Energy Systems	
Hydrogen *Establishment*	+ Strong in natural gas (blue H2, biogas, green H2 as potential tracks) + Larger share of RES in power supply + Electrification of railway transport with fuel cell technology as alternative for building electric power supply infrastructure	• Develop transition of NG system into a zero emission gas system as strategic national R&I area • Build on RTU system study competence • Horizon Europe, Cluster 5, Clean Hydrogen and Clean Energy Transition
	Zero Emission Power Generation Technologie	
Offshore wind *Expansion* **Onshore wind** *Evolution* **Solar powe**r *Establishment*	+ Small energy hubs needed to realise the larger hubs in 2050 + High demand for renewable electricity from all sectors + High demand for renewable electricity from all sectors - Already high share of renewables in power system - Need for energy storage for integrating larger shares of intermittent renewables	• Solutions for integration of intermittent RES • More advanced technologies for power storage, such as batteries and hydrogen • Development of distributed energy systems
	Low Emission Transport System	
Renewable fuels *Expansion*	+ Hydrogen & CCS pushing e-fuels + Advanced biofuels technologies deployed - Lack of infrastructure	• R&I on biorefinery and biofuel technologies, linked to wood processing industry – integrated focus area with Industrial energy systems and cross-cutting technologies
Electrification of transport sector *Establisment*	+ Synergies with more flexible power system/smart charging + Energy efficiency in transport - Lack of infrastructure	• R&I on system impact from larger scale electrification, including charging technologies (e.g. electrical road systems) – linked with power system and digitalisation

Table 6 (continued)

Industrial Energy Systems		
Bioeconomy *Establishment*	+ Biomass resources + Established wood processing and biobased industry as well as infrastructure for use of bioenergy	• Deep decarbonisation of industrial processes, including potential CCS and CCU technologies and their linkages • Increasing efforts on electrification of industrial processes • IEA TCP on Heat Pump Technology – Industrial applicationsr
Urban and Built Environments		
Smart city solutions *Expansion*	+ High potential for continuing the development towards low emissions in the built environment	• Focus on technical solutions and system integration of local systems (heating, transport, power production and storage) for energy positive buildings and built environment through increased digitalisation
Cross-cutting Technologies		
Digital energy technologies *Establishment*	+ With increased renewables, demand will increase for smart digital solutions	• R&I related to energy linkages from the development of both bio- and circular economy

5.4 Technology-needs matrices for Lithuania (Now and 2030)

The main challenges in Lithuania in the "Now" and "2030" time perspective and CET-related R&I activities that can contribute to addressing these challenges have been identified and summed up in Tables 7 and 8, respectively. For a more extensive summary of the specific CET-related R&I actions for Lithuania, please see the country annex in Appendix D. The tables are used as basis for the roadmap development and do not have the ambition to cover all aspects in detail.

Note that policy and market actions needed to accomplish the system transformation are not addressed, although being to some extent included as drivers (and/or barriers) for development in the tables.

In the near term, focus areas for R&I activities that are country-specific to Lithuania include:

- Further development of wind power – both on- and offshore – to increase domestic power generation, focus on collaborative efforts should be on system level aspects related to infrastructure development, power system for integration with high shares of intermittent power generation, and energy storage (e.g., related to planned battery project).
- Further development of solar PV technology, from a technological perspective with respect to material and manufacturing aspects.
- Further strengthening of the strong stakeholder infrastructure within building energy efficiency and district heating, moving R&I focus towards smart city solutions.
- Building on the natural gas infrastructure and stakeholders to increase R&I related to the generation of biofuels, in particular biomethane, as well as the introduction of hydrogen for transport and industry applications.

For the 2030 perspective selected focus areas for R&I activities in Lithuania can be:

- Hydrogen as part of the solution for integrating large shares of renewable energy; both infrastructural aspects (building on natural gas experience) and production & storage aspects.
- Alternative technologies for hydrogen production (apart from electrolysis) and offshore hydrogen production at wind farms primarily via international collaborative efforts.
- Smart city solutions making use of digitalisation technology and integration of PV in buildings as well as safety aspects of these solutions.
- Heat pumps at large scale and at higher temperature levels, fostering both increased electrification/decarbonisation of industry and increased energy efficiency in the building sector.

Table 7. Technology-needs matrix for Lithuania for the "Now" time perspective.

Lithuania– Now		
CET Focus	**Drivers and barriers**	**R&I activities**
Integrated Power and Energy Systems		
Hydrogen *Preparation*	+ Natural gas infrastructure & stakeholders aiming to "greening the grid" (Ambergrid, Litgrid) + Lithuanian hydrogen platform + Center for Hydrogen Energy at LEI - Lack of infrastructure	• R&I in power systems development • Active contribution in IEA TCP Hydrogen – Task 40: Energy Storage and Conversion Based on Hydrogen • Contribute to task "Renewable Hydrogen" (under definition) within IEA TCP Hydrogen (LEI, KTU, Lithuanian Hydrogen Platform)
Batteries for use in energy systems *Establishment*	+ Battery storage project in HV network	• R&I in balancing the system through storage solutions • Horizon Europe call examples: Interoperable solutions for flexibility services using distributed energy storage; Demonstrating offshore production of green hydrogen (linked to Offshore wind power generation)
Zero Emission Power Generation Technologie		
Offshore wind *Establishment* **Onshore wind** *Expansion*	+ 700 MW approved for 2030, may become larger - International projects requiring new agreements - Getting infrastructure in place	• R&I directed towards solutions for integration of large shares of intermittent RES • Build on BaltHub project • IEA Wind TCP
Solar power *Establishment*	+ Large PV panel producer + Possibilities to invest in PV parks as a private person	• Further development of solar PV technologies, building on the industrial and research infrastructure in place (KTU, Protech, SoliTek) • IEA TCP Photovoltaic Power Systems (PVPS) • Engage in international PV material research collaborations; relevant Horizon Europe call example: Novel tandem, high efficiency Photovoltaic technologies targeting low-cost production with earth abundant materials (call closed)

Table 7 (continued)

	Low Emission Transport System	
Renewable fuels for transport *Establishment* **Electrification of transport sector** *Preparation*	+ Sector most difficult to decarbonise - Lack of infrastructure	• Match research on sustainable transport at VilniusTech with complementing elements (biofuels/electrification) in Baltics/Nordics/EU • IEA TCP Hybrid and Electric Vehicles
	Industrial Energy Systems	
Industrial heat recovery *Expansion*	+ Heat recovery for electricity generation (ORC) initiatives	• Initiate a stronger focus on increasing energy efficiency in industry • Strengthen R&I related to deep decarbonisation of industrial processes, primarily linked to the chemical industry • IEA TCP Industrial Energy-Related Technologies and Systems
	Urban and Built Environments	
District heating and cooling *Evolution*	+ LEI involved in Nordic projects + 5th gen of DH networks being developed - High share of heat generation from biomass acts as a break for low-grade (non-fuel) heat sources integration	• Investigate the potential of digitalisation as a tool for an energy-efficient building sector • IEA TCP District Heating and cooling, Task/Annex examples: Optimised transition towards low-temperature and low-carbon DH systems (OPTiTRANS), Integration of Renewable Energy Sources into existing District Heating and Cooling Systems
Smart city solutions *Establishment*	+ Prosumers initiatives started (often linked to PV panels) + Existing research environments	• Build on existing centres/research activities at VilniusTech and KTU • Integration of PV in buildings (IEA TCP PVPS – Task 15)
	Cross-cutting Technologies	
Digital energy technologies *Preparation*	+ Smart digitalisation centre	• Investigate the potential of digitalisation as a tool for an energy-efficient building sector

Table 8. Technology-needs matrix for Lithuania for the 2030 time perspective.

Lithuania – 2030		
CET Focus	**Drivers and barriers**	**R&I activities**
Integrated Power and Energy Systems		
Hydrogen *Establishment*	+ Increased share of intermittent renewable power production, increasing the need for energy storage + Potential CO2 reductions in hard-to-abate sectors - Lack of infrastructure - Low system efficiency	• R&I efforts related to integration of hydrogen, for which there are several stakeholders in Lithuania, in the overall power and energy system • Alternative technologies for hydrogen production (apart from electrolysers) and on system aspects, including storage, transmission and distribution, of larger scale use of hydrogen in the transport system • Potential IEA TCP Hydrogen tasks: Offshore Hydrogen Production, Renewable Hydrogen
Zero Emission Power Generation Technologie		
Offshore wind *Expansion* **Solar power** *Establishment*	+ Small energy hubs needed to realise the larger hubs in 2050 + High demand for renewable electricity from all sectors + Solid foundation in PV sector + New material developments - Need for energy storage for integrating larger shares of intermittent renewables	• IEA TCP Energy Storage • IEA Wind TCP, task examples: Airborne Wind energy, • Addressing material and recycling aspects (TCP Wind task 45) • IEA TCP PVPS – PV Grid Integration (Task 14)
Low Emission Transport System		
Electrification of transport sector *Establishment*	+ Synergies with more flexible power system/smart charging - Lack of infrastructure	• PV-powered vehicles (IEA TCP PVPS)
Industrial Energy Systems		
Electrification of industrial processes *Establishment*	+ Deep decarbonisation of industrial processes + Stronger focus on increasing energy efficiency in industry	• High-Temperature Heat Pumps

Table 8 (continued)

Urban and Built Environments		
District heating and cooling *Evolution* **Smart city solutions** *Expansion*	+ Large-scale use of heat pumps in district heating, and their impact on the power system + Established research environments	• IEA TCP Heat pumps • Integrated local systems (heating, transport, power production and storage) for energy positive buildings and built environment • R&I aiming at benefitting from the potential through digitalisation in the building sector • PV in buildings – IEA TCP PVPS Task 15
Cross-cutting Technologies		
Digital energy technologies *Establishment*	+ With increased renewables, demand will increase for smart digital solutions	• Safety aspects of digital solution • Applied AI for unlocking energy efficiency potential

5.5 Technology-needs matrix for the Baltic states – 2050 and beyond

In the long-term time perspective "2050", which denotes the period from around 2040 to 2050 and beyond, the energy system should have gone through a major transition towards sustainability, and technologies that are currently at low TRL could potentially have been implemented. In this time perspective, as noted above, the relevant CETs and their challenges and opportunities can be expected to be similar for all three Baltic states, which is why the analysis is made for all states together. By this time, the overarching driver for the development is, regardless of currently defined national targets, to reach a sustainable and fossil-free system with zero (or very low) GHG emissions. There will of course still be specific barriers to this development at that time. However, it is impossible to say what those barriers will be. In addition, the existence of current stakeholders and R&I expertise is of less relevance.

In this time perspective, the focus has therefore been set entirely on identifying technologies that are currently at low TRL (maximum TRL 5) and are expected to be especially relevant in the Baltic context towards that time. For these early technologies, there is naturally a high level of uncertainty as to what specific CETs will actually be relevant, and in most cases we therefore describe a type of technology, including more specific examples.

As a background, a few key system developments in the 2050 perspective, primarily based on the BENTE study, can be summarised as:

+ Strong electrification throughout the system, leading to increasing electricity demands, which requires CET development in relation to

- More surface efficient, resource efficient and lower cost RES power production.
- Integrational systems, including e.g. offshore wind energy hubs, hydrogen production and storage solutions.

+ Hydrogen can develop as an important part of the energy system, which is then linked to CET development in relation to

- More efficient, lower cost, hydrogen production technologies.
- Power-to-X, for the production of electrofuels but also chemicals and other materials.
- Technological solutions for storage and transport of hydrogen.
- Adaptation of industrial processes for use of hydrogen.
- Hydrogen-driven vehicles.

+ Continued importance of integrated and efficient district heating systems, which in the BENTE study are strongly linked to

- The use of efficient, large-scale heat pumps, which utilise also sea and river water as heat source.

+ Continued importance of advanced and efficiently produced biofuels for use in heavy vehicles, airplanes and shipping.
+ A strong shift to electric vehicles in the transport sector, which is linked to CET development in relation to

- Electric vehicles and efficient, energy-dense battery technologies.
- Infrastructure and fast-charging technologies.

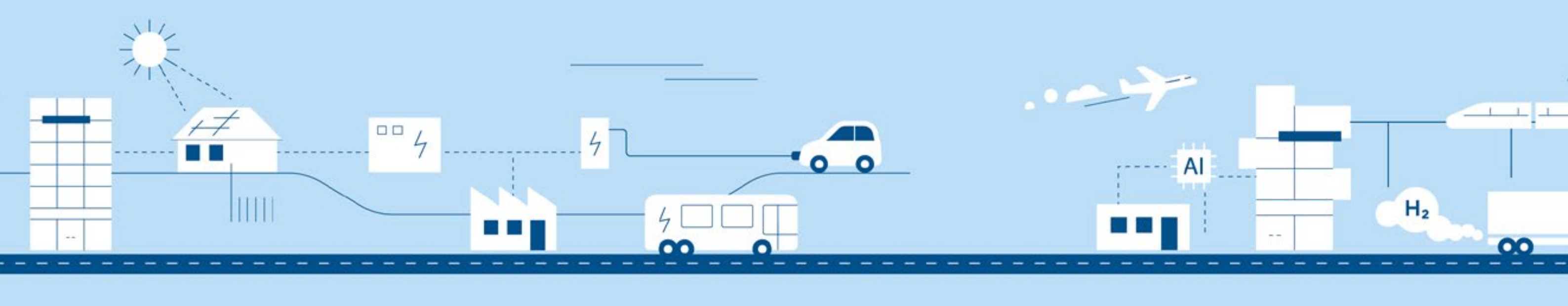
+ CCS technologies, primarily to reduce emissions from cement and ammonia production.
+ Continued efforts to increase and maintain high material and energy efficiency throughout the system.

Table 9. Technology-needs matrix for the Baltic states for the 2050 time perspective and beyond

Baltic states – 2050 and beyond	
CET Focus	**Examples of potentially relevant CETs, currently at low TRL**
Integrated Power and Energy Systems	
Hydrogen *Expansion*	+ Hydrogen for high-temperature heat in e.g. aluminium industry
Carbon capture and storage *Expansion*	+ Direct air capture (solid or liquid) + Mineral storage of CO_2 in rock formations + CO_2 shipping infrastructure, e.g. port-to-offshore
Carbon capture and utilisation/ Power-to-X *Expansion*	+ Carbon recycled feedstock for industry (& transport fuels)
Zero Emission Power Generation Technologie	
Solar power *Expansion*	+ Perovskite solar cells and/or other advanced photovoltaic technologies
Offshore and onshore wind *Expansion*	+ Airborne wind energy systems + Floating hybrid energy platforms
Low Emission Transport System	
Electrification of transports sector *Expansion*	+Battery recycling: – Automatic battery recycling blockchain to track batteries, collaborative human-robot recycling +Inductive battery charging +Hyperloop and other advanced transport technologies
Industrial Energy Systems	
Bio-based industrial processes *Expansion*	+ Strong reduction of biomass demand from power and heating sector + Industrial biomass use – biore-finery solutions + Lignin extraction + Thermal biomass conversion (gasification, thermal liquefaction)
Urban and Built Environments	
Smart city solutions *Expansion*	- Digitalisation / Prosumer concept and regional energy planning taking a prominent role in the energy system
Cross-cutting Technologies	
System integration and energy & material efficiency improvements *Expansion*	+ Digital energy technologies, renewables and smart power grid will allow for increased synergies/benefits through system integration

Chapter 6

Roadmap for Baltic-Nordic energy research collaboration



6.1 Introduction

The basis for the developed roadmap is the information on CETs, needs and stakeholders, collected and structured above, and summarised in the technology-needs matrices. However, to develop the roadmap for Nordic-Baltic collaboration in relation to these matrices, data is also needed on the Nordic relevance in relation to the identified CETs. Therefore, the first section of this chapter includes an overview of the Nordic energy perspective. This overview is centred around the outcomes of the recently published NCES report, accounting mainly for CETs also identified as relevant from the Baltic perspective.

With this added input, a Baltic-Nordic Roadmap for co-operation on CETs has then been developed. The roadmap describes the potential for Baltic-Nordic collaboration to catalyse the efforts for the Baltic and Nordic countries for increasing green export, further development of CETs and achieving climate and energy targets.

It should be possible to use this roadmap to plan collaborative activities, for instance within the Nordic Energy Research framework. As described under Purpose and method, the roadmap is developed under specified overarching economic and policy assumptions, but not linked to any comprehensive scenario development.

6.2 Nordic energy perspective

In general, areas that are highly relevant on a European/Nordic scale also ensure a broader long-term market for technology developers and industry. In addition, at the Nordic level, key developments provide necessary conditions for potential Baltic-Nordic collaboration. At the Nordic level, there is a broad range of stakeholders and research and innovation activities, covering most of the CET categories included in Figure 2, but to a different extent. A detailed description of the Nordic situation is, however, beyond the scope of this study. Further, Baltic-Nordic collaboration requires active stakeholders in both regions.

The NCES report[128] gives a holistic view on the energy system development necessary to achieve climate goals. The near-term actions as well as the developments proposed in a medium-/long-term perspective also identify collaboration among the Nordic countries as a key action. These proposed collaborations have the potential to be extended to become Baltic-Nordic

128 Nordic Energy Research (2021). Nordic Clean Energy Scenarios – Solutions for Carbon Neutrality. Nordic Council of Ministers. Copenhagen, Denmark. http://doi.org/10.6027/NER2021-01.

collaboration. The proposed actions for Nordic collaboration, as well as for the five solution tracks identified by NCES, constitute highly relevant input to the roadmap and are therefore summarised in Table 10.

Table 10. "No-regret actions" according to the Nordic Clean Energy Scenariosreport.[129]

Area	No-regret actions		
Direct electrification	Roll out vehicle charging infrastructure and continue incentivising electric vehicles (EVs); over time, shift the focus from personal EVs towards heavier vehicles	Replace fossil boilers and direct electric household heating with heat pumps	Ensure that regulation supports use of waste heat from industry, data centres and other sources
P2X – a potential game changer	Demonstrate PtX technologies in real operating environments	Strategically locate PtX production and RE refineries in proximity to strong power grids and district heating networks to minimise infrastruc-ture cost and maximise energy efficiency	Develop a roadmap for a Nordic hydrogen infrastructure that considers both green and blue hydrogen
Bioenergy	Ensure that mainly waste, wood waste and forest industry residues are used for bioenergy applications	Ensure adequate biofuel blending requirements in the Nordic countries, including increased mandates for advanced biofuels	Increase and prioritise efforts to produce fossil free aviation fuels
CCS incl. BECCS	Establish clear national positions in support of CCS technologies to build long-term market confidence	Launch initiatives to create economic incentives for negative emissions	Coordinate infra-structure development to reduce investor risk and entry barriers for individual actors
Nordic collaboration	Strengthen joint Nordic action plans for infrastructure needs and development	Develop a joint Nordic roadmap for the role of PtX, including identification of the most promising sites for production in the Nordics	Develop a joint Nordic CCS strategy to increase the potential to realise economies of scale in transport and storage of captured carbon

129 Nordic Energy Research (2021). Nordic Clean Energy Scenarios – Solutions for Carbon Neutrality. Nordic Council of Ministers. Copenhagen, Denmark. http://doi.org/10.6027/NER2021-01.

In relation to the actions to strengthen Nordic collaboration, the differences between the individual countries' energy systems are considered a strength, while the development of necessary infrastructure emerges as a major coordination challenge in all NCES scenarios.

Critical near-term actions from a Nordic energy system perspective
Stronger grids, increased flexibility, wind and solar electricity deployment, electrification of transport, and CCS technologies are vital to all NCES scenarios. Existing solutions, such as bioenergy and district heating, continue to be important, while innovative market developments can unlock the potential of both emerging and existing technologies. Energy demand reduction through efficiency improvements (and behavioural change) will make policy targets easier and less costly to reach. From a Nordic perspective, near-term collaboration efforts are expected to include:

+ Reforming grid planning to enable shorter lead times and more proactive expansion, while looking for system-smart local solutions that can reduce grid capacity needs.

+ Ensuring that electricity markets are designed to incentivise investments aligned with decarbonisation targets as well as other policy objectives such as energy security.

+ Accelerating public investments in research, development, demonstration and deployment RD&D, including in CCS technologies, biorefining and PtX.

6.3 Roadmap

While previous chapters described CET challenges and potential R&I activities in the Baltic countries, the roadmap below focuses entirely on actions especially relevant for Baltic-Nordic collaboration. The development of actions to include has followed the following logic:

- The actions should answer to challenges common to both the Baltic and Nordic countries. In addition, actions that relate to CETs that are especially relevant for the Baltics have been prioritised.

- For near-term actions focusing on facilitating CET deployment (see below), the focus is put on CETs for which there are relevant stakeholders with a high level of expertise in the Baltics.

- However, for actions further into the future and actions focusing rather on capacity-building or exploring potentials, the current level of CET competence and activity is less critical. On the contrary, in areas for which there are extensive experience and expertise in one country or region, but less so in another, collaboration may be especially valuable for capacity-building.

Based on this logic, **three types of actions are included in the roadmap:**

1. **Continued and further strengthening of already initiated collaboration areas (A-level)**, aiming at facilitating shorter-term (further) deployment and implementation of the CET in the Baltic energy system.
2. **Initiation of new collaboration areas (B-level)**, aiming at collaborative research advancing the development of the CET and increasing of the shared knowledge base and/or capacity-building in the Baltic states.
3. **Exploratory actions (C-level)**, aiming at further defining the potential of the CET/group of CETs in the Baltic context, the development status of alternative technology pathways and R&I needs, or competence profiles of potential stakeholders to involve in new collaborations.

Over the time span of the roadmap, collaboration actions related to a specific CET or group of CETs, would then naturally move from *exploratory actions* (C) *to initiation of new collaboration areas* (B) and eventually to *further strengthening of already initiated collaboration areas* (A), depending on the starting point of the CET and the result of the previous action. In addition, relevant stakeholders in the collaborations move from primarily R&I actors to an increasing involvement of market actors.

Furthermore, the proposed roadmap is directly impacted by the societal development towards continuously increasing integration between sectors and strategies for increasing sustainability (such as energy system development, climate strategies, resource efficiency and circular economy), which results in a collaboration areas that are subsequently broader and more complex in nature.

The described areas for collaboration could be implemented through different types of actions by a range of different stakeholders, including, for instance, projects initiated by Nordic Energy Research, bilateral collaborations or development of joint consortia for participating in EU projects or IEA Technology Collaboration Programmes. Further work is needed, directly by involved parties, to determine the most suitable arenas. In the roadmap description below (Table 11 and Table 12), an indication of potential arenas for collaborations is nevertheless included for some of the areas.

A simplified graphic representation of the roadmap is given in a separate factsheet accompanying the present report.

6.3.1 Areas for Baltic-Nordic collaboration in the "Now" time perspective

In the very near term, Baltic-Nordic collaboration should partly build on already initiated collaborations and partly aim at starting up new areas, with a view towards the needs in the 2030 time frame.

The most central CET categories relevant for Baltic-Nordic collaboration at present are *Integrated power and energy systems and Urban and built* *environment* with several already ongoing collaborations within the Joint Baltic-Nordic Energy Research Programme.[130]

The power transmission infrastructure is vital for ensuring efficient and secure integration of renewable power generation. Collaborations within the area of integrated power and energy systems will also be important with regard to establishing a solid foundation for the development of a hydrogen economy in the Baltic-Nordic region in the longer-term.

In terms of *Urban and built environment*, highly relevant collaborations include both continued efforts on increasing the energy efficiency in buildings and the efficient utilisation of waste heat in the district heating systems. For both these areas, there are important system similarities between the Baltics and Nordics, and both regions have R&I environments of high excellence.

All proposed areas for collaboration at the "A level" (seeTable 11), and one at the "B level", are therefore focusing on these two CET categories.

Another area for which it would be relevant to initiate new or strongly intensified collaborations relate to the advanced utilisation of biomass for energy and bioproducts and to industrial energy systems, since especially the Baltic countries, Finland and Sweden have substantial biomass potential and extensive experience from bio-based industry, which should contribute to potentially high benefits from collaboration.

Finally, electrification of private transport – especially research issues related to the development of infrastructure, charging systems and other supporting systems - has been identified as a potential new collaboration area in the shorter time frame between the Baltics and especially Sweden, given the strong Swedish research environments resulting from the interaction with Swedish vehicle and evolving battery industry.

Proposed exploratory actions relate to areas for which it would be relevant to prepare for the strengthening of future collaborations. Based on the needs for capacity-building and technology transfer, four areas of collaboration at the "C level" have been chosen for the near term:

- Baltic-Nordic implementation of CCS and CCU, with the purpose of exploring potential applications, technologies and storage options in the Baltic context, and their linkages to other systems developments in industry, the power sector and for transport fuels.
- Digitalisation in the energy system, further exploring the most relevant areas to utilise digitalisation strategies for the transition towards zero GHG emissions in the longer term.

130 Nordic Energy Research (2020). Three projects launched to address common Baltic-Nordic energy challenges. Joint Baltic-Nordic Energy Research Programme. https://www.nordicenergy.org/article/jbnerp-first-call-completed/. Accessed 2022-01-03.

- Deep decarbonisation of industrial processes, focusing on processes relevant for energy-intensive industry sectors common to both the Baltics and the Nordic countries.
- The potential role of distributed energy systems, including local PV and power storage solutions, in the development of an integrated and stable power system.

Table 11. Major opportunities for Baltic-Nordic collaboration on CETs in the very near term (Now), including examples of stakeholders to involve, as well as market opportunities motivating the collaboration. For more detailed information about international research programmes and stakeholders, see Chapters 2 and 4, Appendix B and Table 20 in Appendix D.

Type	Area of collaboration	Type and examples of stakeholders/projects	Market opportunities (potential arenas for collaboration)
A	**Sustainable and integrated power systems** + Large-scale power storage + Distribution grid infrastructure and Baltic-Nordic interconnections	+ Baltic (TalTech, RTU, KTU and LEI) and Nordic (VTT, Chalmers etc) power systems research + TSOs in the Baltics (Elering, AST and Litgrid) + TSOs and energy companies in Nordic countries (especially FI, SE)	System solutions, including storage, in relation to high level of RES and electrification highly relevant on Baltic, Nordic and European level.
	Large-scale deployment of offshore wind power + Building on on-going BaltHub project + Link to offshore wind power generation experience from North Sea Hub projects	+ Current participants in BaltHub (e.g. DTU, KTU and TalTech) and other research groups + TSOs in the Baltic countries + Energy islands (DK), Vatten-fall (SE), Fortum (FI/SE) + Power and wind power development industry (e.g. Ørsted)	Contribute to extending joint Nordic action plans for infrastructure needs and development proposed by NCES to cover the Baltic-Nordic region. (Continuing/broadening NER projects).
	Zero emission buildings + Extending existing collaboration on NZEBs + Extending heat pump collaborations + Digitalisation / Smart buildings	+ ZEBE Centre of Excellence (EE), RTU (LV), KTU (LI) and other Baltic research + Nordic research; AU (DK), Chalmers (SE) etc. + Building and real estate industry, e.g. via networks like BeBo/BeLOK (SE) + District heating industry	Large renovation demand and tough legal requirements on building energy demand in Baltic states. Relevant also on European level. (NER projects or common participation in EU projects.)
B	**Efficient industrial waste heat utilisation in district heating** + Investigating potential for industrial waste heat utilisation, including process integration + Heat pumps and thermal storage	+ Baltic district heating/energy systems research (e.g. TalTech, RTU) + Lifosa plant (LT) + Nordic and industrial system research (e.g., Chalmers) + District heating industry + Baltic process industry	Potential for increasing utilisation of industrial waste heat potential in Baltic states, by building on experience in SE/FI. (Collaboration via IEA TPA IETS).
	Future biorefineries for the bioeconomy + Baltic-Nordic case studies of biorefinery solutions for the production of both biofuels and biomaterials	+ Baltic bioenergy research (RTU) + Nordic research in biorefineries/bioeconomy (SE/FI/NO) + Pulp and paper and wood processing industry, biorefinery clusters (SE/FI/NO and Baltics)	Large biomass potential, established industry infrastructure and potential for increasing added value and total efficiency of biomass utilisation.

	Electrification of private transport + Common studies of strategies for rolling out vehicle charging infrastructure	+ Nordic and Baltic transport research (VilniusTech) + Vehicle and battery manufacturers (SE) + Charging infrastructure suppliers	Transport responsible for large share of GHG emissions in the Baltic-Nordic region and ambitious emission reduction targets. Also, need for strengthening transport activities in the Baltics.
C	**Baltic-Nordic implementation of CCS and CCU** + Exploring potential applications, technologies and storage options	+ CCS technology and systems integration research (SE, NO) + Stockholm Exergi (SE), Liquid Wind (SE), Statkraft (NO) + Earlier participants in CCS networks (NGCCUS, BASRECCS) + Oil shale and power industry	Potential for achieving net zero/negative emission levels. Also, topical area with many Nordic and international projects to link collaboration with. (Potential for participation in common EU projects.)
	Digitalisation in the energy system + Exploring the most relevant areas for digitalisation in the energy system	+ Digitalisation and energy systems expertise working closely together + TSOs, power industry etc., depending on area	Potential for cost reduction and efficiency improvements, while implementation in energy area still limited.
	Deep decarbonisation of energy-intensive industry + Exploring potentials of more radical measures for decarbonisation of industry, including new processes and electrification	+ Nordic research linked to CemZero, HYBRIT, H2GreenSteel + Developing Baltic research + Energy intensive industry - pulp and paper (SE, FI, EE), cement industry (EE, LV, LI, SE), chemical industry (LI, SE), fertiliser industry (LT, NO)	Create potential for reducing measures in otherwise hard-to-abate sectors. Strong research environments in FI and SE that build-up experience in Nordic pilot and demonstration activities. Bilateral sector-wise collaborations.
	The potential role of distributed energy systems + Integration of prosumers + Demand-side management	+ Baltic and Nordic energy systems research + Energy utility sector, TSOs + Local/regional planning stakeholders	High electricity price levels increase interest for local investments in RES power generation.

6.3.2 Areas for Baltic-Nordic collaboration in the 2030 time perspective

For the 2030 time frame, direct efforts for the integration of power systems are assumed to have moved from an R&I area for collaboration to the more operational phase. On the other hand, increasing renewable power generation and power storage will still be a highly relevant topic, in addition to continuing efforts on reducing demand side energy use in all sectors.

Therefore, we propose that the two first collaboration areas related to the power system above (Sustainable and integrated power systems & Large-scale deployment of offshore wind power) are merged to focus on general system aspects of developing a zero emission power system, including the linkages to CCS/CCU and hydrogen/PtX. This broadening is expected to benefit from the already well-developed collaborative infrastructure within the area, in combination with the explorative actions on CCS/CCU in the shorter time frame. Links to the Nordic Clean Energy scenarios, indicating the potential for the Nordics to become an export hub for renewable power and/or hydrogen are highly relevant for combining Baltic and Nordic efforts in that direction. Synergies from Baltic-Nordic collaboration could thus help in establishing the foundation for the Baltic-Nordic region to gain a strong position in a potential European hydrogen economy.

We also propose that the focus on increasing efficiency in the built environment continue as a highly relevant area for collaboration, but with a broadening scope towards positive energy buildings and smart cities, and by strengthening the inclusion of solutions based on digitalisation.

The newly initiated areas for collaboration in the shorter time frame – efficient waste heat utilisation in district heating, the development of biorefineries as part of the bioeconomy, and electrification of transport – should all be relevant to be continued in the 2030 time frame, with an increasing focus on deployment and implementation. These are therefore included in the "A level" collaboration areas in the 2030 perspective.

Hydrogen is expected to take up a more prominent role within the energy system as a "new" energy carrier, spanning across supply and demand sectors. In addition to the supply system aspects of hydrogen covered above, we therefore propose to initiate a new collaboration area related to the demand aspects of hydrogen as an energy carrier. This primarily includes aspects related to hydrogen use in the industrial sector, heavy transport and maritime transport, but also distribution and storage solutions.

In addition to the power system aspects of CCS/CCU covered above, a new "B level" area for collaboration on CCS/CCU technologies and infrastructure development is proposed. Other "B level" collaboration areas identified include collaboration built on the earlier exploratory actions regarding deep decarbonisation of energy-intensive industry, and the integration of distributed energy systems and prosumers through increased digitalisation.

In addition, we propose to launch collaborative activities, aiming at exploring at a more detailed level the development of new, advanced technological solutions and their relevance in the Baltic-Nordic context. The purpose of these actions would be to be able to focus efforts more precisely in the longer term (in the 2050 perspective). Such explorative "C level" activities include areas related to new advanced technologies for RES power production, energy storage, CCS/CCU/PtX and hydrogen production.

Table 12. Major opportunities for Baltic-Nordic collaboration on CETs in the medium term (2030), including examples of stakeholders to involve, as well as market opportunities motivating the collaboration. For more detailed information about international research programmes and stakeholders, see Chapters 2 and 4, Appendix B and Table 20 in Appendix D.

Type	Area of collaboration	Type and examples of stakeholders/projects	Market opportunities (potential arenas for collaboration)
A	**Developing a zero emission power system** + Building on earlier collaboration on offshore wind power hubs + R&I related to large-scale power storage + Adding aspects related to CCS/CCU and hydrogen/PtX	+ TSOs in all Baltic and Nordic countries (see above) +Baltic and Nordic power systems research + CCS technology and systems integration research (SE, NO, EE) + Hydrogen valley planned in Tartu (EE)	Potential for the Nordics and the Baltic-Nordic region for developing to an export hub. European policy focus-ing on electricity and hydrogen as an energy carrier.
	Positive energy buildings and smart cities + Extending existing collaboration on NZEBs + Increasing focus on digitalisation, positive energy buildings and smart cities	+ ZEBE Centre of Excellence (EE), RTU (LV), KTU (LI) and other Baltic research + Nordic research expertise such as AU (DK), Chalmers (SE) etc. + Building and real estate industry + Municipalities and city planning stakeholders + District heating industry	Large renovation demand and tough legal requirements on building energy demand in Baltic states. Relevant also on European level. (NER projects or common participation in EU projects.)
	Efficient waste heat utilisation in district heating + Implementation case studies of increasing utilisation of industrial waste heat, heat pumps and thermal storage solutions	+ Baltic district heating research (e.g. TalTech EE, RTU, LV) + Nordic and Baltic energy systems research + District heating industry + Baltic process industry	Potential for increasing utilisation of industrial waste heat potential in Baltic states, by building on experience in SE/FI.
	Future biorefineries for the bioeconomy + Demonstrations of biorefinery solutions for the production of both biofuels and biomaterials	+ Baltic bioenergy research (RTU) + Nordic research in biorefineries/bioeconomy (SE/FI/NO) + Pulp and paper and wood processing industry, biorefinery clusters (SE/FI/NO and Baltics)	Large biomass potential, established industry infra-structure and potential for increasing added value and total efficiency of biomass utilisation.
	Electrification of transport + Focus on aspects of heavy transport, maritime transport + Battery recycling	+ Nordic and Baltic transport research (VilniusTech) + Vehicle and battery manufacturers (SE) + Shipping industry	Transport responsible for large share of GHG emissions in the Baltic-Nordic region and ambitious emission reduction targets.

B	**Hydrogen society – demand-side aspects** + Hydrogen in industrial processes + Hydrogen for transport + Distribution and local storage	+ Nordic and Baltic energy and transport systems research + Hydrogen centres and initiatives, e.g Hydrogen valley in Tartu (EE), hydrogen associations in all Baltic countries	Potential for hydrogen use in hard-to abate sectors as industry, transport (fuel cell vehicles). Need for development of distribution and storage, common standards and safety.
	Deep decarbonisation of energy-intensive industry + Baltic-Nordic case studies of radical measures for decarbonisation of industry, including new processes and electrification	+ Nordic research linked to CemZero, HYBRIT, H2GreenSteel. + Developing Baltic research + Energy intensive industry - pulp and paper (SE, FI, EE), cement industry (EE, LV, LI, SE), chemical industry (LI, SE), fertiliser industry	Create potential for reducing measures in otherwise hard-to-abate sectors. Strong research environments in FI and SE that build-up experience in Nor-dic pilot and demonstration activities.
	CCS/CCU technologies and infrastructure + Process technology developments + CO2 transport infrastructure and storage	+ Storage capacities in Nordics (NO) + Industries with potential excess heat that can be used for CO2 separation + Gas competence - NG infrastructure and LNG terminal (Klapeida)	Technological competence and infrastructure development needed to harness potential of CCS/CCU.
	Distributed energy systems + Deploying potential of small-scale remote power generation by prosumers + Developing digital solutions and support systems	+ TSOs pushing smart metering and digitalisation development + VilniusTech/KTU (LT) + TalTech – ORBES + Estonian Smart City Cluster (ESCC)	High electricity price levels increase interest for local investments in RES power generation.
C	**Exploring new advanced technologies within** + RES power generation e.g., solar power (Perovskite PV etc), airborne wind energy, floating hybrid energy platforms + Energy storage, including sustainable materials use + CCS/CCU/PtX, e.g., direct air CO2 capture and mineral CO2 storage + Hydrogen production	+ Baltic and Nordic fundamental technology research in respective area + Renewable energy stakeholders + Solar PV industry (LI)	Electrification and sustainability requirements make increased efficiency and decreased cost necessary. Global market potential. Explorative studies important to focus long-term initiatives "right".

6.3.3 Areas for Baltic-Nordic collaboration in the 2050 time perspective

The long-term collaboration opportunities within the Baltic-Nordic energy system will heavily depend on the choices and decisions made along the pathway to a sustainable energy system and are therefore very hard to be specific about. Overall, by 2050, the energy system should have transitioned to basically zero GHG emission and be fossil-free. Consequently, many of the collaboration areas specified on levels A and B for the 2030 time perspective, should by then be less topical. Nevetheless, we do indicate that R&I collaborations related to the transformation of the transport sector; the development of a hydrogen society; the implementation of CCS/CCU and BECCS for net zero or negative emissions from industry; and further integration of flexible (partly distributed) power generation, storage and demand side are expected to still be relevant.

Apart from this, the opportunities highlighted below largely build on the assumed roadmap development until 2030, and the outcome of the explorative actions included for that time period. The areas in focus are also based on the low TRL technologies identified for the development of the technology needs matrix for 2050 (see Section 5.5).

The roadmap thus indicates that it could be relevant to initiate new collaborations in areas related to the development of new advanced technologies for:

+ RES power generation, such as new more material efficient PV technologies or airborne wind energy.

+ Energy storage solutions, such as advances in batteries from abundant and low-cost materials and systems for battery recycling, both for large-scale storage and for the transport system.

+ Carbon capture and storage and utilisation, including production of PtX, based on for instance direct air capture.

+ Multiple potential applications for, as well as improved technologies for producing hydrogen.

The list could be extended with a large number of technologies that are currently at a very early development stage, but given the framework of the project, the ones considered most relevant in a Baltic-Nordic context have been selected. Also in this time perspective, there will certainly be new technology areas to explore. However, those are impossible to foresee right now, and we have thus chosen not to include any "C level" collaboration areas at all. As stakeholders are basically similar, and it is difficult to argue for market opportunities in this time perspective, they have not been addressed in Table 13.

Table 13. Major opportunities for Baltic-Nordic collaboration on CETs in the long term (2050 and beyond).

Type	Area of collaboration
A	**Zero emission transport system** + Zero emission solutions throughout the transport sector
	Hydrogen society + Hydrogen as an energy carrier + Supply, demand, transmission and storage solutions + New, efficient technologies for hydrogen production
	CCS/CCU for net zero/negative emissions + making use of CCS storage infrastructure in the Baltic-Nordic region + decarbonising cement and ammonia industry sector
	Deep decarbonisation of industry + abating CO2 emissions from e.g. cement and fertiliser industry + electrification of processes, incl. high temperature heat pumps + hydrogen
	Integrated energy system, combining flexible power generation, storage and demand side management + Fully exploiting the synergies through digitalisation
B	**Development/implementation of advanced RES power generation** + Focusing on the most relevant technologies from earlier explorative activities
	Development/implementation of advanced energy storage technologies… + Focusing on the most relevant technologies from earlier explorative activities
	Development/implementation of advanced technologies for CCS/CCU/PtX + Focusing on the most relevant technologies from earlier explorative activities
	Development/implementation of advanced hydrogen production technologies Focusing on the most relevant technologies from earlier explorative activities

References

CHAPTER 1

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CHAPTER 2

Clean Energy Transition Partnership (2020). Strategic Research and Innovation Agenda. 61p. https://eranet-smartenergysystems.eu/global/images/cms/CETP/CETP_SRIA_v1.0_endorsed.pdf. Accessed 2021-08-18.

International Energy Agency (2020). Energy Technology Perspectives 2020. OECD Publishing, Paris. 400p. https://doi.org/10.1787/d07136f0-en.

Mission Innovation (2020). MI Innovation Challenges – Impact Report. 32p. http://mission-innovation.net/wp-content/uploads/2020/09/2.-IC-Impact-Report-Final.pdf. Accessed 2021-08-18.

European Commission, Directorate-General for Research and Innovation (2021). Horizon Europe, the EU research and innovation programme (2021-27): for a green, healthy, digital and inclusive Europe. Publications Office. https://data.europa.eu/doi/10.2777/601756.

European Commission (2021). Horizon Europe Work Programme 2021-2022, 8. Climate, Energy and Mobility. https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/horizon/wp-call/2021-2022/wp-8-climate-energy-and-mobility_horizon-2021-2022_en.pdf. Accessed 2021-08-18.

European Commission (2020). Clean Energy Transitions – Technologies and Innovations. SWD(2020) 953 final. Brussels, Belgium. 364p. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020SC0953. Accessed 2021-08-18.

European Commission (2020). Report from the Commission to the European Parliament and the Council on Progress of Clean Energy Competitiveness. COM(2020) 953 final. Brussels, Belgium. 33p. https://ec.europa.eu/energy/sites/ener/files/report_on_clean_energy_competitiveness_com_2020_953.pdf. Accessed 2021-08-18.

International Energy Agency (2021). ETP Clean Energy Technology Guide. Paris Cedex, France. https://www.iea.org/articles/etp-clean-energy-technology-guide. Accessed 2021-12-06.

Nordic Energy Research (2021). Nordic Clean Energy Scenarios – Solutions for Carbon Neutrality. Nordic Council of Ministers. Copenhagen, Denmark. http://doi.org/10.6027/NER2021-01.

CHAPTER 3

European Commission (2021). Policy scenarios for delivering the European Green Deal. https://ec.europa.eu/energy/data-analysis/energy-modelling/policy-scenarios-delivering-european-green-deal_en. Accessed 2021-11-03.

Lindroos T.J., Lehtilä A., Koljonen T., Kofoed-Wiuff A., Hethey J., Dupont, N. et al. (2018). Baltic Energy Technology Scenarios 2018. TemaNord 2018:515. Nordic Energy Research. Oslo, Norway. 164p. https://www.nordicenergy.org/project/bente/. Accessed 2021-08-18.

United Nations. Greenhouse Gas Inventory Data - Time Series - Annex I - GHG total without LULUCF. https://di.unfccc.int/time_series. Accessed 2021-11-03.

European Commission (2021). Policy scenarios for delivering the European Green Deal - Excel files for MIX scenario. https://energy.ec.europa.eu/publications-new/excel-files-mix-scenario_en. Accessed 2021-11-08.

Elering (2021). Security of supply guaranteed for the short and long term despite uncertainty. https://elering.ee/en/security-supply-guaranteed-short-and-long-term-despite-uncertainty. Accessed 2022-01-04.

Estonian Government Office (2021). Estonia 2035. https://www.valitsus.ee/en/node/31. Accessed 2021-11-08.

Volkova A., Pieper H., Koduvere H, Lepiksaar K. and Siirde A. (2021). Heat pump potential in the Baltic states. Nordic Energy Research. Oslo, Norway. https://doi.org/10.6027/NER2021-02.

Ministry of Economic Affairs and Communication (2019). Estonia's 2030 National Energy and Climate Plan (NECP 2030). https://ec.europa.eu/energy/sites/ener/files/documents/ee_final_necp_main_en.pdf. Accessed 2021-11-08.

Ministry of Economics – Republic of Latvia (2019). Latvia's National Energy and Climate Plan 2021–2030. https://ec.europa.eu/energy/sites/ener/files/documents/lv_final_necp_main_en.pdf. Accessed 2021-11-08.

Ministry of Energy of the Republic of Lithuania (2019). National Energy and Climate Action Plan of the Republic of Lithuania for 2021-2030. https://ec.europa.eu/energy/sites/ener/files/documents/lt_final_necp_main_en.pdf. Accessed 2021-11-08.

Elering (2021) Production and forecast (in Estonian). https://elering.ee/toodang-ja-prognoos. Accessed 2021-11-08.

International Energy Agency (2021). Countries and Regions – Europe. https://www.iea.org/regions/europe. Accessed 2021-11-08.

Ambergird (2022). Gas Interconnection Poland–Lithuania (GIPL). https://www.ambergrid.lt/en/projects/gas-interconnection-poland-lithuania-gipl. Accessed 2022-01-10.

European Commission (2020). Roadmap on regional gas market integration. https://ec.europa.eu/info/files/roadmap-regional-gas-market-integration_en. Accessed 2021-11-08.

ThreeSeas (2021). Connection of offshore wind farm to the electricity transmission grid of Lithuania, https://projects.3seas.eu/projects/connection-of-offshore-wind-farm-to-the-electricity-transmission-grid-of-lithuania. Accessed 2022-01-03.

Nordic Energy Research (2020) Fast, flexible and secure decarbonisation of the Baltic states – possible progress in the next Ten years. Joint Baltic-Nordic Energy Research Programme. https://www.nordicenergy.org/article/jbnerp-first-call-completed/. Accessed 2021-11-08.

Tomi Lindroos. Personal communication. 2021-08-24.

Silovs G. (2021). Latvian experience with energy efficiency programmes. Ministry of Economics. Presentation at Nordic-Baltic Energy conference 2021: Energy delivery in the European Green Deal. https://www.norden.ee/images/rohemajandus/Energiakonverents/Energiakonverents_2021/Gatis_Silovs.pdf. Accessed 2021-11-08.

Ministry of Economic Affairs and Communications (2017). National Development Plan of the Energy Sector until 2030. Tallinn, Estonia. 124p.

Ministry of Energy of the Republic of Lithuania (2018). National Energy Independence Strategy – Energy for Lithuania's Future. (Unofficial translation from Lithuanian to English). https://enmin.lrv.lt/uploads/enmin/documents/files/National_energy_independence_strategy_2018.pdf. Accessed 2021-11-08.

Tardieu P. (2021). Bright future for Offshore Wind? Challenges in the Nordic-Baltic Region. WindEurope. Presentation at Nordic-Baltic Energy conference 2021: Energy delivery in the European Green Deal. https://www.norden.ee/images/rohemajandus/Energiakonverents/Energiakonverents_2021/Pierre_Tardieu.pdf. Accessed 2021-11-08.

Matti J Koivisto. Personal communication. 2021-08-18.
Nordic Energy Research/ABB (2020). Transport Statistical Data and Projections in the Baltic States. Nordic Energy Research. Oslo, Norway. https://www.nordicenergy.org/wordpress/wp-content/uploads/2020/02/20200407_NER_Final-Reportupd.pdf. Accessed 2021-11-08.

Koivisto M.J., Murcia Leon J.P., Sørensen P.E., Münster M., Bramstoft Pedersen R.B. (2021). Interconnecting the Baltic Sea countries via offshore energy hubs (BaltHub). Baltic-Nordic Energy Research Programme. https://orbit.dtu.dk/en/projects/interconnecting-the-baltic-sea-countries-via-offshore-energy-hubs. Accessed 2021-11-08.

CHAPTER 4

Department of Energy Technology. Tallinn University of Technology. https://taltech.ee/en/department-energy-technology. Accessed 2021-08-27.

Department of Electrical Power Engineering and Mechatronics. Tallinn University of Technology. https://taltech.ee/en/department-electrical-power-engineering-mechatronics. Accessed 2021-08-27.

Department of Electrical Power Engineering and Mechatronics. Tallinn University of Technology. Optimised Residential Battery Energy Storage Systems (ORBES). https://taltech.ee/en/orbes. Accessed 2022-03-01.

Elering. Synchronisation with continental Europe. https://elering.ee/en/synchronization-continental-europe. Accessed 2021-10-25.

Institute of Energy Systems and Environment. Riga Technical University. https://videszinatne.rtu.lv/en/science/project-and-research/active/. Accessed 2021-08-27.

Nordic Energy Research (2019). Flex4RES – Flexible Nordic Energy Systems. https://www.nordicenergy.org/flagship/flex4res/. Accessed 2022-01-04.

SMAGRINET. Empowering Smart Grid Expertise in Europe. https://www.smagrinet.eu/. Accessed 2021-08-27.

FuelCellsWorks (2021). Amber Grid – The First Green Hydrogen Production Project Is Launched in Lithuania. https://fuelcellsworks.com/news/amber-grid-the-first-green-hydrogen-production-project-is-launched-in-lithuania/. Accessed 2021-10-25.

Litgrid/DNV GL (2020). Scenario Building for the Evolution of Lithuanian Power Sector for 2020-2050. Report 2020-0430, https://www.litgrid.eu/uploads/files/dir564/dir28/dir1/15_0.php. Accessed 2021-10-25.

EPSOG (2022). Lithuanian Electricity Storage Facilities System Project. https://www.epsog.lt/en/projects/lithuanian-electricity-storage-facilities-system-project. Accessed 2022-01-03.

Latvenergo. Generation. https://latvenergo.lv/en/par-mums/razosana. Accessed 2022-01-03.

Elcogen. Company profile. https://elcogen.com/company/. Accessed 2022-01-03.

UBIK Solutions. Company profile. https://www.ubiksolutions.eu/company. Accessed 2022-01-03.

Estonian Research Information System (2019) Thermal engineers consider increasing the amount of wood in fossil fuels to be a possible solution https://www.etis.ee/Portal/News/Display/c357c4b9-354e-453e-9394-4d47e10d6d04?lang=ENG. Accessed 2022-01-03.

KTU. Perovskite Thin-film Photovoltaics (PERTPV). Kaunas University of Technology, https://en.ktu.edu/projects/perovskite-thin-film-photovoltaics-pertpv/. Accessed 2021-08-27.

Protech. The Applied Research Institute for Prospective Technologies. https://protechnology.lt/. Accessed 2022-01-03.

SoliTek company. https://www.solitek.eu/en/company. Accessed 2021-10-25.

LEI. Lithuanian Energy Institute – Projects. https://www.lei.lt/projects/. Accessed 2022-01-04.

Center for Physical Sciences and Technology. Environmental Research and energetics. https://www.ftmc.lt/environmental-research-and-energetics. Accessed 2022-01-03.

Institute of Solid State Physics - University of Latvia. Research topics. https://www.cfi.lu.lv/en/research/research-topics/. Accessed 2022-01-04.

Baltic InteGrid. Integrated Baltic Offshore Wind Electricity Grid Development. EU Interreg project. http://www.baltic-integrid.eu/. Accessed 2022-01-03.

Estonian Hydrogen Association. https://h2est.ee/eng/. Accessed 2022-01-03.

Latvian Hydrogen Association. http://www.h2lv.eu/. Accessed 2022-01-03.

Lithuanian Hydrogen energy association. https://www.h2lt.eu/. Accessed 2022-01-03.

Hydrogen Valley Roadmap – Tartu. http://h2est.ee/wp-content/uploads/2021/07/4_Tartu-Hydrogen-Valley-Ain-Tammvere.pdf. Accessed 2022-01-03.

AB Klaipėdos nafta. https://www.kn.lt/en/. Accessed 2022-01-03.

Elering. Renewable energy-Green gas-Biomethane. https://elering.ee/en/biomethane. Accessed 2021-08-27.

Tallinn City (2020). Tallinn launched environmentally friendly compressed gas buses in the service. https://www.tallinn.ee/eng/greencapital/Uudis-Tallinn-launched-environmentally-friendly-compressed-gas-buses-in-the-service. Accessed 2021-11-08.

Vilnius Gediminas Technical University. Research Focus. https://vilniustech.lt/research-and-innovation/research-focus/4819. Accessed 2022-01-03.

Possibilities of using waste heat and exhaust cooling in the heating and / or cooling sector and assessing the potential of efficient district heating and cooling in Estonia (in Estonian). https://mkm.ee/sites/default/files/heitsoojuse_ja_-jahutuse_analuus_.zip. Accessed 2022-01-04.

Determination of the Efficiency Potential of Heating and Cooling Supply in Latvia in accordance with EU Energy Efficiency Directive 2012/27/EU (in Latvian). https://ec.europa.eu/energy/sites/default/files/documents/lv_ca_2020_lv.pdf. Accessed 2022-01-04.

EuroChem-Lifosa. Electricity and Heat Energy. https://www.lifosa.com/en/energy-activity/electricity-and-heat-energy/95. Accessed 2021-10-29.

Tartu Regional Energy Agency. https://www.trea.ee/eng/. Accessed 2022-01-04.

Kaunas Regional Energy Agency. https://www.krea.lt/en. Accessed 2022-01-04.

Estonian Smart City Cluster (ESCC). http://smartcitylab.eu/en. Accessed 2022-01-03.

Institute of Environmental Engineering. Kaunas University of Technology. https://apinien.ktu.edu/. Accessed 2021-08-27.

Elering. Estfeed - Secure and legal energy data exchange. https://www.estfeed.eu/en/home. Accessed 2022-01-04.

Lietuvos inžinerijos ir technologijų pramonės asociacija LINPRA. https://linpra.lt/en/. Accessed 2022-01-03.

Tiits M., Karo.E. (2021). What will Estonia's bioeconomy look like in 2050?. Institute of Baltic Studies. https://www.ibs.ee/en/publications/what-will-estonias-bioeconomy-look-like-in-2050/. Accessed 2022-01-03.

BIOEASTsUP (2019). Advancing Sustainable Circular Bioeconomy in Central and Eastern European countries. Horizon 2020 project. https://videszinatne.rtu.lv/en/science/project-and-research/bioeastsup/. Accessed 2022-01-03.

CHAPTER 5

KTH Innovation Readiness Level. https://kthinnovationreadinesslevel.com/. Accessed 2022-01-31.

Elering. Renewable Energy - Reverse auctions. https://elering.ee/en/taastuvenergia-vahempakkumine. Accessed 2022-01-03.

CHAPTER 6

Nordic Energy Research (2020). Three projects launched to address common Baltic-Nordic energy challenges. Joint Baltic-Nordic Energy Research Programme. https://www.nordicenergy.org/article/jbnerp-first-call-completed/. Accessed 2022-01-03.

Appendix A

Interview guidelines and interviewees

The basic questions raised during the interview sessions (interview guidelines) and a list of the Baltic and Nordic energy experts interviewed during the course of the project are given below.

Interview guidelines

1. For which clean energy technologies (CETs) do you see that the Baltic states (or "your" Baltic state) have **especially strong stakeholders?**
   - What type of technology/CET? (Specific sub-system, aspects in focus)
   - What is the status of the development? (Basic research, technology development, demonstration plant, near-market, commercial)
   - Which stakeholders are involved? What is their focus in terms of CET development? (Specific research groups, institutes, industries and persons)
   - Is there an established Baltic-Nordic co-operation linked to this CET or are there specific Baltic-Nordic collaboration needs and opportunities?

2. Are there other CETs for which there are relevant stakeholders in the Baltic states (or "your" Baltic state) that you want to mention? (Not AS strong, in less detail.)

3. Which CETs do you see as most critically **needed** for contributing to the development of the energy system and reaching the climate targets in the Baltic states (or "your" Baltic state)?
   + When in time (now/2030/2050 and beyond) do you expect the CET need to be applied large-scale for targets to be met?
   + Is there an established Baltic-Nordic co-operation linked to this CET or are there specific Baltic-Nordic collaboration needs and opportunities?

4. Which 3–5 CETs do you consider most relevant?
   - With respect to Baltic-Nordic collaboration?

5. - With respect to being critical for achieving climate and energy targets?

List of interviewed experts

Baltic energy experts

- Prof. Dagnija Blumberga, Riga Technical University, Latvia
- Valdis Bisters, former Ministry of Environment, Latvia
- Kristel Nõges, SEI Tallinn, Estonia
- Prof. Andres Siirde, Tallinn University of Technology, Estonia
- Prof. Jarek Kurnitski, Tallinn University of Technology, Estonia
- Prof. Ivo Palu, Tallin University of Technology, Estonia
- Prof. Vytautas Martinaitis, Vilnius Gediminas Technical University, Lithuania
- Prof. Dalia Streimikiene, Lithuanian Energy Institute, Lithuania

Experts in relation to current Baltic-Nordic collaboration projects:

- Kevin Johnsen, NER
- Matti Juhani Koivisto, DTU Wind Energy, BaltHub project
- Tomi J. Lindroos, VTT, FasTen project
- Kim B. Wittchen, Aalborg University, Denmark, NZEB buildings

Appendix B

List of identified stakeholders

Information about Baltic stakeholders has been collected through existing research networks, scientific databases and databases of research projects. At the beginning of the project, the project team drew up lists of the research networks of partner organisations. These lists were complemented by a systematic search in databases of research projects, since research organisations focusing on CETs usually participate in research consortiums. Data has thus been collected from the EU CORDIS project database, the Interreg Baltic Sea Region 2014/20 programme project database and the list of Nordic Energy Research projects. The scientific citation database SCOPUS platform was also used, applying keywords such as "energy", "electricity", "heating", "hydrogen", "PV" etc. and filtering by affiliation country (Latvia, Estonia or Lithuania). Thus, a list of 36 Baltic stakeholders (organisations) was identified: 14 from Estonia, 13 for Lithuania and 9 from Latvia. This list was reviewed and complemented by the project board members, representing each of the Baltic states, in order to expand the list with more stakeholders that do not represent research organisations.

In addition, searching with the SCOPUS platform helped in selecting experts. To reach a higher level of excellence among researchers, researchers with an h-index >7 were selected as interviewees for the survey. Some experts were removed if there were more than two experts from one research group.

The following tables (Tables 14 to 16) represent the identified stakeholder organisations for the three Baltic states.

Table 14. Identified stakeholders for the survey on clean energy-related technologies in Estonia (in alphabetical order).

CET stakeholders in Estonia	
Stakeholder	**Type of organisation**
AKTSIASELTS ELCOGEN https://elcogen.com/	Company
AS FORTUM TARTU	Company
ELERING https://elering.ee/en	Electricity and gas system operator
Estonian Chamber of Agriculture and Commerce www.epkk.ee/	Governmental/public
Estonian University of Life Science https://www.emu.ee/en/	University
Foundation Private Forest Centre (PFC) http://www.eramets.ee/en/activities-3/	Governmental/public
Foundation Tallinn Science Park Tehnopol http://www.tehnopol.ee/en/	Science park
Institute of Baltic Studies https://www.ibs.ee/	Research institute
SIHTASUTUS EESTI TEADUSAGENTUUR https://www.etag.ee/	Research council
SMART CITY LAB http://smartcitylab.eu/	Innovation cluster
Stockholm Environment Institute https://www.sei.org/centres/tallinn/about/	Research institute
Tallinn University of Technology www.taltech.ee	University
Tartu Regional Energy Agency www.trea.ee	Regional agency
Ubik Solutions OÜ www.ubiksolutions.eu	Company
University of Tartu www.ut.ee/en	University
Union of Electricity Industries http://www.elektriliit.ee/	Industry organisation

Table 15. Identified stakeholders for the survey on clean energy-related technologies in Latvia (in alphabetical order).

CET stakeholders in Latvia Stakeholder	Type of organisation
Baltic Environmental Forum – Latvia www.bef.lv	Non-profit association
Green Liberty (LV) https://www.zalabriviba.lv/greenliberty/	NGO
LatvEnergo https://latvenergo.lv/en	Energy supplier
Latvian Hydrogen Association www.H2LV.eu	Association
Latvian State Forest Research Institute Silava www.silava.lv	Research institute
Latvian Technological Center www.innovation.lv\LTC	Innovation centre
LATVIJAS LAUKSAIMNIECIBAS UNIVERSITATE https://www.llu.lv/	University
LATVIJAS UNIVERSITATES CIETVIELU FIZIKAS INSTITUTS https://www.cfi.lu.lv/	University
Ltd. Latvian Rural Advisory and Training Centre www.mkpc.llkc.lv	Consultancy agency
Latvian Transport Development and Education Association (LaTDEA) https://latdea.lv/	Association
Riga Technical University www.rtu.lv/	University
Salaspils Siltums https://salaspilssiltums.lv/en/	Energy supplier
Ventspils Oil Terminals http://www.vnt.lv/en/about-vnt/par-vnt/	Company
Latvian Association of Heat Plants and Suppliers https://www.lsua.lv/layout.php?id=3&me-nu_id=1	Association
Latvian Heat, Gas and Water Technology Engineers Union https://www.lsgutis.lv/	Association

Table 16. Identified stakeholders for the survey on clean energy-related technologies in Lithuania (in alphabetical order).

CET stakeholders in Lithuania	
Stakeholder	**Type of organisation**
Ambergrid https://www.ambergrid.lt/en/	Gas transmission grid operator
Applied Research Institute for Prospective Technologies www.protechnology.lt	Research institute
Association for Energy Economics http://aee.lt/Association/	Association
Association of Lithuania's Independent Heat Producers https://www.lnsga.lt/	Association
Association of Renewable Energy Producers https://www.aega.lt/	Association
Center for Physical Sciences and Technology https://www.ftmc.lt/en	Research institute
CivittaUAB www.civitta.com	Company
Coastal Research and Planning Institute www.corpi.lt	Research institute
Engineering and Technology Industries Association of Lithuania (LINPRA) https://linpra.lt/en/	Association
EPSO-G https://www.epsog.lt/en/	State-owned group of energy transmission and exchange companies
ESO https://www.eso.lt/en/home.html	Electricity and Gas distribution grids' operator
Forest Owners Association of Lithuania www.forest.lt	Trade association
Ignitis Group https://ignitisgrupe.lt/en	Lithuania based international energy company and one of the largest energy groups in the Baltic region
Investor's Forum https://investorsforum.lt/en/	Association

Kaunas Forestry and Environmental Engineer-ing University of Applied Sciences (KMAIK) https://www.kmaik.lt/kategorijos-tevas1	University
Kaunas Regional Energy Agency www.krea.lt	Regional agency
Kaunas Science and Technology Park www.stpkaunas.com	Science park
Kaunas University of Technology https://en.ktu.edu/	University
Klaipeda University www.ku.lt	University
KN https://www.kn.lt/en/	Oil and LNG terminals' operator in Lithuania, becoming a player in global LNG market
Litgrid https://www.litgrid.eu/index.php?lang=2	Transmission system operator
Lithuanian Business Confederation https://www.lpk.lt/en/	Association
Lithuanian Confederation of Industrialists https://www.lpk.lt/en/	Association
Lithuanian Confederation Of Renewable Resources http://ateitiesenergija.lt/en/	Association
Lithuanian District Heating Association https://lsta.lt/en/	Association
LLithuanian Electricity Association http://www.leea.lt/?lang=en	Association
LLithuanian Energy Institut www.lei.lt	Research institute
Lithuanian Hydrogen platform https://www.h2lt.eu/	Association

National Lithuania's Energy Association https://nlea.lt/	Association
Photoelectric Technology And Business Association www.sauleselektrapv.lt	Association
Solitek www.solitek.eu	Company
VILNIAUS UNIVERSITETAS https://www.vu.lt/	University
Vilnius Gediminas Technical University www.vgtu.lt	University
Vytautas Magnus university www.vdu.lt	University

Appendix C

List of identified stakeholders

To back up the information collected from literature, and web searches and expert interviews on the capacities within the relevance of the respective clean energy-related technologies within the Baltic states, a survey was sent out to stakeholders in the Baltics (see tables in Appendix B). Wherever possible, individual persons' e-mail addresses were identified; where that was not possible, standard contact e-mail addresses for the different organisations were used.

The survey was sent out to about 170 e-mail addresses, to be answered anonymously, but asking the participant to specify their country affiliation and type of organisation they represent. The survey was open for 14 days, with reminders to participate sent out twice. The survey was centred around the CET categories and CETs used throughout the present project and illustrated in Figure 2. The participants were asked to rank the CETs within all of the six categories according to the following two questions:

1. **What is your country's capacity with respect to the clean energy technology (CET) in the near-term/2030 perspective?**
2. **What is the relevance of the CET in the long term (2050 and beyond) for your country in terms of realising a sustainable energy system?**

The first question was intended to give an idea of the current status/capacity of each Baltic state with respect to a given CET (R&I activities, stakeholders, projects, actual implementation status and level), while the second question aimed at identifying the most relevant CETs for the Baltic states in a long-term perspective.

The relevance of the CETs was ranked as follows:

0 – not relevant
1 – very low
2 – low
3 – medium
4 – high
5 – very high

The CET categories were presented in a random order for the different survey participants to avoid a bias from people only answering the first questions (which did not turn out to be the case for any of the participants). At the end of each CET category, there was a free text field for comments, asking the survey participants whether they could identify additional relevant CETs:

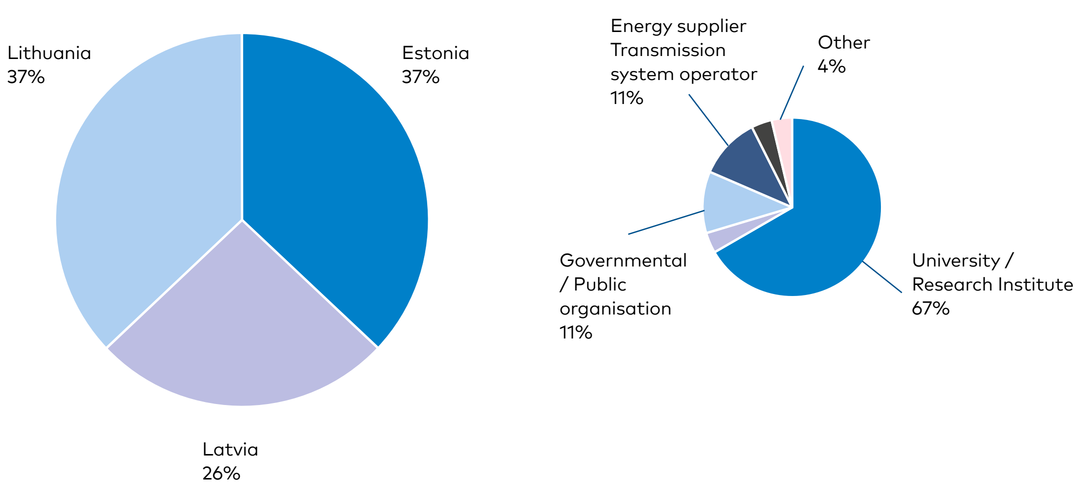
"Other relevant CETs within this category (now/long term)? (Including advanced CETs at low technology readiness level.) National drivers and barriers for the CETs? Specific examples of active stakeholders or projects in this category for your country?"

Survey results

The response rate to the survey was about 17 per cent, resulting in 27 answers. The answers were evenly distributed among the three Baltic states, with the majority of respondents from academia (about 66 per cent), as illustrated in Figure 12.

The survey results and respondents' comments can be found and downloaded through this link: https://www.nordicenergy.org/wordpress/wp-content/uploads/2022/04/BN_Roadmap_surveyresult.pdf

Figure 12: Country (left) and organisation (right) affiliation of the respondents to the survey. Category "Other" in the right pie diagram represented a digital innovation hub.



Appendix D

Country annexes for Estonia, Latvia, Lithuania and the Nordics

Estonia

Estonia has ambitious targets for the reduction of GHG emissions and development of a sustainable energy system. The targets focus on the emissions of GHG, overall share of renewable energy and energy efficiency improvements, while specific targets for the transport sector are not in focus. Ambitions are increasing, and according to the strategy "Estonia 2035", adopted by the Estonian parliament in May 2021, Estonia will be climate neutral by 2050. This is, however, not yet included in the official NDEP targets. One additional challenge, which is especially in focus for Estonia is to ensure security of supply.

Now

The main needs in Estonia in the "Now" time perspective and CETs that can contribute to answering these needs have been identified and summarised below (see Chapter 3 for more details). In this summary, the focus is on CET categories or technologies for which we have the impression that R&I activities would need to be strengthened and/or further developed. Other important CET areas, for which already established research and development activities need to be continued, are only briefly included.

Of specific importance for Estonia in the "Now" time perspective is to:

- Continue the minimisation of GHG emissions from the oil shale industry. CET-specific efforts can be
  - Development and deployment of technologies to reduce carbon emissions, such as co-combustion with biomass.
  - Continuing studies of systems and technologies that could contribute to implementation of CCS and CCU linked to the oil shale plants.
- Continue the increase of energy independence and interconnections within the Baltics, with Finland and with the EU for both the electricity and natural gas systems, by implementing adopted strategies such as the BEMIP. CET-specific efforts can be
  - Continued R&I in power systems development, taking into account increasing shares of RES, including micro- and smart grid solutions and power electronics.
  - Strengthened focus on storage solutions for electricity, such as (in this shorter term) pumped hydropower, but also take steps to strengthen R&I in other storage CETs, such as batteries and hydrogen.

- Further increasing the RES share in electricity production, which is expected to take place mainly through a strong increase in the production of onshore and offshore wind power towards 2025. Biomass-powered production is important for the system, but not expected to increase. CET-specific efforts can be
  - Continued R&I directed towards solutions for integration of intermittent RES and the impact of alternative locations for this capacity in the Estonian power system.
  - Investigating the need for technology-oriented R&I on wind and/or solar power, or defining a strategy for how to fully benefit from technological development elsewhere.
- Further increase the RES share and total system efficiency for district heating, which primarily involves increasing the use of waste heat and heat pumps, since the share of biomass in district heating is already high. This can potentially also contribute to freeing up biomass resources for other purposes. CET-specific efforts can be
  - Continued system-oriented R&I on the use of waste heat including heat pumps in district heating, but also for providing heat locally. Technologies needed are already well-established.
- Strengthen the focus on increasing the RES share and total system efficiency for the transport sector, in which the RES share is currently low. The near-term plans in Estonia focus on increasing the production and use of biomethane for transport, but to reach targets (longer-term) efforts need to be broadened. CET-specific efforts can be
  - Continue efforts linked to the integration of compressed and liquefied biomethane for use in road transport and shipping in the Estonian system and system linkages with the waste handling system. Production technologies for biomethane are already well-established.
  - Strengthen research related to various biorefinery and advanced biofuel technologies, also linked to R&I on energy linkages from the development of a bioeconomy.
  - Initiate additional R&I efforts related to the development of technical systems and infrastructure for electrification of transport in the Estonian context, and actions needed to increase system efficiency (via e.g. increasing the share of collective transport).
  - Further develop strategies for how to fully benefit from R&I related to the international development of electric vehicles and increase vehicle efficiency.
  - Explore the role of digitalisation to support electrification and efficiency improvements in the transport system.
- Initiate a stronger focus on increasing energy efficiency in industry. This area has been identified as important, but currently, there seems to be relatively little focus on R&I, apart from, possibly, utilisation of waste heat in district heating. CET-specific efforts can be
  - Strengthen R&I related to deep decarbonisation of industrial processes, which is highly relevant in relation to e.g. chemical industry and cement production, which are important in Estonian industry.
  - Strengthen R&I related to energy efficiency improvements in SMEs and non-energy-intensive industry.

    - Increase R&I efforts related to energy linkages from the development of both bio- and circular economy and from digitalisation.
- Continue the already strong focus on increasing energy efficiency in the building sector, especially through renovation and measures in existing buildings. CET-specific efforts can be
    - Continue R&I focusing on zero energy and resource efficient buildings, possibly strengthening the focus on improving the processes for renovation of existing building. This is already a very strong area in Estonia.
    - Further investigate the potential of digitalisation as a tool for an energy-efficient building sector and of widening the perspective towards smart and sustainable urban environments.

2030

In the same way as above, the main needs in Estonia and related CETs, in the *2030 time perspective*, have been identified and summarised below (see Chapter 3 for more details). In this perspective, the majority of shale oil-based electricity and heat production is expected to be phased out, the system integration of the natural gas and power systems is expected to be largely accomplished as well as the more straightforward measures for increasing the efficiency of buildings, district heating system and industry. Below, the focus is therefore put on the more demanding challenges and on the need to develop "newer" technologies.

Of specific importance for Estonia in the 2030 time perspective is:

- Continued development of RES in electricity production, with a particular focus on
    - Continued R&I directed towards solutions for integration of intermittent RES and the impact of alternative locations for this capacity, including large-scale offshore wind farms and solar power installations at a system-relevant scale.
    - Further R&I directed towards the use of "newer" technologies for power storage, such as batteries and hydrogen.
- Continued development of the district heating system, with particular focus on
    - Continued system-oriented R&I on large-scale use of heat pumps in district heating, and the impact from such developments on the power system.
- Stronger focus on increasing the RES share and total system efficiency for the transport sector, with a particular focus on
    - R&I related to various biorefinery and advanced biofuel technologies, also linked to R&I on energy linkages from the development of a bioeconomy.
    - R&I related to alternative technologies for hydrogen production (apart from eletrolysers) and on system aspects, including storage, transmission and distribution of hydrogen for use in the transport system.

    - R&I efforts related to the system impact from larger scale electrification of the transport system, including charging technologies (e.g. electrical road systems).
    - R&I efforts aiming at implementation of digitalisation efforts for supporting electrification and efficiency improvements in the transport system.
- Stronger focus on increasing energy efficiency in industry, with a particular focus on
    - R&I related to deep decarbonisation of industrial processes, including potential CCS and CCU technologies and their system linkages.
    - Increasing R&I related to electrification of industrial processes.
    - R&I related to energy linkages from the development of both bio- and circular economy and from digitalisation.
- Continued R&I related to increasing energy efficiency in the building sector, with a particular focus on
    - Integrated local systems (heating, transport, power production and storage) for energy positive building and built environment.
    - R&I aiming at benefitting from the potential through digitalisation in the building sector.

As relevant CETs for the **2050 and beyond** time perspective are common to all three Baltic states, please refer to section 5.2.4 in Chapter 5 (the content is not repeated in this Appendix).

Latvia

Latvia has the lowest total and per capita GHG emissions of the Baltic states (see Figure 1), as a result of a high share of hydropower in power production. The country has already achieved the current targets for GHG emission reduction until 2030 and longer-term targets are yet to be determined. In addition to GHG emission reductions, the country has, however, also ambitious targets for RES share and energy efficiency, especially when it comes to heat use in buildings, while specific targets for the transport sector are not in focus.

Now

The main needs in Latvia in the "Now" time perspective and CETs that can contribute to answering these needs have been identified and summarised below (see Chapter 3 for more details). In this summary, the focus is on CET categories or technologies for which we have the impression that R&I activities would need to be strengthened and/or further developed. Other important CET areas, for which already established research and development activities need to be continued, are only included in brief.

Of specific importance for Latvia in the "Now" time perspective is to:

- Continue the increase of energy independence and interconnections within the Baltics, with Finland and with the EU for both the electricity and natural gas systems, by implementing adopted strategies such as the BEMIP. For Latvia, which is largely self-dependent in power production, the focus on the natural gas system is relatively higher. CET-specific efforts can be
  - Continued R&I in power systems development, taking into account increasing shares of intermittent RES and utilisation of hydropower for balancing and storage (which makes this aspect less pressing in Latvia than in the other Baltic states).
  - Continued R&I related to systems aspects in the natural gas system, including the role for gas storage and greening of the supply through blending with biogas, and increasing focus on the role of hydrogen in such a system.
- Further increase the RES share in electricity production, although already relatively high. There is a substantial potential for onshore and offshore wind production, which can contribute to decreasing the share of power for natural gas, and potentially contribute to the export of green electricity. CET-specific efforts can be
  - Continued R&I directed towards solutions for integration of large shares of intermittent RES and the impact of alternative locations for this capacity in the Latvian power system.
  - Investigating the need for technology-oriented R&I on wind and/or solar power or defining a strategy for how to fully benefit from technological development elsewhere.
- Further increase the RES share and total system efficiency for district heating, which involves both increasing shares of biomass-based heat and the use of waste heat and heat pumps. CET-specific efforts can be
  - Continued system-oriented R&I on the use of waste heat, including heat pumps in district heating as well as for providing heat locally. Technologies needed are already well-established.
- Strengthen the focus on increasing the RES share and total system efficiency for the transport sector, in which the RES share is currently low. The near-term plans in Latvia focus on increasing the production and use of biomethane for transport, but also include a discussion on bioethanol and hydrogen. CET-specific efforts can be
  - Continue efforts linked to the integration of compressed and liquefied biomethane for use in road transport and shipping in the Latvian system and on system linkages with the waste handling system. Production technologies for biomethane are already well-established.
  - Strengthen research related to various biorefinery and advanced biofuel technologies, also linked to R&I on energy linkages from the development of a bioeconomy.
  - Initiate additional R&I efforts related to the development of technical system and infrastructure for electrification of transport in the Latvian context, and on actions needed to increase system efficiency (via e.g. increasing the share of collective transport).

    - Initiate R&I efforts to follow-up on the impact and experience from recent hydrogen initiatives.
    - Further develop strategies for how to fully benefit from R&I related to the international development of electric vehicles and increasing vehicle efficiency.
    - Explore the role of digitalisation in supporting electrification and efficiency improvements in the transport system.
- Initiate a stronger focus on increasing energy efficiency in industry. This area has been identified as important, but currently there seem to be a relatively little focus in R&I, apart from, possibly, utilisation of waste heat in district heating. CET-specific efforts can be
    - Strengthen R&I related to deep decarbonisation of industrial processes, primarily linked to the sectors wood processing and cement production.
    - Strengthen R&I related to energy efficiency improvements in SMEs and non-energy-intensive industry.
    - Increase R&I efforts related to energy linkages from the development of both bio- and circular economy and from digitalisation.
- Continue the already strong focus on increasing energy efficiency in the building sector, especially through renovation and measures in existing buildings. CET-specific efforts can be
    - Continue and strengthen R&I focusing on energy efficiency in buildings and on the development of smart and sustainable urban environments, possibly strengthening the focus on improving the processes for renovation of existing building.
    - Further investigate the potential from digitalisation as a tool for an energy-efficient building sector.

2030

In the same way as above, the main needs in Latvia, and associated CETs, in the *2030 time perspective*, have been identified and summarised below (see Chapter 3 for more detail). In this perspective, the RES share in the Latvian power system is expected to have increased substantially, the system integration of the natural gas and power systems is expected to be largely accomplished, as well as the more straightforward measures for increasing the efficiency of buildings, district heating system and industry. Below, the focus is therefore on the more demanding challenges and on the need for added developments of "newer" technologies.

Of specific importance for Latvia in the 2030 time perspective is:

- Continuing the development of RES in electricity production, with a particular focus on
    - Continued R&I directed towards solutions for integration of large shares of intermittent RES, together with the existing hydropower, and the impact of alternative locations for this capacity, including large-scale offshore wind farms and solar power installations at system-relevant scale.
    - Integration of hydrogen in the overall power and energy system.

- Continued development of the district heating system, with particular focus on
  - Continued system-oriented R&I on large-scale use of heat pumps in district heating, and the impact of such developments on the power system.
- Stronger focus on increasing the RES share and total system efficiency for the transport sector, with a particular focus on
  - R&I related to various biorefinery and advanced biofuel technologies, also linked to the wood processing industry and R&I on energy linkages from the development of a bioeconomy.
  - R&I related to alternative technologies for hydrogen production (apart from electrolysers) and on system aspects, including storage, transmission and distribution of larger scale use of hydrogen in the transport system.
  - R&I efforts related to the system impact from larger scale electrification of the transport system, including charging technologies (e.g. electrical road systems).
  - R&I efforts aiming at implementation of digitalisation efforts for supporting electrification and efficiency improvements in the transport system.
- Stronger focus on increasing energy efficiency in industry, with a particular focus on
  - R&I related to deep decarbonisation of industrial processes and to electrification of industrial processes.
  - R&I related to energy linkages from the development of both bio- and circular economy and from digitalisation.
- Continued R&I related to increasing energy efficiency in the building sector, with a particular focus on
  - Integrated local systems (heating, transport, power production and storage) for energy positive buildings and built environment.
  - R&I aiming at benefitting from the potential through digitalisation in the building sector.

As relevant CETs for the **2050 and beyond** time perspective are common to all three Baltic states, please refer to 5.2.4 in Chapter 5 (the content is not repeated in this Appendix).

Lithuania

Lithuania has the most detailed climate and energy targets of the Baltic states, focusing more on increasing the shares of RES, reducing energy intensity and increasing energy self-dependency, than on reduction of GHG per se. The country produced only 32 per cent of final electricity consumption domestically in 2019, of which almost 80 per cent was from renewable sources. Lithuania also stands out among the Baltic states in that it also has a specific target for RES share in the transport sector (15 per cent by 2030). In 2050, electricity and district heating systems should be 100 per cent fossil-free. The national strategy (NEIS) includes four priority areas, which, in addition to climate, include reliability, competitiveness and involvement of business stakeholders.

Now

The main challenges in Lithuania in the "Now" time perspective and CETs that can contribute to addressing these challenges have been identified and summarised below (see Chapter Fejl! Henvisningskilde ikke fundet. for more details). In this summary, the focus is on CET categories or technologies for which we have the impression that R&I activities would need to be strengthened and/or further developed. Other important CET areas, for which already established research and development activities need to be continued, are only included in brief.

Of specific importance for Lithuania in the "Now" time perspective is to:

- Continue the increase of energy independence and interconnections within the Baltics, with Finland and with the EU for both the electricity and natural gas systems, by implementing adopted strategies such as the BEMIP. For Lithuania this need is especially pressing and of high priority. CET-specific efforts can be
  - Continued R&I in power systems development, taking into account increasing shares of intermittent RES, including measures for balancing the system through storage solutions.
- Increase the absolute amount of electricity produced from RES, so that the high RES share can be maintained with increasing total production. Also in Lithuania, there is a substantial potential for onshore and offshore wind production. In addition, one of the leading European manufacturers of solar PV elements is located in the country. CET-specific efforts can be
  - Continue R&I directed towards solutions for integration of large shares of intermittent RES and the impact of alternative locations for this capacity in the Latvian power system.
  - Strengthen research directed at further development of solar PV technologies, building on the industrial and research infrastructure in place.
  - Investigate the need for technology-oriented R&I on other RES technologies (primarily wind power) or define a strategy for how to fully benefit from technological developments elsewhere.
- Further increase the RES share and total system efficiency for district heating, which involves both increasing shares of biomass-based heat, the use of waste heat and heat pumps. CET-specific efforts can be
  - Continued system-oriented R&I on the use of waste heat including heat pumps in district heating, but also for providing heat locally. Technologies needed are already well-established.
- Strengthen the focus on increasing the RES share and total system efficiency for the transport sector, in which the RES share is currently low and which is responsible for the largest share of total GHG emissions. Further, to reach the specified target for 2030, immediate actions

are needed. The near-term plans in Lithuania focus on increasing the production and use of biomethane for transport, and on the development of recharging infrastructure. CET-specific efforts can be

  - Strengthen research efforts linked to the integration of compressed and liquefied biomethane and on system linkages with the waste handling system. Production technologies for biomethane is already well-established.
  - Strengthen R&I related to sustainable transport systems, which seem to be at an early stage of development in the country. This includes R&I efforts related to the development of technical systems and infrastructure for electrification of transport in the Lithuanian context, and on actions needed to increase system efficiency (via e.g. increasing the share of collective transport).
  - Further develop strategies for how to fully benefit from R&I related to the international development of electric vehicles and increase vehicle efficiency.
  - Explore the role of digitalisation for supporting electrification and efficiency improvements in the transport system.
- Initiate a stronger focus on increasing energy efficiency in industry. This area has been identified as important, but currently there seems to be relatively little focus on R&I, apart from, possibly, utilisation of waste heat in district heating. CET-specific efforts can be
  - Strengthen R&I related to deep decarbonisation of industrial processes, primarily linked to the chemical industry, which dominates industrial energy use in Lithuania.
  - Strengthen R&I related to energy efficiency improvements in SMEs and non-energy-intensive industry.
  - Increase R&I efforts related to energy linkages from the development of especially circular economy and digitalisation, in line with the digitalisation strategy adopted.
- Continue the already strong focus on increasing energy efficiency in the building sector, especially through renovation and measures in existing buildings. CET-specific efforts can be
  - Continue and strengthen R&I focusing on energy efficiency in buildings and on the development of smart and sustainable urban environments, possibly strengthening the focus on improving the processes for renovation of existing buildings.
  - Further investigate the potential from digitalisation as a tool for an energy-efficient building sector.

2030

In the same way as above, the main CET challenges in Lithuania and connected R&I activities in the *2030 time perspective*, have been identified and summarised below (see Chapter 3 for more details). In this perspective, the self-dependency of the Lithuanian power system is expected to have increased substantially, but may still be an important challenge to take into account. Further, the system integration of the natural gas and power systems is expected to be largely accomplished as well as the more straightforward measures for increasing the efficiency of buildings, district heating system and industry. Below, the focus is therefore put on the more demanding challenges and on the need for added developments of "newer" technologies.

Of specific importance for Lithuania in the 2030 time perspective is to:

- Continuing the development of RES in electricity production, with a particular focus on
  - Continued R&I directed towards solutions for integration of large shares of intermittent RES, including large-scale offshore wind farms, solar power installations at system-relevant scale and storage systems.
  - R&I efforts related to integration of hydrogen, for which there are several stakeholders in Lithuania, in the overall power and energy system.
- Continued development of the district heating system, with particular focus on
  - Continued system-oriented R&I on large-scale use of heat pumps in district heating, and the impact from such developments on the power system.
- Stronger focus on increasing the RES share and total system efficiency for the transport sector, with a particular focus on
  - R&I related to alternative technologies for hydrogen production (apart from electrolysers) and on system aspects, including storage, transmission and distribution, of larger scale use of hydrogen in the transport system.
  - R&I efforts related to the system impact from larger scale electrification of the transport system, including charging technologies (e.g. electrical road systems).
  - R&I efforts aiming at implementation of digitalisation efforts for supporting electrification and efficiency improvements in the transport system.
- Stronger focus on increasing energy efficiency in industry, with a particular focus on
  - R&I related to deep decarbonisation of industrial processes and to electrification of industrial processes in chemical industry.
  - R&I related to energy linkages from the development of both bio- and circular economy and from digitalisation.
- Continued R&I related to increasing energy efficiency in the building sector, with a particular focus on
  - Integrated local systems (heating, transport, power production and storage) for energy positive buildings and built environment.
  - R&I aiming at benefitting from the potential through digitalisation in the building sector.

As relevant CETs for the **2050 and beyond** time perspective are common to all three Baltic states, please refer to section 5.2.4 in Chapter 5 (the content is not repeated in this Appendix).

Nordics

The current status and expected development of different CETs in a Nordic context is extensively described in the Nordic Clean Energy Scenarios (NCES) report. The report is used as a major source of input to the current situation and future development of the energy system in the Nordics, with focus on Baltic-Nordic co-operation opportunities. Here, the key initiatives and areas of competence in the Nordics for collaboration are outlined.

A summary of the major impacts of the proposed five solution tracks in NCES is given below, followed by a table, collecting stakeholders and activities within the Nordics that are potentially relevant for Baltic-Nordic near- and medium-term collaborations.

Direct electrification central to all scenarios
Nordic electricity demand grows in all NCES scenarios, with transport and PtX fuels being the main drivers. From 390 TWh in 2020 to about between 535 and 760 TWh in 2050, depending on the scenario. A massive expansion of renewable power generation will be needed.

P2X – a potential game changer
The demand for P2X fuels will only be high for some of the scenarios, its higher costs and lower energy efficiency being the major barriers. Given a massive expansion of renewable power generation in combination with limited availability of biomass (due to e.g. biodiversity issues), P2X may however become important, potentially even being exported from the Nordics to continental Europe. The EUs aggressive hydrogen strategy and industry projects could also lead to a dramatic increase in demand for hydrogen, favouring P2X fuel production in the Nordics.

Bioenergy
Nordic bioenergy use remains high towards 2050, with transport and industry driving the increase in demand. Towards 2050, there is expected to be an increasing shift of biomass use to hard-to-abate sectors such as heavy transport, steel and cement.

CCS including BECCS
Carbon capture and storage, and negative emissions are essential. Large-scale roll-out of CCS is required from 2030, underscoring the need to develop needed infrastructure and accelerate deployment through policy support.

Nordic collaboration
The differences between the individual countries' energy systems are a strength, resulting in a number of potential synergy effects through collaboration, while the development of necessary infrastructure emerges as a major coordination challenge in all NCES scenarios.

Critical near-term actions
Among the most critical near-term actions to foster rapid clean energy technology deployment at large scale, the NCES report points out the following issues for the Nordic countries, which are vital to all NCES scenarios:

- stronger grids
- increased flexibility
- wind and solar electricity deployment
- electrification of transport
- CCS technologies

Existing solutions continue to be important, such as:

- bioenergy and
- district heating

At the same time, innovative market developments can unlock the potential of both emerging and existing technologies.

To make policy targets easier and less costly to reach, it is important to reduce the energy demand through:

- efficiency improvements and
- behavioural change

Relating to the abovementioned near-term actions, a number of ongoing and planned initiatives, including the stakeholders related to these projects, are presented in Table 23, grouped by the CET categories used in the present report. The list is far from being a complete overview of initiatives but presents some relevant examples on CET projects that could also be of interest in a Baltic-Nordic context.

Table 23. Nordic projects and stakeholders [SH1] for potential Baltic-Nordic collaborations within Clean Energy Technologies (mainly based on the NCES report). Stakeholders/initiatives active in multiple CET categories have only been listed once.

CET categori with Nordic projects/stakeholders

INTEGRATED POWER AND ENERGY SYSTEMS

CCS – Northern Lights/Longship Project (NO)[1 2]
Stockholm Exergi – BECCS (SE)[3]
NEL Hydrogen (NO)[4]
Denmark – Energy islands (DK)[5]
Liquid Wind – e-MeOH (SE)[6]
Carbon Recycling Internationals– e-MeOH (IS)[7]
Statkraft, Yara, Aker – e-NH3 (NO)[8]

ZERO EMISSION POWER GENERATION TECHNOLOGIES

Vattenfal[9]
Fortum[10]
Ørsted[11]
Equinor (NO)[12]
Siemens Energy[13]

LOW EMISSION TRANSPORT SYSTEMS

Battery electric trucks – Volvo[14] / Scania[15]
Hydrogen Fuel Cell Electric trucks – Volvo[14]
Northvolt[16] – Battery production/recycling
Electric road systems – 4 projects in Sweden (Elonroad Lund[17]
eRoadArlanda[18], Scania/Siemens Gävle[19], Smartroad Gotland[20]
HVO/Advanced biofuels – Preem (SE)[21]
HVO – Neste (FI)[22]
HVO/Biofuels – St1 (SE/FI)[23]
Green ammonia in shipping – Zeeds (NO)[24]
Nordic Electrofuel – e-crude/jet fuel (NO)[25]
The Swedish Knowledge Centre for Renewable Transportation Fuels (SE)[26]
Bio4Fuels (NO)[27]

INDUSTRIAL ENERGY SYSTEMS

CemZero[28] – Cementa, Vattenfall
HYBRIT[29] – SSAB, LKAB, Vattenfall
H2GreenSteel[30]
Pulp & Paper Industry (SE/FI)
Biorefinery clusters (SE/FI/NO)
Valmet (FI)[31]

URBAN AND BUILT ENVIRONMENTS

Centre for IT-Intelligent Energy Systems (DK)[32]
Department of the Built Environment – Aalborg University (DK)[33]
SmartCitySweden (SE)[34]
FinEst Centre for Smart Cities (FI (& Estonia)[35]
NTNU Smart Sustainable Cities (NO)[36]

CROSS-CUTTING TECHNOLOGIES

DigIn – Digital innovation of business models (SE)[37]
Finnish Centre of Artificial Intelligence (FI)[38]
ICT and digitalisation at Aalto University (FI)[39]
DigitalNorway (NO)[40]

See footnotes next page

[1] https://northernlightsccs.com/

2 https://ccsnorway.com/

[3] https://www.stockholmexergi.se/minusutslapp/beccs/

[4] https://nelhydrogen.com/

[5] https://en.energinet.dk/Green-Transition/Energy-Islands

[6] https://www.liquidwind.se/

[7] https://www.carbonrecycling.is/

[8] https://www.yara.com/this-is-yara/yara-clean-ammonia/

[9] https://group.vattenfall.com/

[10] https://www.fortum.com/

[11] https://orsted.com/

[12] https://www.equinor.com/

[13] https://www.siemens-energy.com/

[14] https://www.volvotrucks.se/

[15] https://www.scania.com/

[16] https://northvolt.com/

[17] https://elonroad.com/

[18] https://eroadarlanda.se/

[19] https://www.regiongavleborg.se/regional-utveckling/samhallsplanering-och-infrastruktur/elvag/

[20] https://sv.smartroadgotland.com/

[21] https://www.preem.com/in-english/

[22] https://www.neste.com/

[23] https://www.st1.com/

[24] https://zeedsinitiative.com/

[25] https://nordicelectrofuel.no/

[26] https://f3centre.se/en/

[27] https://www.nmbu.no/en/services/centers/bio4fuels

[28] https://www.cementa.se/sv/cemzero

[29] https://group.vattenfall.com/se/var-verksamhet/vagen-mot-ett-fossilfritt-liv/minska-industrins-koldioxidutslapp/hybrit

[30] https://www.h2greensteel.com/

[31] https://www.valmet.com/

[32] https://smart-cities-centre.org/

[33] https://www.en.build.aau.dk/

[34] https://smartcitysweden.com/

[35] https://www.finestcentre.eu/

[36] https://www.ntnu.edu/smartcities

[37] https://www.ltu.se/research/subjects/Entrepreneurship-and-Innovation/Forskningsprojekt/DigIn?l=en

[38] https://fcai.fi/

[39] https://www.aalto.fi/en/research-art/ict-and-digitalisation

[40] https://digitalnorway.com/

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Stefan Heyne, Ingrid Nyström, Anna Volkova

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