Transitioning to a climate-neutral electricity generation

Deliverable 8 Report: Final report

Contract details

European Commission – DG Reform

Transitioning to a climate-neutral electricity generation

REFORM/SC2020/068

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Transitioning to a climate neutral electricity generation

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Introduction

The Estonian Government, after hosting thorough debate in The Estonian Climate and Energy Committee, chaired by the Prime Minister, has publicly committed to achieve climate neutrality in EU by 2050, in line the objectives of the Paris Agreement. To achieve this target, the Estonian government will need to assess how existing governance mechanisms can be supplemented with various plausible technologies and policies over the next three decades in order to decarbonise electricity.

This is the Final Report for the project on the *"Transition to a Climate-Neutral Electricity Generation"* for the European Commission (DG REFORM), which supports the Estonian Ministry of Economic Affairs and Communication to define pathways and develop an Action Plan in order to achieve climate neutral electricity production by 2050. The results of this study are to provide Estonian officials a clear understanding of the costs and benefits association with different pathways to electricity decarbonisation and provide evidence-based recommendations for future policies to scale Estonia's low carbon transition. The project has been developed in collaboration with Trinomics, the Stockholm Environment Institute (SEI) and E3-Modelling (E3M).

This final report includes the following:

- An executive summary
- Overview of the project activities and results;
- Answers to study questions;
- Lessons learned and recommendations;
- Overview of project monitoring indicators;
- Overview of key project challenges;
- Annexes.

Executive summary

This is the summary for the project “Transition to a Climate-Neutral Electricity Generation” for the European Commission (DG REFORM), which aims to support the Estonian Ministry of Economic Affairs and Communication in defining the strategy to achieve climate neutrality by 2050 (in line with the objectives of the European Green Deal). To achieve this target, the Estonian government needs to assess how which technologies and policies can be deployed over the next three decades in order to decarbonise the generation of electricity. The overall objective of this study is to propose institutional, administrative and growth-sustaining reforms in Estonia to achieve the decarbonisation of the power sector. Specifically, the study supports the Estonian Ministry of Economic Affairs and Communications by a) Defining pathways towards climate neutral electricity production; and b) Developing an Action Plan on decarbonising electricity production, for eventual adoption.

The results of this study are to provide Estonian officials with a clear understanding of the costs and benefits associated with different pathways for the decarbonisation of electricity and provide evidence-based recommendations for future policies to scale Estonia’s low carbon transition. The project has been developed in collaboration with Trinomics (lead partner), the Stockholm Environment Institute (SEI) and E3-Modelling (E3M) from September 2020 to September 2022.

Pathways for Estonian electricity generation

The study examined one reference (business as usual) and seven climate neutral electricity production pathways for Estonia, their key distinguishing characteristics are summarised below in Table 0-1.

Table 0-1 Pathways and their key characteristics

Pathway	Key characteristics[1]
Reference	- BAU unconstrained by EU Reference Scenario 2020 capacity projections, which is a continuation of today’s trends[2] - Includes demand for economically feasible levels of Power-to-X[3]
Renewables + storage (offshore wind)	- 1 GW offshore wind installed in Estonia by 2030, 2GW by 2035, 3GW by 2040, 4GW by 2050
Nuclear	- 900 MW Gen III+ small modular nuclear reactor capacity built in Estonia by 2040
CCU	- Carbon capture added to Oil Shale plants TG11 in 2025 and Auvere in 2030
Renewable gas	- 1 GW of renewable (bio)gas capacity built in Estonia by 2030
All technologies	- Investments in all low-carbon technologies allowed - No additional constraints on imports or capacity
1000 MW dispatchable capacity	- Investments in all low-carbon technologies allowed - At least 1000 MW of dispatchable capacity installed in Estonia at all times
AT-NIMP	- Investments in all low-carbon technologies allowed - Balanced electricity imports/exports into/out of Estonia each year

[1] In the technology-focused and technology competition pathways, no net non-biogenic CO_2 emissions are allowed from electricity production in Estonia in 2050, and direct air capture of CO_2 is available. Each technology-focused pathway requires an investment in a core low-carbon technology, with additional investments in all storage and renewable generation technologies (e.g., onshore wind, solar PV, Paldiski hydro plant, batteries) permitted.

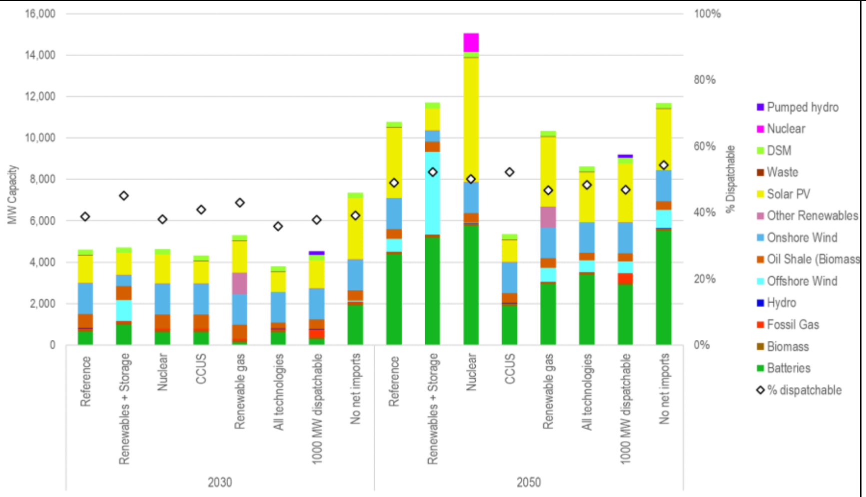
[2] The EC’s analysis of the Reference Scenarios 2020 (https://energy.ec.europa.eu/data-and-analysis/energy-modelling/eu-reference-scenario-2020_en) assumed the addition of new renewable energy capacity in the Baltic and Nordic countries, this analysis did not assume this, but allowed the model to choose in which country and to what extent it is more feasible to build new capacity.

[3] Power-to-X refers to the conversion of surplus renewable electricity in the grid into either gas, liquid fuels or heat (e.g. hydrogen production from electricity or heat storage from heat pumps).

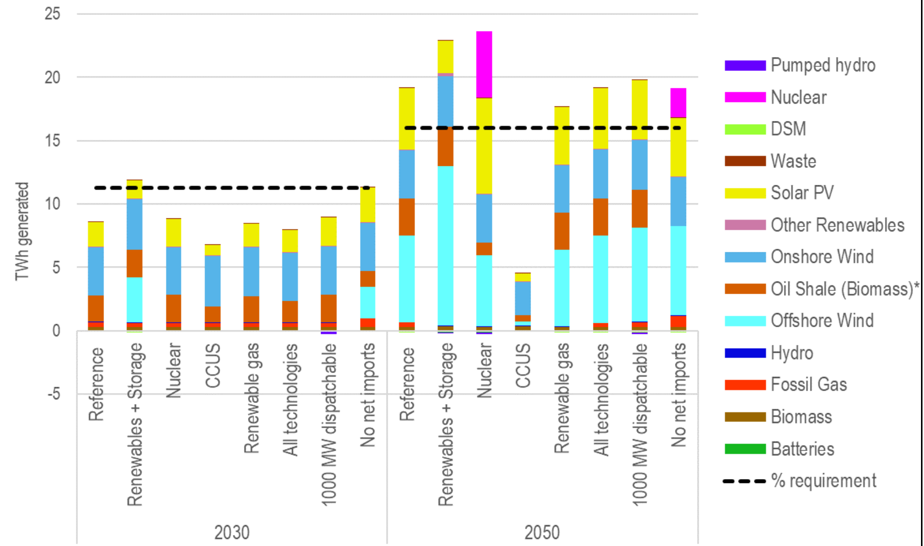
The main results of the pathways in terms of capacity, generation, prices and emissions are presented in the following table 0-2.

Table 0-2. Key pathway results

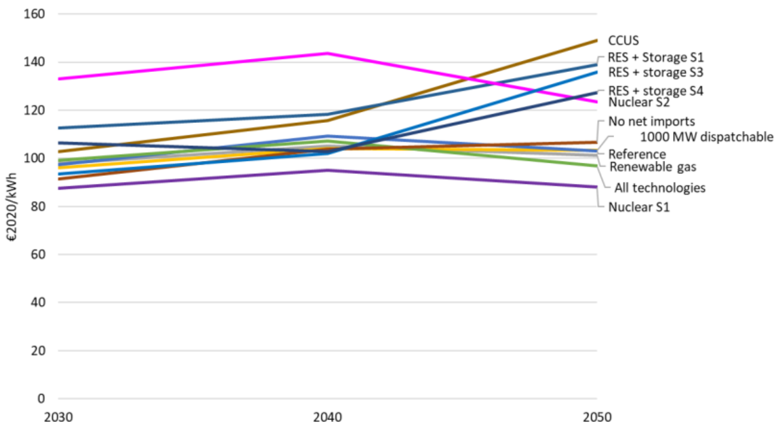
Capacity (MW)



Generation (TWh)



Prices (EUR/MWh)



Emissions (ktCO2e)

GHG emissions	2020	2030	2040	2050	Total cumulative 2020-2050
BAU	2 667	763	98	187	**24 306**
RES+STORAGE	2 667	782	84	79	**23 761**
Nuclear	2 667	754	41	30	**22 780**
CCU	2 667	493	-136	-147	**17 430**
RES-GAS	2 667	728	77	68	**23 092**
AT	2 667	722	77	167	**23 572**
AT+1000	2 667	787	213	199	**25 764**
AT-NIMP	2 667	766	784	324	**31 950**

* in all scenarios except CCU the oil shale plants are converted to run on biomass in the 2030's

Amongst the other key assumptions relevant for the pathways are assumptions regarding the EU-ETS price to 2050 and the total electricity demand. These are presented below in Table 0-3.

Table 0-3 Key assumptions in pathway modelling

	2030	2035	2040	2050
EU-ETS price assumption [EUR/tCO_2]	50	55	80	159
Estonia electricity demand requirement [TWh]	11.30	12.17	13.04	16.03

Technology development and required investment

Based on the modelling results, this analysis concluded that a few technologies reach their full deployment potential in all scenarios considered, namely onshore wind and demand side management (DSM), and to a lesser extent solar PV. Deployment of other technologies, such as offshore wind, CCU and nuclear, depends on the technology mix of each scenario. Across all scenarios, the expected deployment of storage (e.g. batteries) at the required capacities is a recurring challenge. The required investments for technology deployment and transmission reinforcement in all scenarios are substantial, amounting on average to €8.0 billion up to 2050. There are also additional costs for the policy actions required to support these technology pathways, however, providing reliable cost estimates is not possible within the limitations of this study.

Scenario selection

Table 0-4 (below) provides an overview of the assessment of the pathways, an assessment carried out according to the two sets of criteria described in detail in the summary of the key results. According to the first set of criteria[4], the **All technologies** and the **Renewable + Storage (offshore wind)** scenario are the pathways that appear to offer the best combination of benefits, costs, risks and feasibility. Another option that appears to offer a balanced outcome is the *RES GAS* scenario (positive rating across the range of indicators considered), but the construction of the capacity of biogas generation envisioned in the model should be carefully revisited (significantly reduced) as the model shows that biogas generates little electricity due to high operational costs (high cost of biogas feedstock). According to the second set of criteria, the **Nuclear**, the **Renewable + Storage (offshore wind)** and the **All technologies** are instead the scenarios that rank on top. Combining both assessments, the **Renewable + Storage (offshore wind)** and the **All technologies** scenarios emerge as the most promising.

However, the choice of the preferred pathway is a “political” choice, as all pathways presented reach the decarbonisation objectives and the other main objectives set for the Estonian electricity system. This report, and the evaluation it provides, should be used by decision makers and stakeholders to identify the path towards decarbonisation that they feel more comfortable with, rather than to be considered the final decision. We expect different stakeholders to put different weight on different indicators, and arrive at different conclusions on the preferred pathway.

[4] The first set of criteria was more comprehensive and included 12 different parameters, e.g. stakeholder preferences, implementation risks, socio-economic benefits, financial costs and environmental impacts

Table 0-4 Summary assessment of pathways

	Consultant assessment	Alternative ranking*	Assessment and key actions
RES + storage	Recommended	2	Is the most ambitious pathway, which foresees the deployment of large amounts of offshore wind and storage, and that results in the highest total investment costs, both in generation and transmission infrastructure. However, the investment generates positive economic impacts, and environmental impacts from large offshore deployment can be managed. Key actions focus on facilitating offshore deployment (technology-specific support; offshore grid; transmission capacity), on supporting the deployment of storage solutions, and on protecting vulnerable consumers from possible increases in energy bills.
Renewable gas	Recommended	4	While the modelling results for the Renewable gas scenario provide a relatively balanced power system, there are inconsistencies that suggest this may not be an ideal trajectory for Estonia, unless some of the assumptions change. In particular, deploying lower quantities of biogas would create a more cost effective system.
All Technologies	Recommended	2	This is the base case technology neutral scenario. It provides a balanced generation mix and investment profile over time. While it does not score particularly positive in any of the areas considered, it also has no major negative point.
No net imports	Viable	6	The other two technology-competition pathways have similar results in terms of technology mix, costs and dispatchable capacities. Based on the assumptions, different technologies emerge. Recommended actions also follow a technology-neutral approach, and aim to keep all options open until costs become clearer. The *AT-NIMP* is amongst the pathways expected to be most economically beneficial. It is also one of the few pathways that does not rely on biomass-fuelled oil shale plants for a significant share of generation after 2030, which points to a more sustainable impact on Estonian forests, however at the cost of greater use of natural gas
1000 MW dispatchable capacity	Viable	5	
Nuclear	Not recommended	1	The pathway is characterised by a focus on nuclear and solar PV, and it is expected to be the second most expensive pathway, although it is expected to have lower electricity prices in 2050. The main actions identified concern the development of a national nuclear programme and supporting actions to other renewables. According to stakeholders, this is the riskiest scenario, especially as it relies on a technology that has no history in Estonia and that is not expected to come online before 2035.
CCU	Not recommended	7	This scenario requires the lowest investment and continues exploiting fossil fuel reserves in the long term, although modelling suggests this will still decline to around ¼ of current levels. While the actions required for its implementation are fewer and simpler than for other pathways, this is the pathway expected to be worst for the economy and employment, and would leave Estonia most dependent on power imports in future. CCU could be a good option for Estonia if further use and transport options for CO_2 are identified, so that carbon capture can be deployed to other power plants (beyond the two considered in this analysis) and industrial installations, and if costs can be made economically competitive.

*based on 5 criteria: investment costs, electricity prices in 2050, GDP, job creation and share of domestic generation in 2050.

Priority actions

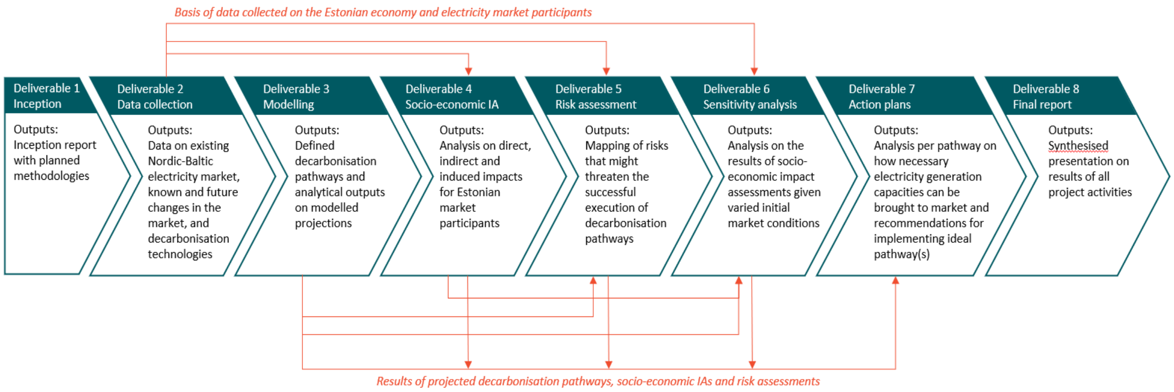
This analysis also identified several actions that are likely to be needed across all pathways:

1. Review of the planning process;
2. Renewables support;
3. Expand the electricity system balancing market to encourage investments in flexibility technologies; and
4. Reinforcement to the transmission network (reinforcement to the distribution network, while not assessed in this assignment, are also likely to be required).

1 Overview of project activities and results

The project activities consisted of eight interlinked tasks. Figure 1-1 shows the overview of our approach, deliverables, activities, and sequence of tasks. The project includes eight deliverables. Deliverable 1 is the inception phase during which the different steps were discussed with the client. Deliverable 2 was the data collection. The other 6 deliverables are explained in further detail in the following sections. The final chapter gives answers to additional questions raised during the study.

Figure 1-1 The project activities



1.1 DLV3: Modelling pathways

Deliverable 3 aimed at defining and analysing the potential routes to a decarbonised electricity production in Estonia by 2050. The modelling accounted for relevant market, policy, and physical dynamics in Estonia and considered nine future scenarios: a Business-as-usual (BAU) scenario, a Reference scenario (used as the baseline for comparisons), four technology-focused decarbonisation pathways (each exploring the impacts of investing in a particular low-carbon power technology in Estonia), and three decarbonisation pathways that allow for competition between technologies, given set constraints.

The modelling covers the period from 2015 to 2050, with each year divided into 192 sub-annual time slices. The time slices represent with hourly resolution a typical weekday and a typical weekend day in each of four seasons (winter, spring, summer, and fall). Results for this interval were calibrated to known historical data and were validated by Elering. Projections begin in 2021 and run through 2050. Geographically, the model distinguishes 21 regions, including: five regions of Estonia; Nord Pool bidding areas for Denmark, Finland, Germany, Latvia, Lithuania, Norway, and Sweden; and Poland.

The modelling of final electricity demand is broken down by major sector or source within Estonia, including the residential sector, agriculture, mining and manufacturing, construction, other industry, retail and services, and transport[5]. In other regions, total final electricity demand is projected without sectoral detail. Intermediate demands for electricity producers' own use are represented in

[5] The total electricity supply requirement (demand) is: 2020 = 10.3 TWh; 2030 = 11.3 TWh; 2040 = 13.0 TWh; and, 2050 = 16.0 TWh, a breakdown per sector is provided in Figure 3-3.

all regions, as are losses in the electricity transmission and distribution grids. In Estonia, electricity demand for hydrogen production is also modelled as part of an analysis of economically feasible power-to-X. It is assumed that 4.1 TWh of electricity will be required to produce 160 kt of hydrogen, the economically feasible hydrogen demand in Estonia in 2050.

On the supply side, the model individually represents significant electricity generation and storage plants and units within Estonia, such as the existing Auvere oil shale plant and the proposed pumped hydro facility at Paldiski[6]. Other electricity generation and storage capacity, both in Estonia and other regions, is aggregated by technology. High-voltage transmission connections among the modelled regions and between third countries (i.e., countries outside the study area) and modelled regions are simulated as well. Transmission capacity is aggregated by pair of trading partners (modelled regions and third countries) rather than representing each transmission line separately.

The principal simulation method in the Deliverable 3 modelling is cost optimisation. Given a projection of electricity demands, and subject to physical limits and other constraints imposed in scenarios, the model finds a supply solution that minimizes discounted, system-wide electricity production costs.

The preliminary modelling results of Deliverable 3[7] indicate that in all climate-neutral (non-baseline) pathways, Estonian electricity production **shifts from oil shale toward wind and solar** (with 70-85% of domestic generation from wind and solar under all pathways by 2050). Fluctuations in wind and solar output are **balanced primarily by built-up dispatchable generation and storage[8], with some demand-side management (DSM) and electricity imports**. Pumped hydro only emerges in some scenarios (RES+storage, nuclear and 1000 MW), but at much lower capacities than batteries (making up at most 4% of total storage capacity in 2050 in the 1000 MW scenario). The model prefers to deploy batteries because of the cost and because of the limited potential of pumped hydro available.

Among these options, batteries and DSM are particularly cost-competitive across scenarios. A large build-out of batteries (4.6 - 9.3 GW) is projected in every pathway due to their flexibility and declining costs. There are reliability advantages to developing wind and solar power together in Estonia owing to **complementarity in the availability of wind and solar resources**. **Onshore wind** is generally **more cost-competitive than offshore wind** across scenarios, but some offshore wind is installed in Estonia in nearly every climate-neutral pathway (in some pathways by 2030 or 2040, in others only by 2050). New transmission investments are needed to exploit Estonia's offshore wind potential (likely 600-1300 MW between Lääne-Eesti and other regions).

Later analysis identified that it would be better to use alternative wind availability curves in the pathway modelling; these were applied as part of the sensitivity analysis in Deliverable 6, and the first sensitivity analysis (S1) of that deliverable presents the main pathway outputs. These revised

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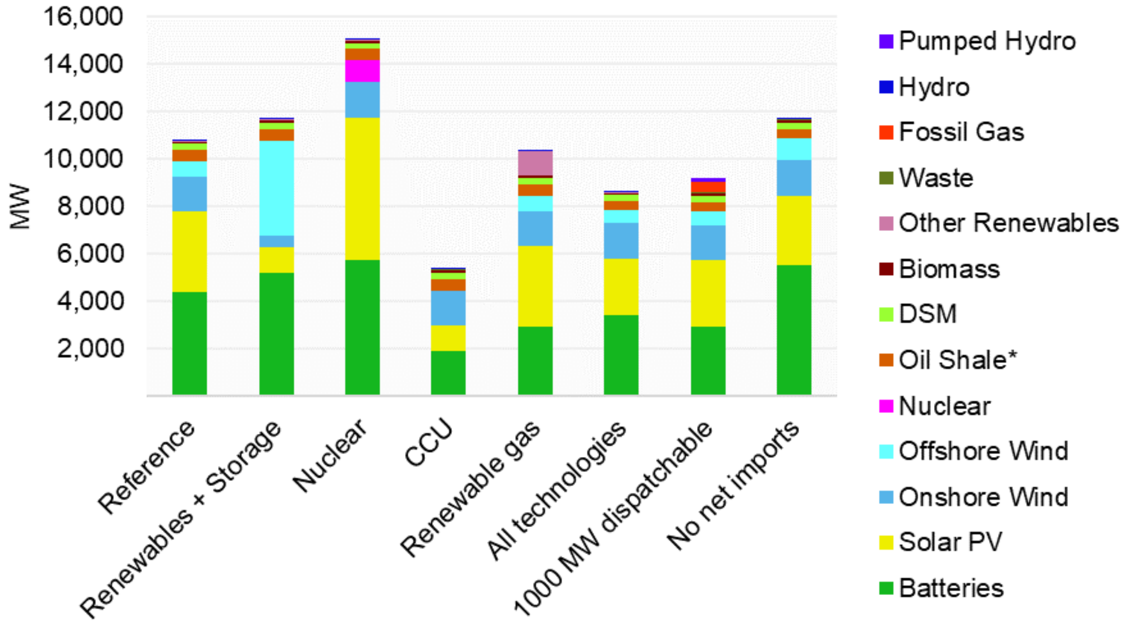
[6] Around 50 individual plants, plant units or technologies, both existing and potentially new, were modelled in the work. A full list is provided in Annex D to Deliverable D3.
[7] It is important to note that the results of Deliverable 6 (sensitivity analysis) are used as the final results for the action plan (Deliverable 7).
[8] In all scenarios, battery storage accounts for over 90% of all storage capacity in 2030 and 2050.

results represent the base pathways for the analysis and the results are presented in the section covering Deliverable 6.

Figure 1-2 shows projected installed capacity in Estonia in 2050 for each (S1) pathway. Low technology costs drive significant build-up of batteries, solar PV, and onshore wind across all scenarios. Onshore wind and DSM potential is fully utilized in most scenarios. However, there is limited or no potential to expand waste or biomass capacity, as resource use is limited, or hydropower capacity, which is not cost-competitive compared to alternative technologies.

Figure 1-2 Projected capacities per pathway (S1), Estonia 2050



** By 2050, former oil shale plants are converted to use 100% biomass, unless they're retrofitted with CCU (only permissible in the CCU and All technologies pathways).*

1.2 DLV4: Analysis of Socio-economic impacts

The aim of Deliverable 4 was to assess the socioeconomic impacts of the pathways toward climate neutrality developed and analysed in Deliverable 3. The modelling focused on quantifying the impacts on energy sector investment, on GDP, on employment, and on disposable income associated with each pathway. The socio-economic outputs were also updated at the same time as the updated pathways presented in D6, the results presented below are from the D6 update.

The socio-economic impacts were modelled in a few different ways and with differing assumptions on financing. The starting point was the investments made in the energy system, the volume of investments is shown in Table 1-1 below. This shows that the highest investments are needed in the RES-Storage, Nuclear and RES-Gas pathways, the least in the CCU pathway.

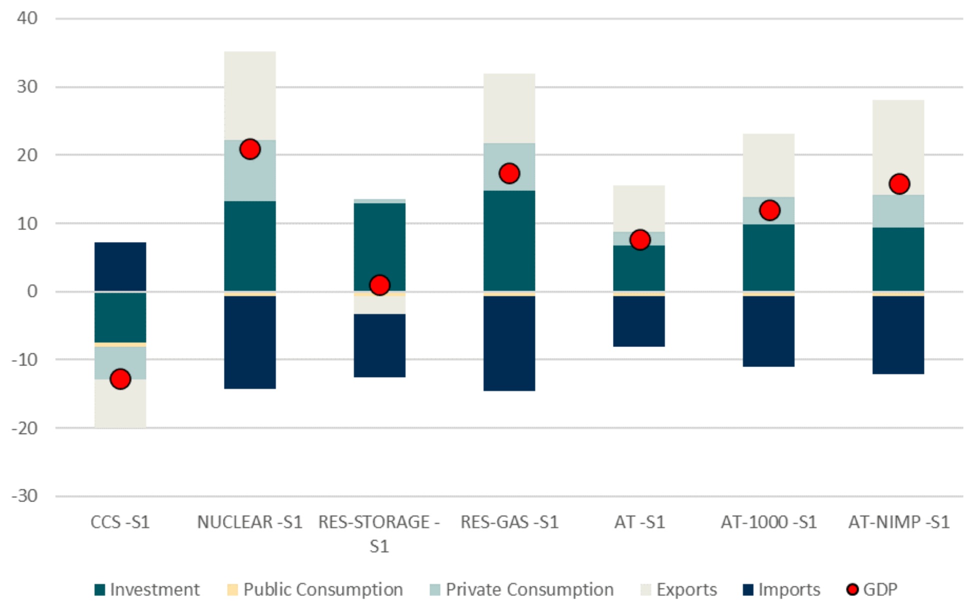
Table 1-1. Investment per pathway including Capital Costs and Interest payments (mil. €)

	Sensitivity case	Capital	Interest payments	Total	Post 2050 remaining payments
Reference	S1	6,884	2,027	8,911	3,295
All Technologies (AT)	S1	6,972	2,053	9,025	3,327
AT-1000	S1	7,623	2,245	9,868	3,311
AT - No Net Imports (NIMP)	S1	8,075	2,379	10,454	2,540
RES - Storage	S1	11,040	3,253	14,293	2,182
RES - Gas	S1	8,942	2,635	11,577	2,983
Nuclear	S1	9,338	2,751	12,089	3,193
CCU	S1	3,065	901	3,966	344

These investments were used to model economic impacts, with Figure 1-3 presenting the overall cumulative macroeconomic adjustment for each pathway for 2025-2050, this shows that all except the CCU pathway result in positive economic outcomes. The Nuclear, RES-Gas and AT-NIMP pathways show the most positive outcomes, the balance of the economic multipliers of increased investment and the impact of energy price changes on the economy combining positively. For RES-Storage a strong economic impact of investment was offset by increased prices which affect domestic demand and international competitiveness. Sensitivity analyses demonstrated that if prices could be kept lower then RES-Storage would become one of the most favourable pathways for socio-economic outcomes. For the nuclear pathway the trend was reversed in the sensitivity of enforcing a 90% load factor (i.e. preferential treatment for nuclear power, compared to the 65-70% values it achieves in the S1 base case)[9], with this leading to the highest economic positive turning negative as it drives price increases, undermining competitiveness.

[9] The S1 pathways only used alternative wind curves. The S3 pathway is where a 90% load factor for nuclear was imposed.

Figure 1-3 S1- Macroeconomic adjustment of the different scenarios (demand & price effects) - GDP - cumulative (2025-2050) (based on S1 base case results)



Employment changes follow the overall pattern of GDP impact, with the modelled changes leading to a +0.4% increase in employment in the nuclear pathway compared to the reference pathway, and a -0.3% change for the CCU pathway. The other pathways falling between these two levels. Employment gains are most significant in lower skilled occupations, particularly in construction and services.

Analysis of the distributional implications of the pathways on household income showed that the RES-Storage, NUCLEAR and RES-GAS pathways have the most positive impacts, primarily due to the impacts of additional investments on wages. CCU has positive impacts in the short term, but after 2035 turns negative compared to the reference pathway. The all technologies pathways have little impact on disposable incomes.

Overall, the Nuclear, RES-GAS, AT-NIMP and RES-Storage pathways deliver the best socio-economic outcomes, and CCU by far the worst. Sensitivity checks highlighted that socio-economic outcomes can be improved for RES-Storage when price increases are reduced, while for nuclear, positive socio-economic outcomes are dependent on it not being forced to run at very high loads.

1.3 DLV 5: Risk analysis

Deliverable 5 aimed at evaluating the key risks that may affect the successful implementation of the pathways, going beyond the risks that could be better represented via modelling (e.g. risk related to wind output). The analysis focussed on 5 areas of risks: Regulatory risk, Technological Risk, Socio-environmental Risks, Energy Market risks and Economic risks. The analysis of the risks can be found in the Deliverable 5 report and more specifically, the risks per pathway can be found in the Deliverable 7 report.

The methodology adopted aimed at evaluating stakeholders' perception of these risks, and how different scenarios may be affected by them. To do so, a questionnaire was shared with stakeholders, asking a series of open questions and requesting stakeholders to rate the likelihood and severity of different risks for each pathway.

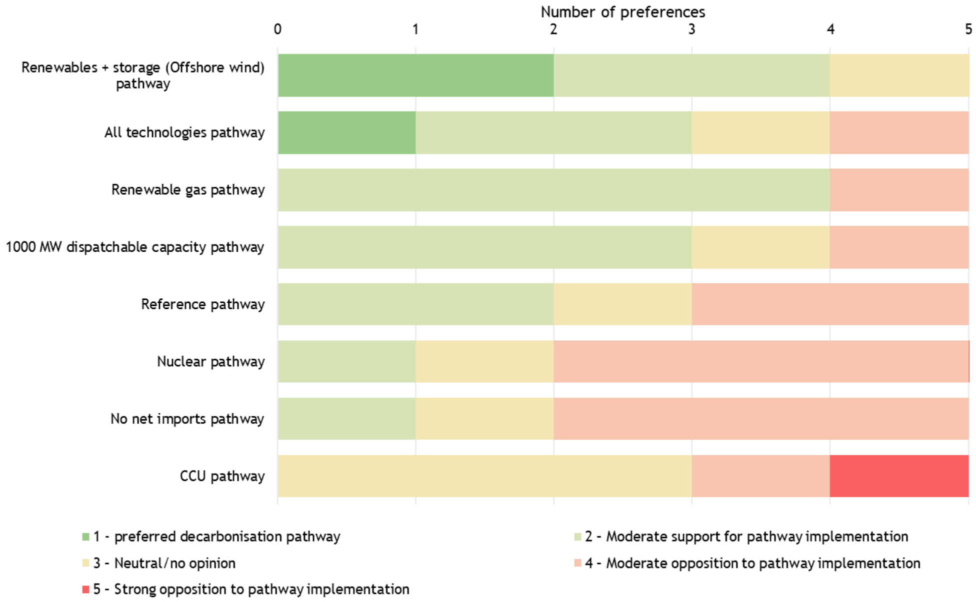
Stakeholders consider the nuclear pathway as the riskiest (a medium-high level of risk), while Renewable gas is the less risky one – although marginally less than all other pathways. The average score across all respondents and all categories of risks (Table 1-2) shows how the scenarios' scores compare for likelihood and severity across all risks.

Table 1-2 Average risk score by pathway (all risks)

	Likelihood	Severity	Total	Summary
Renewable gas	2.61	2.67	2.64	Less risky scenario, overall liked by stakeholders. Very exposed to international energy prices but less exposed to the risk of competition for rare materials needed for batteries.
All technologies	2.88	2.82	2.85	Low risk scenario with good stakeholder support.
Reference	2.88	2.98	2.93	-
1000 MW dispatchable capacity	2.93	3.00	2.96	Second best scenario, liked by stakeholders.
CCU	2.94	3.16	3.05	Medium risk scenario, but disliked by stakeholders. Main risk is technological
Renewables + storage (Offshore wind)	2.92	3.23	3.07	Perceived as risky by stakeholders, although it is the most supported. Exposed to high energy market risk
No net imports	3.24	3.27	3.26	Second highest risk, overall disliked by stakeholders. High regulatory risks
Nuclear	3.52	3.83	3.67	Riskiest scenario, stakeholders moderately negative about it. Main risks are related to citizens opposition, regulation, and technological delay and cost overruns.
Grand Total	**3.02**	**3.17**	**3.09**	

Survey respondents were also asked to rank preferred pathways using a scale of 1 to 5, with 1 being the preferred pathway and 5 being the least favourite pathway (opposed to). *Renewables + storage is* the pathway that attracted the highest support, followed by the *All technologies pathway*. These are followed by the *Renewable gas pathway*, that received several votes as "moderate support". The *CCU pathway* is the one with the lowest support and the only one for which a stakeholder came out as clearly opposing it.

Figure 1-4 Pathway by preference



The survey was followed by a series of seven targeted interviews which involved main stakeholders (developers, trade associations, experts). During the interviews, stakeholders were asked to elaborate on the results of the survey, and helped to provide further insights on the different categories of risks.

During the interviews, stakeholders were also asked to provide their view concerning currently existing barriers to the uptake of these pathways, and to suggest actions that should be implemented to address overcome barriers and address risks.

1.4 DLV 6: Sensitivity analysis

The aim of Deliverable 6 was to assess the robustness of the critical assumptions underlying the modelling of the decarbonisation pathways (Deliverable 3). This assessment is done by investigating four sensitivities, the first of which became the new base case for the pathway modelling, replacing the results of Deliverable 3:

- *(S1) Sensitivity to test alternate wind availability curves in all pathways:* Uses a more granular version of the wind variability profile for Estonia that better represents the variances in availability over a year. The pathways produced using this sensitivity supersede the pathways produced in D3, and are also used as the basis for the following sensitivity analyses;
- *(S2) Sensitivity to test higher nuclear dispatch in the NUCLEAR pathway:* Enforcing a dispatch rate of 90% on nuclear generation and comparing resulting outcomes to the nuclear pathway.
- *(S3) Sensitivity to higher biomass prices in the Renewables + storage [RES storage] pathway:* assume a rising price for biomass (that could reflect potential restrictions on harvesting, or a new definition of biomass's sustainability) by 2050. Compare resulting model outcomes to the Renewables + storage pathway.

- (S4) Sensitivity to higher battery costs and construction of Paldiski pumped hydro facility, including sensitivities (S1), (S2) and S3) in the Renewables + storage [RES storage] pathway: The RES+storage pathway emerged as one of the most attractive potential options, however storage plays a crucial role, testing the impact of higher battery capital costs (x2.5 higher than base case), and the role that pumped hydro could play are important sensitivities to support the analysis. As noted, this sensitivity scenario also includes all other sensitivities.

The full 2050 results for S1 are presented below in Table 1-3.

The S1 analysis shows that batteries and DSM are particularly cost-competitive across scenarios. A large build-out of batteries (4.5-9.3 GW) is projected in every pathway due to their flexibility, declining costs and need to balance intermittent renewable sources. There are reliability advantages to developing wind and solar power together in Estonia owing to complementarity in the availability of wind and solar resources. Onshore wind is generally more cost-competitive than offshore wind across scenarios, but some offshore wind is installed in Estonia in nearly every climate-neutral pathway (in some pathways by 2030 or 2040, in others only by 2050) except CCU. New transmission investments are needed to exploit Estonia's offshore wind potential (likely 600-1300 MW between Lääne-Eesti and other regions).

Low technology costs drive significant build-up of batteries, solar PV, and onshore wind across all scenarios. Onshore wind and DSM potential is fully utilized in most scenarios. However, there is limited or no potential to expand waste or biomass capacity, as resource use is limited, or hydropower capacity, where potential is low and it is not cost-competitive compared to alternative technologies.

Dispatchable capacity increases a little in all pathways between 2030 and 2050 but this is almost entirely from the addition of battery capacity and continued reliance on oil shale plants running on biomass. The pathways which add the most alternative dispatchable capacity are Nuclear (900MW nuclear), Renewable-Gas (1000MW biogas), AT-1000MW (348MW pumped hydro and 190MW Gas) and AT-NIMP (406MW Gas and 300MW Nuclear).

There is a significant improvement in the share of electricity demand met with domestic generation in most scenarios, in 2030 the RES-Storage and AT No-net Imports (AT-NIMP) already meet the net requirement. By 2050 all pathways do, except the CCU pathway which delivers less than 30% of demand by 2050. Investments in dispatchable capacity facilitate a lower reliance on electricity imports. Estonia acts as a net exporter of electricity by 2050 in all but the CCU pathway, achieving this already in 2030 in the RES-Storage pathway and by 2040 in the Nuclear pathway. Investments in generation capacity in Estonia tend to improve the electricity import-export balance and reduce electricity prices. Imports continue to be used at certain times of the year in all pathways, however.

Projected electricity prices[10] in Estonia are higher in all climate-neutral pathways than they are today. Across scenarios, projected prices range between around 90 – 110 EUR/MWh, however prices

[10] Estimated by proxy on the basis of weighted average levelized costs of electricity as price modelling was not possible within the scope of the work

in the RES-Storage (increasing to around 140 EUR/MWh) and especially CCU (increasing to more than 145 EUR/MWh) pathways are notably higher. For RES-Storage the alternative wind curves have a significant impact on prices, if wind availability is increased, as anecdotal evidence suggests can be possible (better wind than expected at higher turbine heights/altitudes), then it is likely that prices for this pathway will be lower.

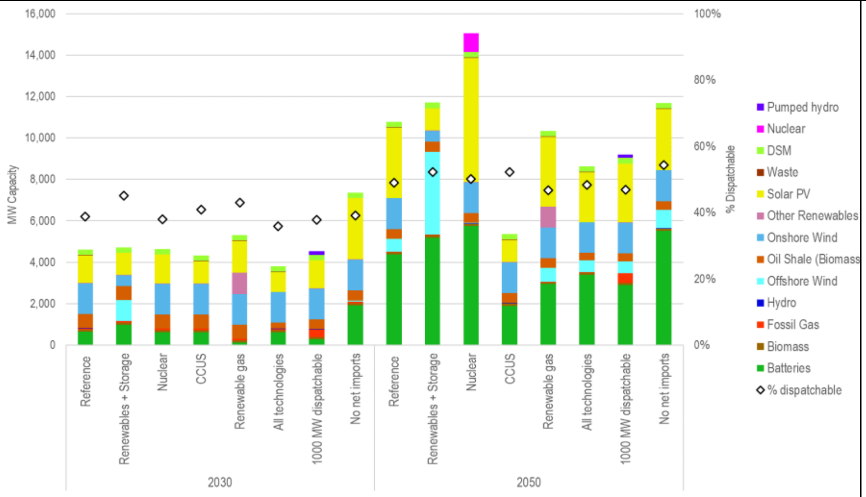
GHG emissions decline rapidly in all pathways, which by 2050 are climate neutral, using assumed direct air capture of CO2 to achieve net zero emissions if emissions are not zero. This supports the Fit-for-55 and Net zero trajectories. However, there are some differences between the scenarios, with the CCU pathway able to achieve net positive emissions through bioenergy with carbon capture and storage (BECCS)[11] and the all technologies pathways, particularly no net imports having higher emissions due to continued use of fossil gas by 2050.

Compared to the original D3 pathways the main results of the alternate wind curves was to increase dispatchable capacity in most pathways, mainly via battery capacity. There were also increases in solar PV capacity in 2030 and offshore wind capacity in 2050; increase electricity generation in most pathways in 2030 and 2050; generally lead to an increase in average electricity prices for most pathways over time; and lead to a small increase in GHG emissions for all pathways.

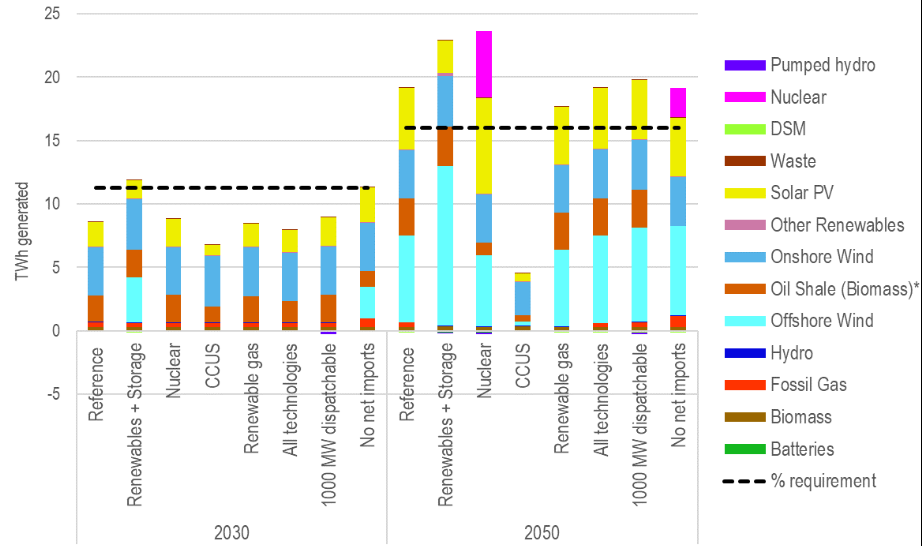
[11] A note of caution, by GHG accounting Estonian power sector emissions would be positive in the CCU pathway, however the fact that nearly 70% of electricity would be imported means that potentially significant emissions would be caused indirectly by Estonian needs.

Table 1-3. Key pathway results for Deliverable 6 S1 using alternate wind curves

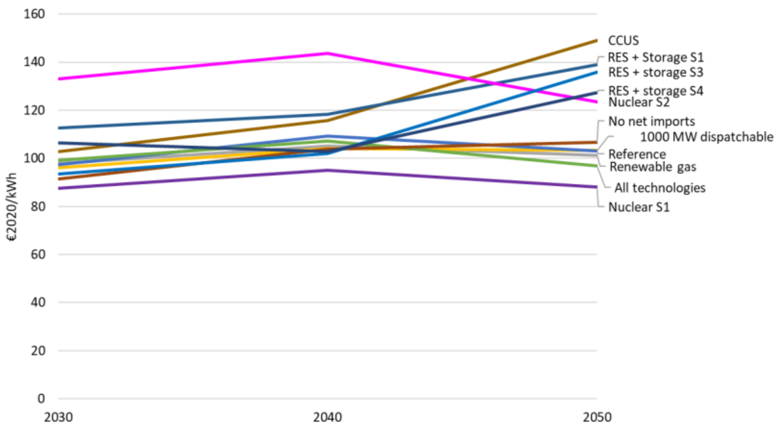
Capacity (MW)



Generation (TWh)



Prices (EUR/MWh)



Emissions (ktCO2e)

GHG emissions	2020	2030	2040	2050	Total cumulative 2020-2050
BAU	2 667	763	98	187	**24 306**
RES+STORAGE	2 667	782	84	79	**23 761**
Nuclear	2 667	754	41	30	**22 780**
CCU	2 667	493	-136	-147	**17 430**
RES-GAS	2 667	728	77	68	**23 092**
AT	2 667	722	77	167	**23 572**
AT+1000	2 667	787	213	199	**25 764**
AT-NIMP	2 667	766	784	324	**31 950**

* in all scenarios except CCU the oil shale plants are converted to run on biomass in the 2030's

The results of the other three sensitivity analyses are summarised below.

- For the second sensitivity test (S2), the impact of enforcing 90% nuclear dispatch on the Nuclear pathway would be: increase in overall capacity (mainly due to more battery capacity) and slight increase in percentage of dispatchable capacity, increase in generated electricity, significantly higher average electricity prices, and greater GHG emissions. The increase in prices eroding the largest part of the socio-economic benefits otherwise experienced in this pathway.
- For the third sensitivity test (S3), higher biomass prices would impact the Renewables and Storage pathway by: additional capacity (mainly battery and solar PV capacity), increasing generated electricity, higher average electricity prices in 2040 and 2050, and greater GHG emissions.
- For the fourth sensitivity test (S4), higher battery costs and construction of the Paldiski pumped hydro plant, in addition to all the other sensitivities, impact the Renewables and Storage pathway by: reducing battery and solar PV capacity additions, total generation, prices and investment costs compared to S1. The pumped hydro facility naturally displaces some battery storage, but the increase in battery costs reduces the business case for the battery and solar PV combination.

1.5 DLV 7: Action plans

Deliverable 7 brings together the results of the various deliverables and to propose a series of actions that would allow the implementation of the pathways. The action plan is based on the pathway results of the S1 sensitivity case from Deliverable 6 (higher wind sensitivity), which better represents the variance in wind speed over the year.

Deliverable 7 provides a series of actions organised under 6 action sets and provide further calibration of these actions for each pathways. The intervention areas and actions are identified in the table below. The actions listed are considered for the different pathways. How the actions relate to each pathway is shown in the Annex.

Table 1-4 List of actions

Action set	Actions	Pathways more closely related
Planning	1A. Streamline the infrastructure planning approval process	• All pathways
	1B. Increase administrative resources dedicated to planning and permissions	• All pathways, excluding CCU
	1C. Supporting actions to speed-up the approval process	• All pathways, excluding CCU
Institutional reform	2A. Set up a nuclear regulator	• Nuclear • All technologies
	2B. Review the mandate of the Estonian National Regulatory Agency	• All pathways
	2C. Set up an Energy and Climate Agency	• All pathways
	2D. Increase cross border cooperation	• All pathways

Risk reduction instruments	3A. actions to stimulate the uptake of Power Purchase Agreements (PPAs)	• All pathways
	3B. Amendment to the current renewable electricity auction scheme	• All pathways, excluding CCU
	3C. Move all or part of the funding for renewable electricity to the fossil gas bill or to other funds	• RES + storage (offshore wind) • Nuclear
	3D. Extend the current size of state guarantees provided by the Estonian Business and Innovation Agency | KredEx and develop a broader framework for government guarantees	• All pathways
	3E. Public co-investing and sharing risks	• Nuclear • CCU
RES for households and SMEs	4A. Set up an on-site small scale renewable generation support scheme, in combination with other actions to incentivise building renovation	• All pathways, excluding CCU
	4B. Allow Households and SMEs to invest in remote renewable electricity generation	• All pathways, excluding CCU
Power networks	5A. Develop a national flexibility strategy	• All pathways, excluding CCU
	5B. Further improve the transparency of the Baltic balancing market	• All pathways, lower relevance for CCU and Nuclear
	5C. Improve batteries' economic viability and access to finance	• All pathways, lower relevance for CCU and nuclear
	5D. Create a demand side management framework	• All pathways
	5E. Other actions to support storage know-how and reduce barriers	• All pathways
	5F. Consider alternative design models and funding mechanisms for key offshore infrastructure	• RES + storage (offshore wind) • All technologies
	5G. Reinforcement to Transmission and interconnection infrastructure	• All pathways
Involvement of the civil society	6A. Information campaign to be launched together with a new renewable energy strategy	• All pathways
	6B. Setup One-stop shops	• All pathways
	6C. Local action groups	• All pathways
	6D. Facilitate the uptake of Citizens and Renewable Energy communities	• All pathways
Other actions	7A. Support for vulnerable households	• All pathways
	7B. Skills development	• Nuclear

Several actions are relevant across all pathways considered. These are:

- **Actions to streamline the planning process**, in particular to simplify the administrative requirements, to speed up decision time (by providing more resources and incentives to Local Authorities in charge of taking the decision). Additionally, if these improvements are still not sufficient to stimulate the required technologies in sufficient quantities, planning and approval responsibilities should be transferred to the national level. These are to be tailored to the preferred strategy (e.g. focussing on small/large projects, national/local administrations, etc.).
- **Actions to reduce risks on renewable or low carbon investments**. For the majority of renewables, market risks are the more relevant – i.e. the risk that future deployment may reduce market prices at the time when they are able to generate. The recommended

mechanism is a contract for difference, with different budgets according to the targeted deployment capacities and targeted technology mx. Other technologies such as renewable gases, nuclear energy and CCU will instead need more tailored risk reduction instruments that address technology-specific risks.

- Improve the transparency in the Baltic market for reserve capacity, flexibility and ancillary services, open to different technologies, to nearby countries and to prosumers. This would be an important instrument to drive the deployment of batteries or other storage solutions which are needed in every pathway.
- **Actions to support the uptake of Demand Side Management (DSM).** In all scenarios, all available DSM capacity (261 MW) is exploited, with broadly similar utilisation level in 2030 (between 25 and 29 GWh) and 2050 (between 21 and 27 GWh). DSM should participate in the market for flexibility capacity discussed at the previous point.
- **Actions to facilitate the diffusion of PPAs**. These actions aim at simplifying agreements between contracting parties (generators and consumers) by creating standard contracts and incentives to consumers that decide to sign them.
- Increased funding and limits for guarantees provided by the Estonian Business and Innovation Agency (KredEx), to support developers with low credit rating and to lower risk premiums demanded by investors.
- **Actions to support vulnerable households**. These should include different type of support, including economic, technical, and informational. Some of the pathways considered may have a significant impact on the energy bill, so the most vulnerable consumers should be supported to reduce their consumption and access programmes that can support with the installation of energy efficiency measures.

Some further details at action set level are provided in Table 1-5 while further below an indicative timeline for the proposed actions is presented.

Table 1-5. Action sets details

Action sets	Objective	Timeline	Responsible	Other key stakeholders	Cost/ resources
1.Planning process reform	Speed up approval process and reduce developers' risks	Short term (2023 - 2030)	Central government	Local administrations	Low cost, mostly human resources
2.Institutional reform	Provide more independent and dedicated resources	Medium term (2023 - 2035)	Central government	Depends on the reform and how it is implemented	Low cost. Mostly resources transfer and reallocation of responsibilities
3.Risk reduction instruments	Reduce developers and investors risk	Award: short term (2023 - 2030) Implementation: medium/long term (2023-2040)	Central government	Financial institutions Large electricity users	Costs vary significantly with pathway and will depend on future energy prices
4.Support for households and SMEs	Reduce network reinforcement costs; exploit low-cost opportunities; raise private finance	Medium term (2023 - 2035)	Central government	Depends on the chosen delivery method	Costs vary significantly with pathway and will depend on future energy prices

5.Power networks	Allow integration of renewables at the lowest system cost	Medium term (2023 - 2035)	TSO	Central government	Financed via energy bills
6.Civil society	Reduce public opposition to renewables	Short term (2023 - 2030)	Central government	Depends on action	Low cost
7.Other actions	Avoid negative effect on households; ensure skills are available	--	Central government	Depend on action	Varies with scenario and macroeconomic factors

Figures A-1 and A-2 in the Annex provide the general timeline of the proposed actions. The priority actions and the responsible body for each action are identified.

1.5.1 Key actions at pathway level

Further considerations at pathway level are summarised below:

- **Renewables + storage (offshore wind):** Is the most ambitious pathway, which foresees the deployment of large amounts of offshore wind and storage, and that results in the highest total investment costs, both in generation and transmission infrastructure. However, the investment generates positive economic impacts, and environmental impacts from large offshore deployment can be managed. Key actions focus on facilitating offshore deployment (technology-specific support; offshore grid; transmission capacity), on supporting the deployment of storage solutions, and on protecting vulnerable consumers from possible increases in energy bills.
- **Renewable gas (modified):** While the modelling results for the Renewable gas scenario provide a relatively balanced power system, there are inconsistencies that suggest this may not be an ideal trajectory for Estonia, unless some of the assumptions change. In particular, deploying lower quantities of biogas would create a more cost effective system. The key action is technology-specific support for biogas installations.
- **All technologies**: This is the base case technology neutral scenario. It provides a balanced generation mix and investment profile over time. While it does not score particularly positive in any of the areas considered, it also has no major negative point. The key action is establishing technology-neutral risk reduction instruments.
- **No net imports and 1000 MW dispatchable capacity**: The other two technology-competition pathways have similar results in terms of technology mix, costs and dispatchable capacities. Based on the assumptions, different technologies emerge. Recommended actions also follow a technology-neutral approach, and aim to keep all options open until costs become clearer. The AT-NIMP is amongst the pathways expected to be most economically beneficial. It is also one of the few pathways that does not rely on biomass-fuelled oil shale plants for a significant share of generation after 2030, which points to a more sustainable impact on Estonian forests, however at the cost of greater use of natural gas. The key action for the no net imports pathway is beginning the ground work for future nuclear deployment and the key action for the 1000MW dispatchable capacity pathway is having a dedicated instrument to reward required dispatchable capacity.
- **Nuclear:** The pathway is characterised by a focus on nuclear and solar PV, and it is expected to be the second most expensive pathway, although it is expected to have lower electricity prices

in 2050. The main actions identified concern the development of a national nuclear programme and supporting actions to other renewables. According to stakeholders, this is the riskiest scenario, especially as it relies on a technology that has no history in Estonia and that is not expected to come online before 2035.

- **CCU**: CCU would be applied on power production from oil shale. This scenario requires the lowest investment and continues exploiting fossil fuel reserves in the long term, although modelling suggests this will still decline to around ¼ of current levels. While the actions required for its implementation are fewer and simpler than for other pathways (the key action being a CCU programme), this is the pathway expected to be worst for the economy and employment, and would leave Estonia most dependent on power imports in future. CCU could be a good option for Estonia if further use and transport options for CO_2 are identified, so that carbon capture can be deployed to other power plants (beyond the two considered in this analysis) and industrial installations, and if costs can be made economically competitive.

1.5.2 Recommended actions to reduce negative impacts and increase positive impacts

The table below provides an overview of the recommended actions for the different environmental, social and economic impacts of the different technology developments. The relevance for each pathway is identified.

Table 1-6. Overview of the recommended actions to reduce negative impacts and increase positive impacts

Impact from	Type of impact	Recommendations	Pathway relevance
Offshore wind	Environmental	• Ensure careful design, monitoring and management of construction works to reduce disturbances to marine wildlife and maintain water quality; • Use proper materials to create a suitable artificial reef and prevent erosion; • Enforce fishing restrictions near wind farms; • Define a strategy to ensure the health of marine areas is maintained	• All pathways except the CCU pathway
	Social	• Construct offshore wind farms near industrial areas where the landscape is already altered to reduce additional visual disturbances for the local community	
	Economic	• Ensure relevant stakeholders are involved in early consultations, such as fishing industry and maritime sector; • Adequate measures to ensure consumers are not significantly impacted by RES charges; • Ensure supply of highly skilled professionals in the wind energy industry	
Onshore wind	Environmental	• Ensure careful design, monitoring and management of wind parks to avoid disturbing wildlife and their habitat	• All pathways
	Social	• Ensure onshore wind parks are not close to houses of local population (cf. environmental law)	
	Economic	• Ensure supply of highly skilled professionals in the wind energy industry	
Solar PV	Environmental	• Ensure careful design, monitoring and management of solar parks to avoid disturbing wildlife and their habitat	• All pathways
	Economic	• Ensure supply of highly skilled professionals in the solar energy industry	
Nuclear	Environmental	• Strict control of water use and disposal (due to thermal pollution); • Strict limitations on the release of toxic and radioactive waste into the environment and ensure proper waste management	• Nuclear • No net imports
	Social	• Strict requirements for prevention and mitigation of severe accidents	
	Economic	• Ensure that nationally there are enough highly skilled professionals in the nuclear energy industry	

Impact from	Type of impact	Recommendations	Pathway relevance
Biomass & Biogas	Environmental	• Adequate regulation and management of the use of forest timber for energy	• RES+Storage • Renewable Gas • All technologies • No net imports • 1000 MW dispatchable capacity
	Economic	• Ensure that nationally there are enough highly skilled professionals in the bioenergy industry; • Adopt strict sustainability criteria for ALL bioenergy (thus incl. non subsidized one where RED criteria don't apply), to minimise negative impact on other industries	
Battery storage	Environmental	• Requirements for proper disposal/recycling of batteries at end of life.	• All pathways
	Economic	• Modernise the electricity grid with smart technologies to enhance the development of battery storage (EU recommendation); • Ensure supply of highly skilled professionals in the energy storage industry	
Transmission & distribution	Environmental	• Plan construction of new transmission and distribution lines underground or underwater where technically possible; • Avoid unnecessary cutting of trees; • Reduce noise pollution via construction and technical solutions; • Strict requirements for maintenance and disposal of equipment (e.g. SF6)	• All pathways
	Social	• Impose restrictions on high-voltage lines near housing to reduce health impact (applying environmental legislation); • Avoid overhead lines in populated areas to reduce visual impact	
	Economic	• Ensure availability of highly skilled professionals in the T&D industry	

2 Deliverable 8: Key results and findings

Deliverable 8 aims to summarise the performed activities and provide corresponding recommendations for further actions based on these previous project results, including evaluation and monitoring of project outcomes. The result of which is a synthesised presentation of the results of all of the project activities, a description of the project challenges encountered and how they were overcome. In this section, the lessons learned and recommendations are presented.

2.1 Summary assessment

Table 2-1 shows the pathways' assessment across a range of criteria. An extended version of the table, with the underlying data, is available in Annex. The table attempts to show the comparative results across key indicators as assessed in different parts of the project, and shows the overall assessment according to the consultant and according to the alternative set of criteria. While consultant's criteria are not weighted, they are ranked according to the consultant's view (i.e., criteria in the rows at the top are considered more important than criteria at the bottom). The importance of every criterion is not "absolute", but depends on how the indicators were calculated for the project.

The indicators selected shows that all pathways have pro and cons. In some cases, the pathway presents several very favourable ratings (++) but also some very negative ones (--). In some cases, such as stakeholders' views and the assessment of how challenging the implementation of the pathway is, the indicators do give a strong implicit weight.

The contractor's recommendation, based on the above analysis, is that the *All technologies*, *Renewable gas* and the *RES + Storage* scenarios are those to be preferred. However, there is an important clarification necessary concerning the Renewable gas scenario. While the scenario is overall positive, an analysis of capacity and utilisation of different technologies shows that the large (1GW) of biogas capacity is barely used. Therefore, if the decision to implement the biogas scenario is taken, the amount of biogas capacity should be significantly reduced in favour of other cheaper dispatchable technologies.

The assessment against the five alternative criteria shows how pathways rank across a number of selected metrics and overall (simple sum of rankings), where rankings are to be understood as the lower the better. According to this assessment, the *Nuclear* pathway comes on top, followed by the *RES + Storage* and the *All technologies*. It is important to note that the overall ranking is dependent on the selected indicators, and a different set of indicators will return a different pathways' order.

Also, it is important to recall that all pathways meet the main objectives set for the Estonian power system to decarbonise by 2050, and that all estimates are subject to wide uncertainty over the time period considered (30 years). For this reasons, the analysis presented in this report should be used as a guide to support the necessary political decisions, not as an absolute conclusion about the potential for a specific technology in Estonia. CCU, Nuclear and Biogas plants (to be used for backup only), which do not appear convenient based on the assumptions used to carry out this study, may well be the best option for Estonia under a different set of assumptions and value judgments.

Table 2-1 Summary assessment across criteria

Criteria*	DLV	RES+Storage	All technologies (AT)	Nuclear	Renewable Gas	No net imports	1000 MW dispatchable capacity	CCU
Stakeholders' preference[12]	5	++	++	-	+	-	0	--
Socioeconomic impacts	4	++	0	-	++	++	0	--
Security of supply	3	++	0	+	0	0	++	--
Main implementation challenges	7	0	++	--	0	0	0	-
Risk analysis[13]	5	0	++	--	++	--	++	--
Limit of fossil use (fossil gas gen. in 2050)	3	++	-	++	++	--	-	--
Sensitivity analysis	6	++	0	++	++	++	0	--
Avg. electricity prices in 2050	4	-	+	++	+	+	+	--
Total cumulative investment costs (2022-2050)	4	--	0	--	--	0	0	++
Renewable subsidies costs in 2030	7	--	0	0	0	--	0	++
CO_2 emissions by 2050	4	0	0	0	0	-	0	++
Electricity from Biomass in 2050	3	--	--	0	--	++	--	++
Overall consultant assessment		**Recommended**	**Recommended**	**Not Recommended**	**Recommended**	**Viable**	**Viable**	**Not recommended**
Alternative ranking according to 5 criteria[14]								
Investment cost	7	7	2	6	5	4	3	1
Electricity price in 2050		6	2	1	3	5	4	7
GDP**		1	6	2	3	4	5	7
Jobs created (2030 to 2050)		2	4	1	3	5	6	7
Share of domestic generation in 2050		2	4	1	6	5	3	7
Overall ranking according to 5 criteria		**2**	**2**	**1**	**4**	**6**	**5**	**7**

Very favourable (++); moderately favourable (+); neutral/no impact (0); moderately unfavourable (-); very unfavourable (--)

*Criteria in the rows at the top are considered more important than criteria at the bottom

[12] Stakeholder preferences are based on the survey results and interviews taken place during the risk assessment
[13] Regulatory, technological, socio-environmental, energy market and economic risks.
[14] The values for these ranking criteria can be found in Table A-2

**Output changes compared to reference; GDP output includes tax revenues

2.2 Key findings

Estonia can reach carbon neutrality and reduce its energy dependence by deploying different technology mixes up to 2050. In all options considered, the deployed capacity and the share of domestic consumption covered by domestic generation increase substantially. All of the pathways have GHG emissions below the Fit-for-55 trajectory. ***The comprehensive summary of the key findings can be found in Table A-2 in the Annex***.

Once the full impact on the economy has been considered, pathways with a focus on offshore wind and renewable gas, even if expensive, present the best outcomes in terms of renewable generation, security of supply and socioeconomic impacts. However, modelling suggests that investment in renewable gas capacity would not be useful for the power system as operating costs are so high compared to other technologies and imports, it would be too expensive to actually use. The high costs are due to the cost of the biogas feed, which are expected to stay high even if the supply chain is better developed and economies of scale are achieved.

2.2.1 Technology development

A few technologies reach their full deployment potential in all scenarios considered. In the modelling, capacities of onshore wind and Demand Side Management are deployed to their full extent by 2030 (1,479 MW and 261 MW deployed by 2030, respectively). Additionally, very high deployment of Solar PV is expected in all scenarios (between 725 MW and 2,390 MW by 2030 and between 725 MW and 6,573 MW by 2050). The deployment of other technologies also does not vary substantially across scenarios, but these are currently existing capacities: hydro (8 MW), waste (18.5 MW), other renewables (20.32 MW, excluding additional biogas), biomass excluding future conversions (101 MW).

A recurring challenge across all scenarios is the expected deployment of storage capacity, in particular of batteries. Modelling shows that Estonia will need to deploy between 860 MW and 2,235 MW of batteries by 2030 (almost 50% of the average renewables capacity) and between 4,570 MW and 9,300 MW by 2050 (over 100% of the average renewables capacity). This will require an investment of between €526 million and €1,034 million by 2050. To encourage investors to provide investments to this extent, it is necessary to improve the transparency of the Baltic balancing market, so that the right long-term signals are sent to investors.

Table 1-32 provides an overview of the estimated electricity capacity and generation per pathway

Table 2-2 Total electricity capacity (MW) and generation (GWh) by 2050 by technology for each pathway

Pathway	Capacity (MW) & generation (GWh))	Onshore	Offshore	PV	Batteries[15]	Other techs	Total	% dispatchable
RES+storage	MW	1,479	4,000	2,094	8,617	1,235	**17,425**	55%
	GWh	3,994	12,550	2,504	-127	3,842	**22,764**	

[15] Generation (GWh) for batteries is battery usage whereas capacity (MW) of batteries is the capacity of storage.

Renewable gas	MW	1,479	1,883	3,837	5,907	1,901	**15,007**	*52%*
	GWh	3,750	6,079	4,555	-88	3,316	**17,612**	
All Technologies (AT)	MW	1,479	1,968	4,057	7,970	1,045	**16,519**	*55%*
	GWh	3,812	6,881	4,811	-102	3,676	**19,078**	
No net imports	MW	1,479	1,967	3,933	7,705	1,125	**16,209**	*54%*
	GWh	3,821	7,008	4,615	-97	3,648	**18,995**	
1000 MW dispatchable capacity	MW	1,479	2,098	3,920	7,533	1,424	**16,453**	*52%*
	GWh	3,885	7,417	4,681	-97	3,636	**19,723**	
Nuclear	MW	1,479	1,576	6,573	9,288	1,975	**20,892**	*53%*
	GWh	3,795	5,594	7,549	-114	6,656	**23,480**	
CCU	MW	1,479	123	725	4,571	923	**7,821**	*70%*
	GWh	2,640	321	647	-13	989	**4,585**	

The amount of biomass required for electricity production varies substantially among pathways. The conversion of existing oil shale plants to biomass can result in a significant increase in biomass consumption by the power sector compared to the current situation, i.e. most pathways expect to generate more than 2 TWh of power from this source in 2030, and this increasing towards 3 TWh by 2050. This level of power generation from biomass would equate to around 3 million m^3 of biomass material (or 30% of the national harvest in 2021[16]) at current conversion efficiencies, however it is expected that conversion efficiencies will increase so that less biomass is actually needed. Exceptions to this are the CCU (continues with oil shale), No net imports (substitutes for fossil gas and then nuclear), and nuclear (substitute for nuclear) pathways.

2.2.2 Policy actions

Given the complex technology mix foreseen in every pathway, several actions are required to support the implementation of the pathways considered. Most of these actions are identical across pathways, while others need to be aligned to the expected capacities to be deployed. The list of actions can be found in Table 1-4 and the timeline, responsible body, key stakeholders and costs/resources of these set of actions can be found in Table 1-5 in Section 1.5.

Four actions are a priority in every scenario considered:

1. Review of the planning process;
2. Renewables support;
3. Expand the electricity system balancing market to encourage investments in flexibility technologies; and
4. Reinforcement to the transmission network (reinforcement to the distribution network, while not assessed in this assignment, are also likely to be required).

Figures A-1 and A-2 in the Annex provide the general timeline of the proposed actions and Table A-1 provides an overview of the priority actions per pathway. Additionally, recommended actions to

[16] Keskkonnaagentuur (2022). Keskkonnaagentuur: mullune raiemaht jäi 10,6 miljoni tihumeetri juurde. Available at: https://keskkonnaagentuur.ee/uudised/keskkonnaagentuur-mullune-raiemaht-jai-106-miljoni-tihumeetri-juurde

reduce negative impacts and increase positive impacts for each technology are summarised in Table 1-6.

2.2.3 Required investments for technologies and policy actions

The required investments are substantial in all scenarios, and amount on average to €8.0 billion[17] up to 2050. Total investment (for new capacity and network reinforcement) in the scenarios considered vary between €3.2 billion for the CCU pathway and €11.4 billion for the Renewable + storage scenario. Transmission reinforcement costs are around 2% and 4% of total investment cost, while the technology with the largest investment varies with scenarios. Across all scenarios considered, investment in onshore wind and solar PV are always significant.

Providing reliable cost estimates for the actions proposed is not possible given the limitations of this assignment. The majority of the actions considered are reforms and improvements to the working of markets and existing instruments. The majority of their direct costs are likely to be staff time, but may entail additional costs which cannot be forecast with precision.

Table 2-3 Summary of costs per pathway, cumulative to 2050

	Stakeholder responsible	RES+Storage	All technologies (AT)	Nuclear	No net imports	Renewable Gas	1000 MW dispatchable capacity	CCU
Cumulative investment to 2050[18]	Private and state-controlled investors	**€14,293M**	**€9,025M**	**€12,089M**	**€10,454M**	**€11,577M**	**€9,868M**	**€3,966M**
Capital costs		€11,040M	€6,972M	€9,338M	€8,075M	€8,942M	€7,623M	€3,065M
Interest payments		€3,253M	€2,053M	€2,751M	€2,379M	€2,635M	€2,245M	€901M
Network reinforcement		€355M	€155M	€230M	€135M	€141M	€155M	€135M
Cost of reviewing the planning process	Central and local government	Low (admin. resources)	Low (admin. resources)	Low (admin. resources)	Low (admin. resources)	Low (admin. resources)	Low (admin. resources)	Low (admin. resources)
Cost of expanding balancing market	System operator / TSO	Low (admin. resources, software)	Low (admin. resources, software)	Low (admin. resources, software)	Low (admin. resources, software)	Low (admin. resources, software)	Low (admin. resources, software)	Low (admin. resources, software)
Renewable subsidies in 2030 (low-high est.)	Central government	€105-209M	€36-71M	€39-78M	€94-189M	€37-73M	€41-82M	€28-55M

A preliminary assessment of the support needed by renewable technologies in different pathways suggests subsidies would range between €28 million per year and €209 million per year in 2030, depending on the pathway and assumed wholesale electricity prices. The recommended support instrument (a contract for difference scheme), provides support to renewable generators only in case wholesale prices are low, which is why the estimated cost range is so wide.

2.2.4 Pathway advice

[17] This includes capital costs and network reinforcement costs (does not include interest payments)
[18] Excluding network reinforcement

Among the alternatives considered, the CCU scenario does not appear to be a viable option because it falls short of the domestic generation requirement and in other key indicators such as electricity prices, socioeconomic impacts, stakeholders' preferences and risks. The CCU pathway, while being the cheapest, does not stimulate sufficient deployment of renewable technologies and has the highest average electricity prices. While the scenario as modelled is not recommended, the technology itself could be considered in combination with other, and be part of a more balanced technology mix.

The Nuclear pathway has the lowest average electricity prices, but it is the scenario with the highest perceived risks, in particular the risk that delays to the deployment of the technology and cost overruns will prevent Estonia from reaching its decarbonisation targets. Historically, nuclear projects are characterised by higher than expected costs, repeated cost increases during the project, and delays. Delays are generally due to several reasons (financial, technical, political), and are the main factor that influences stakeholders' opinion. The scenario only achieves this price level in the case where the nuclear plant varies its production, having a load factor of 65-70%. Enforcing a higher load factor is expected to ***increase average prices significantly*** as at times of low demand nuclear would displace other cheaper forms of generation.

2.3 Recommendations

Based on the outcomes of the five project deliverables and of the analysis presented in this report, we propose the following recommendations:

- THE ESTONIAN GOVERNMENT NEEDS TO SHOW CLARITY ON ITS DECARBONISATION STRATEGY AND COMMITMENT TO IT

Based on the scenarios and actions presented, **the Estonian government should publish a clear and unambiguous strategy for the decarbonisation of the power sector**. The strategy does not need to exactly mirror one of the scenarios presented, but it must include a coherent set of objectives, actions and financial commitments, including they sources (general taxation, energy bills, private finance, institutional investors). There must be a clear commitment coming from the Ministry of Finance and from the Prime Minister, and to the extent possible receive the support of all major political parties. The strategy will have to be clearly communicated to citizens and public administrators at all levels.

- SCENARIO SELECTION

Table 2-4 reiterates the overview of the assessment of the pathways, where the underlying values for the criteria can be found in Table A-2 in the Annex. Across the seven potential scenarios examined, the **All technologies** and the **Renewable + Storage (offshore wind)** scenario are the pathways that appear to offer the best combination of benefits, costs, risks and feasibility. The RES + Storage scenario scores positively concerning security of supply, limit to fossil fuel use, socio-economic impacts and CO_2 emissions, but its high costs are the key challenge. A strategy led by renewables also aligns well with deployment in neighbouring countries, is based on proven technologies and the actions required are relatively straightforward. For a more balanced pathway, the All Technologies scenario does not have very positive score across any of the aspects considered, but at the same time it also does not have any strong negative points, and the costs are lower than other pathways. Aiming for no net imports improves socio-economic outcomes, but also increases the required investments.

Another option that appears to offer a balanced outcome is the *RES GAS* scenario (positive rating across the range of indicators considered), but the construction of the capacity of biogas generation envisioned in the model should be carefully revisited (significantly reduced) as the model shows that biogas generates little electricity due to high operational costs (high cost of biogas feedstock).

However, the government may consider a number of actions to keep "alive" also the *Nuclear* and the *CCU* scenarios, and focus more on these technologies if the situation changes: deploying CCU without the possibility to exploit economies of scale does not make economic sense, while relying too heavily on unproven nuclear technologies is too risky. An added risk of the *Nuclear* pathway is that it may create a "false sense of security", and be used as a justification to postpone important decisions.

An alternative set of criteria is also used to rank pathways. Considering these indicators in 2050, the *Nuclear* pathway emerges at the top, while the *No Net imports* slides towards the bottom of the ranking. Other high-scoring pathways are the *All technologies* and the *1000 MW dispatchable capacity*. This result is more deterministic, and obviously more dependent on the indicators chosen – i.e., selecting different indicators will result in a different pathway being selected, given that no weight is applied.

The choice of the preferred pathway is a "political" choice, as all pathways presented reach the decarbonisation objectives and the other main objectives set for the Estonian electricity system. This report, and the evaluation it provides, should be used by decision makers and stakeholders to identify the path towards decarbonisation that they feel more comfortable with, rather than to be considered the final decision. We expect different stakeholders to put different weight on different indicators, and arrive at different conclusions on the preferred choice.

Table 2-4 Summary assessment of pathways

	Consultant assessment	Alternative ranking*	Comments
RES + storage	Recommended	2	Is the most ambitious pathway, which foresees the deployment of large amounts of offshore wind and storage, and that results in the highest total investment costs, both in generation and transmission infrastructure. However, the investment generates positive economic impacts, and environmental impacts from large offshore deployment can be managed. Key actions focus on facilitating offshore deployment (technology-specific support; offshore grid; transmission capacity), on supporting the deployment of storage solutions, and on protecting vulnerable consumers from possible increases in energy bills.
Renewable gas	Recommended	4	While the modelling results for the Renewable gas scenario provide a relatively balanced power system, there are inconsistencies that suggest this may not be an ideal trajectory for Estonia, unless some of the assumptions change. In particular, deploying lower quantities of biogas would create a more cost effective system.

All Technologies	Recommended	2	This is the base case technology neutral scenario. It provides a balanced generation mix and investment profile over time. While it does not score particularly positive in any of the areas considered, it also has no major negative point.
No net imports	Viable	6	The other two technology-competition pathways have similar results in terms of technology mix, costs and dispatchable capacities. Based on the assumptions, different technologies emerge. Recommended actions also follow a technology-neutral approach, and aim to keep all options open until costs become clearer. The *AT-NIMP* is amongst the pathways expected to be most economically beneficial. It is also one of the few pathways that does not rely on biomass-fuelled oil shale plants for a significant share of generation after 2030, which points to a more sustainable impact on Estonian forests, however at the cost of greater use of natural gas
1000 MW dispatchable capacity	Viable	5	
Nuclear	Not recommended	1	The pathway is characterised by a focus on nuclear and solar PV, and it is expected to be the second most expensive pathway, although it is expected to have lower electricity prices in 2050. The main actions identified concern the development of a national nuclear programme and supporting actions to other renewables. According to stakeholders, this is the riskiest scenario, especially as it relies on a technology that has no history in Estonia and that is not expected to come online before 2035.
CCU	Not recommended	7	This scenario requires the lowest investment and continues exploiting fossil fuel reserves in the long term, although modelling suggests this will still decline to around ¼ of current levels. While the actions required for its implementation are fewer and simpler than for other pathways, this is the pathway expected to be worst for the economy and employment, and would leave Estonia most dependent on power imports in future. CCU could be a good option for Estonia if further use and transport options for CO_2 are identified, so that carbon capture can be deployed to other power plants (beyond the two considered in this analysis) and industrial installations, and if costs can be made economically competitive.

*based on 5 criteria: investment costs, electricity prices in 2050, GDP, job creation and share of domestic generation in 2050.

- **TO ACHIEVE DECARBONISATION TARGETS AT COUNTRY LEVEL, THE ANALYSIS HERE PRESENTED SHOULD BE COMPLEMENTED WITH FURTHER ANALYSIS THAT FOCUSSES ON OTHER SECTORS (HEATING, TRANSPORT, AGRICULTURE & FORESTRY, BUILDINGS, INDUSTRY) AND THAT BRINGS SYSTEM INTEGRATION ASPECTS.**

Once a scenario has been chosen, and before the decarbonisation strategy has been defined, the government should perform an analysis of the chosen scenario under a system integration perspective. This analysis should examine the implications for other sectors of the trajectories and actions associated with the preferred scenario, and the implications for other power sector of other sectors' decarbonisation strategies. Key sectors to consider are the heating and cooling sector; buildings (energy efficiency); and the transport sector. The present analysis should also be repeated regularly to ensure that the preferred technology mix is still the best way to achieve the decarbonisation targets.

2.4 lessons learned for future projects in other Member States

In this section, recommendations and lessons learned are presented to provide insights for the European Commission for future projects in other Member States.

- **EARLY, DIRECT CONTACT WITH MOST IMPORTANT NATIONAL ENERGY ACTORS**

For this type of project, it is important to have direct contacts with the most important energy actors in the country. For this project, the feedback came quite late and resulted in numerous revisions of the pathways. This led to a delay in the timeline of the project. To avoid this issue, having more direct contacts with a more selective group of national energy actors would help make sure that feedback is more likely to be on time and more concise. Calling main stakeholders to request for feedback might be necessary if responses are not provided in a timely manner.

- **More internal discussions with different energy actors about the potential directions**

There should be more internal discussion with different national energy actors, guided by the responsible ministry, about the potential directions. In this project, different energy actors formulated their own wishes directly to the consultants.

- **More time should be allocated for the earlier development of the actions and provide more clarity on the method of development**

The Terms of Reference (ToR) should foresee more time for the development of the actions and should also make it more clear how these actions should be developed. The development of these actions should also start in an earlier stage of the project, namely after the scenario development, but before the modelling. This way, the policy actions can be considered in the modelling. This allows for more insights concerning the actions, namely the costs and revenues. Setting up the talks on policy actions earlier in the process also allows for more time to receive feedback from stakeholders, which could reduce delays in the project.

- **Provide specifications about whether certain key element are needed**

The Terms of Reference should specify if certain key elements are needed. For this project, the needed governance structure and legal framework were key elements, however, they were not included in the ToR.

- **Limit the final options chosen for the modelling pathways**

One of the major challenges for this project were the numerous pathways which had to be analysed. While it is important to take into account several options in the beginning, it would be beneficial for these pathway options to be narrowed down before proceeding with the detailed analysis.

- **Organise small expert panels in place of large workshops for receiving stakeholder feedback**

An alternative to holding large stakeholder workshops is to host small expert panels. While a large outreach through workshops can provide a diversity of feedback, this feedback is often scattered and it can be difficult to determine what are the most crucial feedback points. Further, the risk of hosting workshops with numerous stakeholders is that this can lead to lead to a dilution of focus in the project. It is recommended to make stakeholder feedback focused by organising expert panels with specific stakeholders, which are able to represent a diversity of viewpoints while also providing concise feedback. This should help ensure minimal delays in the project implementation. However, for sharing information with stakeholders, we still recommend larger workshops.

- **Designate a dedicated Policy Officer from the Commission to the project**

Considering that the Member State ministries do not usually have separate project managers for such studies and international projects, it would be helpful for there to be a dedicate Policy Officer from the Commission to guide the Member State ministry throughout the progress of the project.

- **Establish a physical kick-off meeting in the Member State**

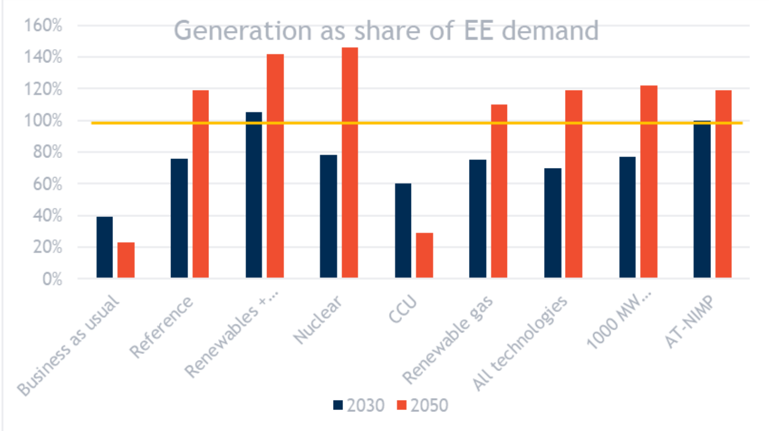
Based on the experience of the Trinomics team, having a physical kick-off in the Member State of focus of the project is an effective way for the consulting team and the client to begin the project to synchronise expectations and this also provides the consulting team an opportunity to have a deeper understanding of the most important aspects for the client.

3 Answers to study questions

Based on the results of the previous project deliverables, the study questions are answered in the table below.

Answers to study questions

Question	Answer
1. To reach 2030 objectives will renewables auctions be enough?	Across the pathways examined, after the outcome of the completed and planned renewable auctions has been considered, there is still a gap of between 2.7 GWh and 7 GWh of renewable electricity missing. This amount of additional generation is unlikely to come forward without dedicated support because investors are not willing to take on the full market risk. Risk reduction instruments, such as extending state guarantees and public co-investing/sharing risks, are possible actions to increase private investment.
2. Based on current knowledge and modelling results would it be feasible and secure to invest in Nuclear power?	Relying on nuclear is a too risky strategy, as nuclear is exposed to several risks, mostly related to public perception and to the challenges with the technology (nuclear projects have historically been subject to long delays and cost overruns). Stakeholder opposition is not related to the technology per se, but is influenced by the example of other countries in Europe that have recently attempted to develop new nuclear power plants (UK, France, Finland). In the three cases, the project is substantially delayed, several times more expensive than initially planned, and in two out of three cases required support from the taxpayers or the consumer. Even in the most promising scenario, nuclear electricity is unlikely to be available before mid to late 2030s, so the scenario is not recommended even if modelled electricity prices in 2050 are the lowest. Concerning the latter point, the sensitivity analysis showed that the scenario results in terms of electricity prices are not robust, as a change in generation from nuclear sees prices increase.
3. From which source we will get electricity after 10 years in cold and dark winter night?	Nights are not the time of the day with the highest consumption, this happens usually during evening time. The answer to the question depends on the scenario, but in general in the mid 2030s, generation when solar is unavailable will come from: • Any dispatchable capacity (oil shale, biomass, gas, hydro) • Wind energy and interconnectors (imports) • Batteries (in some scenarios biogas or pumped hydro) will fill any capacity gap For example in the two most highly recommended pathways the following mix is envisioned in 2030, against an estimated peak power requirement of 2 200MW: • RES-Storage: Total capacity: 7.1 GW, of which 48% is dispatchable power, 16% excluding batteries. Dispatchable capacity provides 24% of annual generation. Main technologies are Offshore Wind 1 000MW, Solar 1 249MW, Onshore Wind 1 479MW, 2 235MW Batteries. Generation: 3.9 TWh onshore wind, 3.5 TWh offshore wind, 2.2 TWh Oil shale, 1.4 TWh solar. This provides 105% of the annual net domestic requirement, allowing for net exports over the year. • AT: Total capacity: 5.6 GW, of which 46% is dispatchable power, 17% excluding batteries. Dispatchable capacity provides 29% of annual generation. Main technologies are Solar 1 507MW, Onshore Wind 1 479MW, 1 607MW Batteries. Generation: 3.8 TWh onshore wind, 1.7 TWh Oil shale, 1.8 TWh solar. This provides 70% of the annual net domestic requirement, the gap met through imports. • In all pathways there is a base of dispatchable capacity, primarily the oil shale facilities (676MW in 2030) which are later fuelled by biomass, but also small dedicated biomass plants (101MW), Fossil gas capacity (70MW in 2030 in most pathways), Hydro (8MW), Biogas (20MW) and waste (19MW). Few of these smaller contributors can be upscaled economically. The largest potential is with fossil gas, but this is contradictory to the climate neutral goal. In the long term Nuclear could also be used.
4. Is it necessary to keep certain amount of local capacity MW for security of power supply and how much?	• One of the no-regret actions, recommended in most scenarios, is to develop a new flexibility strategy aimed at incentivizing the deployment of batteries and other flexibility technologies. The strategy should consider alternative to the current approach (strategic reserve) so that investors see a clear business case in investing in batteries. However, suddenly removing reserve capacity may create substantial risk and excessive price spikes. Therefore, the withdrawal of reserve capacity should be dependent on the deployment of batteries and non-dispatchable sources. • In the long term, the most cost-effective solution is having well-functioning and transparent flexibility market, open to demand response and to installations based in other countries.
5. Which is a fluctuation and change of dependency from import in different pathways?	All scenarios considered excluding the CCU pathway deploy enough capacity to generate over 100% of electricity demand. The RES+Storage and AT NIMP pathways are the only ones that reach this by 2030.

	
6. Will it be feasible to have off-shore wind parks already in 2025-2030 and what is necessary to do for that (supporting)?	While 2025 is highly unlikely, 2030 is feasible, as long three priority actions are carried out in the very short term: • Review of the planning process (single application procedure) • Support developers with the baseline studies to be carried out. For example, the Government could carry out Geological and Archeological desktop studies, Geotechnical and Geophysical field studies, seabed mobility studies, wind resources and LCOE assessments and make these studies available to potential bidders in renewable auctions . A similar action has already been undertaken as part of the ELWIND project. • Definition of a technology-specific price support mechanism (e.g. price floor/ feed-in premium) The completion of the relevant elements of the offshore grid (an initiative of Baltic and Nordic TSOs) will be an additional step that would greatly increases the chances of offshore wind being in place by 2030.
7. Is there a straight correlation between CO_2 price and investments to renewables (does higher CO_2 price bring more investments)?	It is not the CO_2 price per se, but the expectation of a high-CO_2 prices in the medium-long term, sufficiently high to keep wholesale price from fossil plants above their LCOE. However, other considerations will also be important, in particular: • expectations concerning future incentive schemes, that may cannibalize revenue (e.g., the more wind farm in the future, the lower the wholesale price when wind is the marginal generator; • expectations on the use of the strategic reserve, which would limit temporary high prices that may benefit renewables; • whether a price support system is in place.
8. How realistic would it be to use CCU in Estonia and what are necessary additional technologies, costs etc. for that?	Retrofitting CCU to Auvere and TG11, as assumed in the CCU pathway, is feasible for a cost of around €1 billion. The required technologies are the capture equipment to be installed during refurbishment operations, together with other technologies required as part of the chosen process. However, such an investment would have negative returns unless other outlets for CO_2 are found, e.g. a storage site outside Estonia.
9. What would be necessary actions to be in compliance with Fit 55?	Fit for 55 does not require any specific actions, but it requires a certain amount of CO_2 emissions reductions. All pathways examined reach this objective, which means that all actions in support of renewable technologies should be put in place to ensure these come forward (review of the planning and approval process; PPAs; risk-reduction instruments; incentives for households and SMEs). The broader question for policymakers is how much extra weight (if any) should the power sector bear in reducing total national emissions. Typically as one of the easier sectors to decarbonize it is asked to do more than difficult sectors such as agriculture or transport. All pathways produce emissions reductions far in excess of the 55% reduction, i.e. 95% reductions by 2030, creating potential to offset slower reductions in other sectors. All pathways also significantly exceed the share of renewable energy goals (i.e. all pathways >70% RES in 2030, compared to 40% target).
10. Which pathways and action plans would be the best to reach climate neutrality based on prognosis of CO2 reduction and measures related?	All pathway emissions are significantly lower than the Fit-for-55 trajectory. The CCU pathway has the lowest emissions, however, this pathway generates the least electricity - significantly lower than the electricity requirements. All pathways are modelled to achieve net zero by 2050, using direct air capture technologies to deal with any small remaining emissions as needed.
11. Which would be the spatial distribution of capacities and their impacts in every pathway?	Modelling in all pathways suggests additional onshore wind capacity should be deployed as follows in all pathways by 2030: Lääne Eesti 850 MW; Põhja-Eesti, Kesk-Eesti and Kirde Eesti: each 100 MW, Lõuna-Eesti, no additional wind capacity added. This deployment requires an estimated land use of around 230-460 km^2 (or less than 1% of the total land area in Estonia) Offshore wind capacity is modelled to be added in proximity to Lääne Eesti.

<table>
<tr>
<td>12. How much (what would be the range) do we need to bring investments with help of support funding and/or abroad loans (in GWh and euros) in addition to renewables actions (these actions are financed from renewables tax of consumers)?</td>
<td>While renewable auctions provide operational support to renewable generation, they do not finance the construction of the wind or solar farms. This means that finance for these will also have to come from investors.
<table>
<tr><th>EUR million by 2050</th><th>Generation investment</th><th>Transmission investment</th></tr>
<tr><td>Renewables + storage</td><td>11,040</td><td>355</td></tr>
<tr><td>Nuclear</td><td>9,338</td><td>230</td></tr>
<tr><td>CCU</td><td>3,065</td><td>135</td></tr>
<tr><td>Renewable gas</td><td>8,942</td><td>141</td></tr>
<tr><td>All technologies</td><td>6,972</td><td>155</td></tr>
<tr><td>No net imports</td><td>8,075</td><td>135</td></tr>
<tr><td>1000 MW dispatchable capacity</td><td>7,623</td><td>155</td></tr>
</table>
According to the technology and transmission investment, support funding from the EU and other institutional investors will be available. For example, to help with the deployment of CCU, interconnectors, large flexibility and storage projects.</td>
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<td>13. Which are financial institutions and their main conditions (project size by euros and duration, location, international cooperation etc.) to get investment loans or support as well as needs and possibilities for successful application process?</td>
<td>There are several options both for public sector initiatives and private developers. The more suitable institution and product depends on the need and type of project. Details are available in Deliverable 7 report, Annex D.</td>
</tr>
<tr>
<td>14. Which are the basic and most important steps, actions/measures to shorten project timelines for new renewable capacities as well as storages.</td>
<td>The three main steps identified are:

Review the planning process and identify steps that can be streamlined/shorted (action 1A):

Update the legal framework surrounding the approval process for renewable energy installations, including the creation of a single approval procedure and single contact point beginning with large projects (e.g. offshore wind energy farms) but with the aim to extend to all applications. The contact point will coordinate inputs from other relevant authorities.
Establish maximum allowable time-limits for all stages of the planning process, including the approval of the environmental impact assessment;
Set up a group of sectoral experts, national defense and representatives from the civil society to resolve conflicts concerning proposed development sites for wind and solar energy. Options should be considered whether such a group could play a formal role in the appeal process. This role could be assigned to a newly formed energy Agency.

Provide more administrative resources to LAs in charge of approving projects (action 1B)

Dedicate additional human and financial resources at national level (e.g. experts, commission studies, prioritization in approval processes) to support projects of national interest. The Government should define a set of criteria that identify projects of national interest, according to the overall strategic direction chosen. The overall project size (capacity) and its contribution to the energy and climate targets and security of energy supply (electricity system stability, independence from imported fossil fuels) should be major criteria; in this context wind energy farms and nuclear and conventional power plants could be considered as projects of national interest. See below (Institutional Reform) the suggested action concerning a new agency and the role it could play in respect to these projects.
Support local administrations with additional resources to timely deal with project proposals. Solutions may include:

Providing additional budget;
Providing experts (secondments);
Providing tools to facilitate the process;

Carry out a series of other supporting actions (Action 1C)

Make the inclusion of new promising renewable energy production areas mandatory in local statutory, thematic and special plans, and link payments from the local government equalization fund to this requirement. This action should have a short-term conclusion (i.e., max by end of 2023);
If, following the previous action, the number of sites identified is not sufficient, a new spatial plan will be defined at national level. Further studies should be carried out to quantify this with more precision according to the selected scenario;
Create possibilities for municipalities to benefit from renewable energy investments in their jurisdictions. This could take the form of

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	profit/revenue sharing with municipalities, co-financing via local authorities or energy communities, or direct purchase contracts; o Options should be explored to increase the areas that can be used for onshore wind energy projects. These options should consider brownfield and greyfield sites (e.g. previously developed areas, underdeveloped industrial parks), combined use (e.g. in industrial areas, co-location with other infrastructure) and options to locate alternative onshore wind turbine designs, such as bladeless wind turbines.
15. What are the most important measures and costs related to different stake holders?	**Review of the planning process** The cost of the measure depends on several factors (extent of the review and pathway), but the main impact of his measure is the additional staff costs, either at central or local level. The cost will be borne by central and local government. **Renewables support** The cost of this measure depends on future electricity prices, and it would affect consumers bills (the cost will be borne by all consumers according to their tariffs and consumption). Estimated cost in 2030 range between 0 (in case of persistently high energy prices) and €209 million per year. **Electricity system balancing** The cost of setting up a balancing market are low compared to its benefits, and would be paid by market participants via market fee. The initial investment would be made by the system operator, and passed to consumers via energy bills as part of the RAB model. **Transmission network reinforcement** Additional investment costs have been estimated to vary between €135 million and €355 million depending on the scenario (total costs up to 2050). The cost will be borne by the TSO (or by private investors in the case of private assets) and recovered either via network fees to consumers or via electricity wholesale cost in the case of private assets.
16. What are the main steps and actions to break down local opposition to new installations, how to motivate local people (best practices from other countries) and rise ability to understand importance of new units? There is going on a process regulating local benefit from renewables, would it be enough?	To reduce local opposition, it will not be sufficient to increase local benefits. The action plan proposes a series of coordinated measures to ensure local communities feel more part of the transition and directly benefit from it: • One-stop shops • Energy communities • Providing financial advantages to local administrations that are more proactive in identifying suitable areas • Identifying mechanisms for local communities to directly benefit from installations in their proximity
17. Which are necessary investments (costs) to speed up transmission developments for renewables, storage, DSM etc.?	The modelling analysis returns the following interventions: • Lääne-Eesti and Latvia: according to the pathway, are necessary up to 332 MW of interconnection capacity by 2030 and between 600 MW and 1200 MW by 2050. Total investment cost up to 2050 vary between €135 million and €266 million depending on the scenario • Lääne-Eesti and Põhja-Eesti: 377 MW of transmission capacity by 2050, for a total investment of €89 million
18. Based on which technologies would the necessary dispatchable capacity be most cost effective?	The modelling did not require a specific level of dispatchable capacity, demand is satisfied in all pathways either via domestic production or imports. Setting a necessary level of dispatchable capacity is a strategic decision. However, differences between the pathways are relatively small in the percentage of dispatchable % of total capacity, with around 40% in 2030 increasing to 45% in 2040 and around 50% in 2050. With the biomass-fuelled oil shale and batteries (by far) providing the largest part of this capacity. The RES+storage (batteries), nuclear (nuclear) and AT-NIMP (fossil gas, nuclear) have the highest dispatchable capacity percentage by 2050 (full results are available in Annex to the Action plan report, Deliverable 7).
19. Based on which sources and technologies is covered our security of supply in cold winter period in 2030 and 2050 and to realize that which actions we should take?	The scenarios modelled ensure that demand is met at all time, although quite often this will be via batteries. The scenarios with lowest dispatchable capacity are more reliant on imports, but in general the expected amount of batteries will fill the gap.
20. What would be the most realistic pathway considering public costs and state taxes, risks and impacts to SKP, income tax etc.?	Across the seven potential scenarios examined, the *All technologies* and the *Renewable + Storage (offshore wind)* scenario are the pathways that appear to offer the best combination of benefits, costs, risks and feasibility. The *RES + Storage* scenario scores positively concerning security of supply, limit to fossil fuel use, socio-economic impacts and CO_2 emissions, but its high costs are the key challenge. Refer to Table 2-1 for the synthetic score and the Annex for the underlying justification for the scores.

All final deliverables produced as part of this work are provided separately as Annexes to this report.

4 Monitoring indicators

4.1 Key developments and indicators

Table 4-1 provides an overview of the project implementation indicators. All the deliverables of the project are 100% finalised, including this present report. Additionally, stakeholder interviews were carried out in Deliverable 5, which were not intended, due to low response rate to the survey.

Table 4-1 Development of project implementation indicators

Project implementation indicators	Results by 5/10
No. of reports completed and circulated	9/8
No. of project reports approved	5/8
No. of progress reports	20/20
No. of steering committee meetings held	16/16
No. of progress meetings with MKM held	46
No. of other stakeholder meetings held	17

4.1.1 Workshops overview

The project included four workshops. The table below provides an overview of the date of the workshop and the number of participants. The list of organisations for the first and fourth workshop can be found in the Annex **ITõrge! Ei leia viiteallikat.**. The other workshops were hosted by the client.

Table 4-2 Summary of workshops

Workshop	Date	Number of participants
WS1: framing of the analysis (DLV3)	12/5/2021	57
WS2: feedback of the preliminary results (DLV3)	2/12/2021	n/a
WS3: Feedback on Action Plan (DLV 7)	22/2/2022	~40 (workshop hosted by client)
WS4: Final results presentation	11/5/2022	102

4.1.2 Interviews overview

For Deliverable 5, seven interviews were held to supplement the risk survey. These interviews were held in January 2022 with stakeholders who represented different industries in the power generation sector. Table 4-3 lists the interviewees and their sector.

Table 4-3 Deliverable 5 Interviewees

Organisation	Representative	Date
Renewables Association	Mihkel Annus	12/1/2022
Wind Association	Terje Talv	14/1/2022
Nuclear Energy interested company Fermi OÜ (also representing Power Industry Association)	Kalev Kallemets	17/1/2022
Biofuels Association	Ülo Kask	12/1/2022
Chamber of environmental organisations	Johanna Maarja Tiik and Ingrid Nielsen (Estonian Nature Fund), Silver Sillak (Estonian Green Movement)	18/1/2022
Sunly (renewable energy developer/investor)	Priit Lepasepp	27/1/2022
Alexela (investors in energy)	Marti Hääl	27/1/2022

Additionally, the project team interviewed Erkki Sapp, Siim Limre and Hardi Koduvere from Elering (TSO) on 25/5/2022.

4.2 Deliverables tracker

Deliverable		Work-stream started	Work-stream completed	Draft report submitted	Revised report submitted	Final report submitted	Final report accepted	Changes in timing compared to contract
1	Inception report	✓	✓	14/10/20	11/11/20	18/11/20	20/11/20	n/a
2	Baseline data collection report	✓	✓	12/2/21	-	22/3/21	22/4/21	Slight delays to allow for data validation with Elering, MKM
3	Report - Development of pathways for reaching climate-neutral electricity generation	✓	✓	17/5/21	6/8/21	21/9/21	5/11/21	Delays due to summer holidays, extensive timeframe to allow for MKM and stakeholder feedback, followed by required time for revisions
4	Socio-economic impact assessment	✓	✓	12/10/21	9/11/21	29/11/21	Dec. 2021	Delayed due to length of time required to finalise D3
5	Risk analysis	✓	✓	3/1/2022	--	3/2/2022	15/2/2022	Delayed due to length of time required to finalise D3
6	Sensitivity analysis	✓	✓	10/03/2022	2/5/2022	13/6/2022	14/10/2022	Delayed due to length of time required to finalise D3; extra time anticipated to validate results with stakeholders
7	Action Plans for decarbonising electricity generation	✓	✓	10/3/2022	2/5/2022	21/6/2022	14/10/2022	Delayed due to length of time required to finalise D3; extra time anticipated to collect stakeholder feedback
8	Final report	✓	✓	10/3/2022	(June 2022)	27/7/2022	14/10/2022	Delayed due to length of time required to finalise D3
	Summary report	✓	✓	6/5/2022	10/5/2022	27/7/2022	14/10/2022	

Please note that dates in ( ) are anticipated; TBC = To be confirmed

4.3 Monitoring indicators for results/outcomes after the completion of the project

Based on the results of the project deliverables, the following monitoring indicators for the results/outcomes after the completion of the project are propose:

- Carbon emissions from the power sector (total CO_2 emissions; grid intensity gCO2/kWh);
- Estimated average generation costs (levelized cost in €/MWh; investment cost per technology in €/MWh);
- Energy dependency (net imports/final electricity consumption);
- Installed and planned capacity per technology (for on- and offshore wind, batteries and solar PV in MW);
- Generation from oil shale (in GWh);
- Share of renewable energy in gross final energy consumption (%); and
- Share of climate neutral electricity production in gross final energy consumption (%).

5 Key Challenges

In this section, the main challenges the project team faced during the development of the deliverables is explained here, detailing what occurred and how the project team dealt with the challenges.

Challenge 1: Delays in the finalisation of deliverable 3

A key challenge for this project was the delay of the finalisation of Deliverable 3 – the pathway modelling. Since the results of Deliverable 3 are input for the following deliverables, this delay had a cascading effect on the timeline of the rest of the deliverables. To manage this delay, extra time was required to deliver the Deliverables 4-8. Although the project team was able to submit the deliverables at a later date, the issue remained a problem until the end of the project.

Challenge 2: Deliverable 7 was affected significantly

Relating the Challenge 1, Deliverable 7 (the Action Plan) was significantly affected by this cascading delay. While the modelling results were supposed to have been available at the beginning of the task, the full modelling results were not available until the day before submission. This gave the project team for Deliverable 7 very little time to analyse and write the report concerning the modelling results. The project team overcame this challenge by preparing the report as much as possible without the results and later filling in the remaining gaps once the results were available.

Challenge 3: Complexity of pathways modelling and numerous specific requests

The pathway modelling considered a high number of pathways and the project team received a high number of specific requests. This not only created delays in the project, but also because of this, the project team’s effort had to be diluted in too many strands of the analysis. The team managed this by considering all of the specific requests and pathways, though it did lead to delays in the project.

Challenge 4: Limited responses from stakeholders to the risk survey for Deliverable 5

The stakeholder survey concerning the risks for the pathways for Deliverable 5 (the risk analysis) received only 8 responses from 7 organisations. The survey was sent to 62 stakeholders from 37 organisations, who were all familiar with the ongoing project work. To mitigate this challenge, the survey deadline for stakeholders was extended, though there still remained few responses. Further, in January 2022, the project team interviewed a number of stakeholders representing different views from the power generation sector to provide more insights on stakeholder perception of risk for the pathways. For a more active role from stakeholders, providing the feedback material and the survey in the native language could be a solution.

Annexes: Deliverable reports and excel sheets

All annexes, except Annex A, are attached separately

Annex A: Summary report

Annex B: Deliverable 1 report

Annex C: Deliverable 2 report and supporting Excel files

Annex D: Deliverable 3 report and supporting Excel files

Annex D.1: Spreadsheets of model results: Scenario-specific spreadsheets with major results from the model are available at this link (password = estonia2050). These files have been edited to emphasise trends that are discussed in the "Responses to stakeholder feedback" file compiled to answer questions received from Estonian stakeholders.

Annex D.2: Spreadsheet of report charts: A spreadsheet used to prepare the charts for this report can be accessed at this link (password = estonia2050).

Annex E: Deliverable 4 report and supporting Excel files

Annex F: Deliverable 5 report and supporting Excel files

Annex G: Deliverable 6 report and supporting Excel files

Annex H: Deliverable 7 report

Annex I: List of participants at workshops

Annex A - Actions list and summary table

The figures below provide an indicative timeline of the proposed actions and designates the responsible body for the action.

Figure A-1 Indicative timeline and roles of the proposed actions (1/2)

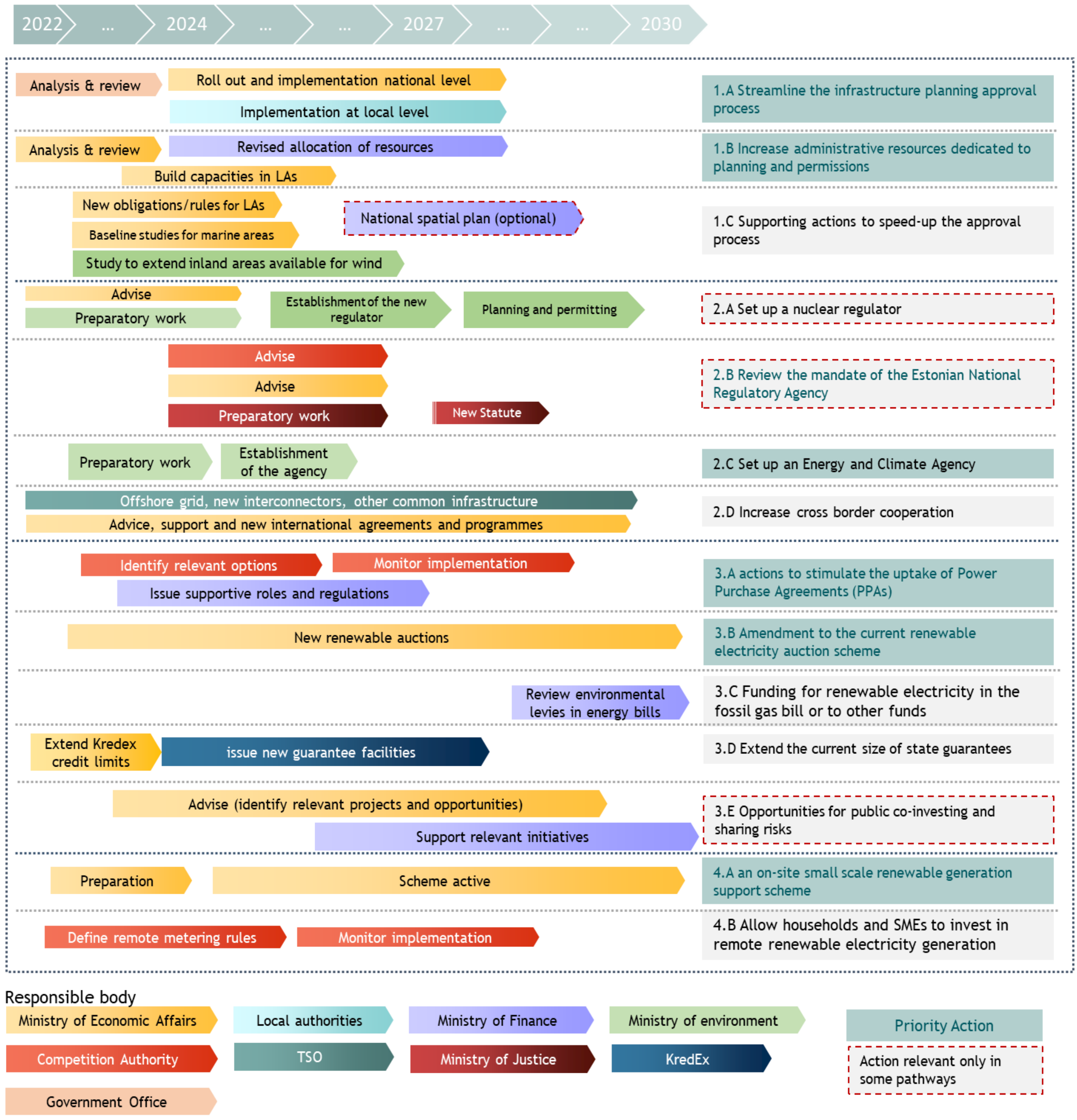
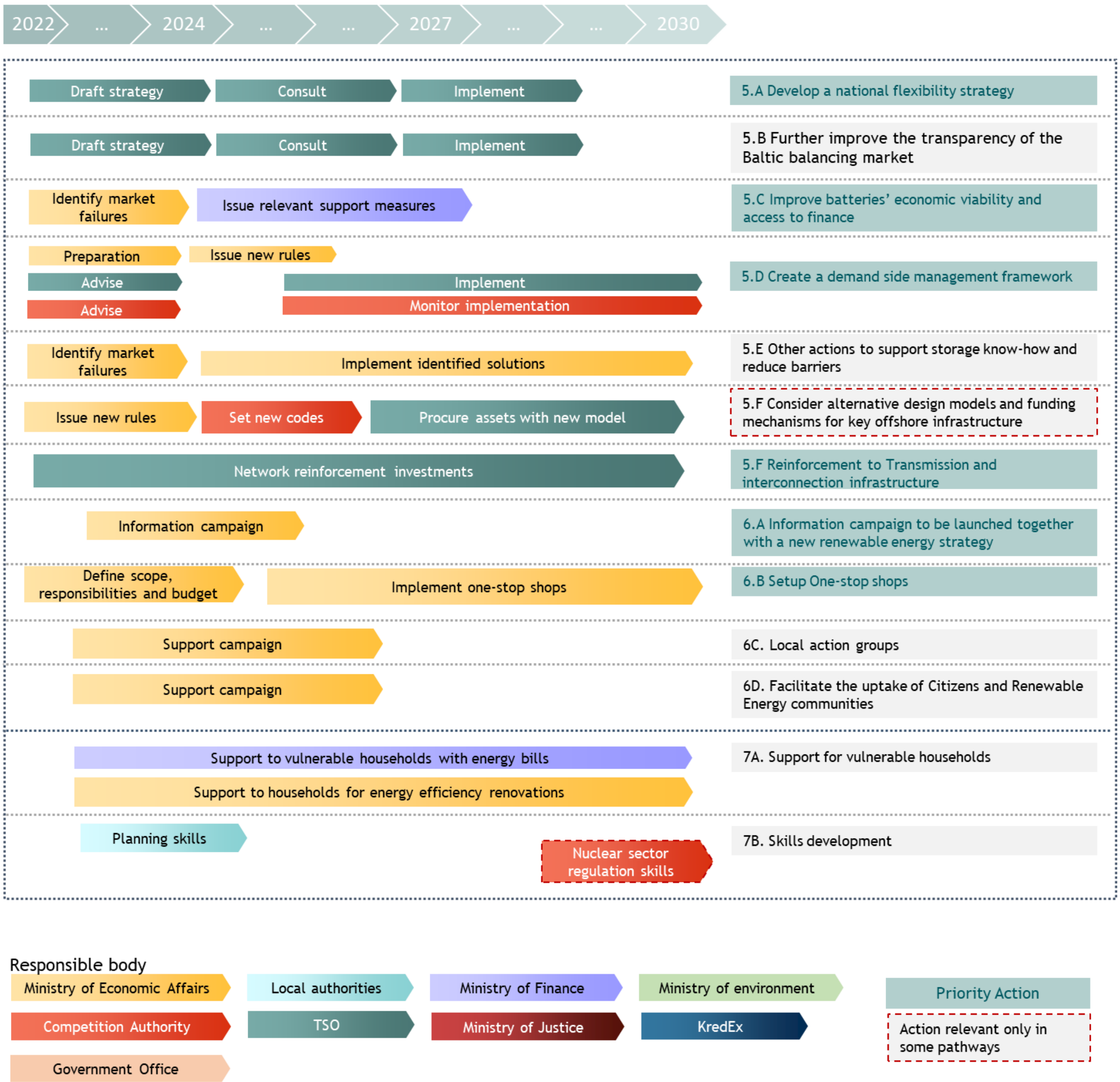


Figure A-2 Indicative timeline and roles of the proposed actions (2/2)



The below table list the priority actions of each pathway, where priority actions are critical actions for the implementation of the pathway and supporting actions are importance, but less critical actions.

Table A-1 Action list

Action set	Actions	Renewables + storage	Nuclear	CCU	Renewable gas	All technologies	No net imports	AT 1000W
1. Planning	1A. Streamline the infrastructure planning approval process	P	P	P	P	P	P	P
	1B. Increase administrative resources dedicated to planning and permissions	P	✓	✓	✓	P	P	P
	1C. Supporting actions to speed-up the approval process	P	✓	✓	✓	P	P	P
2. Institutional reform	2A. Set up a nuclear regulator		P					✓
	2B. Review the mandate of the Estonian National Regulatory Agency		P	P				
	2C. Set up an Energy and Climate Agency	✓	✓	✓	✓	✓	✓	✓
	2D. Increase cross border cooperation	P		P			✓	✓
3. Risk reduction instruments	3A. actions to stimulate the uptake of Power Purchase Agreements (PPAs)	P	✓	✓	✓	P	P	P
	3B. Amendment to the current renewable electricity auction scheme	P	P		P	P	P	P

	3C. Move all or part of the funding for renewable electricity to the fossil gas bill or to other funds	✓	✓	✓	✓	✓	✓	✓
	3D. Extend the current size of state guarantees provided by Kredex and develop a broader framework for government guarantees	P	P	P	P	P	P	P
	3E. Public co-investing and sharing risks		P	P				
4. RES for households and SMEs	4A. Set up an on-site small scale renewable generation support scheme, in combination with other actions to incentivise building renovation	✓	✓		✓	✓	✓	✓
	4B. Allow Households and SMEs to invest in remote renewable electricity generation	✓	✓		✓	✓	✓	✓
5. Power networks	5A. Develop a national flexibility strategy	✓	✓		P	✓	✓	✓
	5B. Review the approach for balancing the electricity system	P	P	P	P	P	P	P
	5C. Improve batteries' economic viability and access to finance	P	P			✓	✓	✓
	5D. Remove the double network charges for network-connected storage	P	P	✓	✓	✓	✓	✓
	5E. Create a demand side management framework	P	P	P	P	P	P	P

	5F. Other actions to support storage know-how and reduce barriers	✓	✓			✓	✓	✓
	5G. Consider alternative design models and funding mechanisms for key offshore infrastructure	✓		✓		✓	✓	✓
	5H. Reinforcement to Transmission and interconnection infrastructure	P	✓	✓	✓	✓	✓	✓
6. Involvement of the civil society	6A. Information campaign to be launched together with a new renewable energy strategy	P	P	P	✓	✓	✓	✓
	6B. Setup One-stop shops	✓	✓	✓	✓	✓	✓	✓
	6C. Local action groups	✓	✓	✓	✓	✓	✓	✓
	6D. Facilitate the uptake of Citizens and Renewable Energy communities	✓	✓	✓	✓	✓	✓	✓
7. Other actions	1. Support for vulnerable households	P	P	P	P	P	P	P
	2. Skills development	✓	P	✓	✓	✓	✓	✓

P = priority action ✓ = supporting actions

Table A-2 Summary table

DLV		RES+Storage	Nuclear	CCU	Renewable Gas	All technologies (AT)	No net imports	1000 MW dispatchable capacity
	Summary	*is the most ambitious pathway, which foresees the deployment of large amounts of offshore wind and storage, and that results in the highest total investment costs, both in generation and transmission infrastructure. However, the investment generates positive economic impacts, and environmental impacts from large offshore deployment can be managed. Key actions focus on facilitating offshore deployment (technology-specific support; offshore grid; transmission capacity), on supporting to the deployment of storage solutions, and on protecting vulnerable consumers from possible increases in energy bills.*	*the pathway is characterised by a focus on nuclear and solar PV, and it is expected to be the second most expensive pathway. The main actions identified concern the development of a national nuclear programme and supporting actions to other renewables. According to stakeholders, this is the riskiest scenario, especially as it relies on a technology that has no history in Estonia and that is not expected to come online before 2035.*	*is the scenario which requires the lowest investment and that allow to continue exploiting fossil fuel reserves. While the actions required for its implementation are fewer and simpler than for other pathways, this is the pathway that is modelled to be worst for the economy and employment, and would leave Estonia most dependent on power imports in future. CCU could be a good option for Estonia if further use and transport options for CO2 are identified, so that carbon capture can be deployed to other power plants (beyond the two considered in this analysis) and industrial installations, and if costs can be made economically competitive.*	*similar to the CCU pathway, while the modelling results provide a relatively balanced power system, there are inconsistencies that suggest this may not be an ideal trajectory for Estonia, unless some of the assumptions change. In this case, the cost of biogas is too high to make it competitive as a dispatchable resource, and deploying large capacities of biogas plants (1 GW) to be used only as flexibility instrument is a highly inefficient choice and complex to implement from a policy point of view. Nonetheless, actions to incentivise the deployment of biogas as part of a technology neutral approach could be considered.*	*the three technology-competition pathways have similar results in terms of technology mix, costs and dispatchable capacities. Based on the assumptions, different technologies emerge, but overall all three scenarios appear more balanced than other technology-specific options. The actions recommended for these pathways follows a technology-neutral approach, and aim to keep all options open until costs become clearer. Among the three scenarios, the AT 1000 MW is estimated to be most expensive for the consumer, while the no net import objective (AT-NIMP) does not increase costs substantially and is amongst the pathways expected to be most economically beneficial. It is also one of the few pathways that does not rely on biomass-fuelled oil shale plants for a significant share of generation after 2030, which points to a more sustainable impact on Estonian forests, however at the cost of greater use of natural gas.*		
	Overall assessment	**RECOMMENDED**	**NOT RECOMMENDED**	**NOT RECOMMENDED**	**RECOMMENDED (with changes)**	**RECOMMENDED**	**Also viable**	**Also viable**
	Alternative ranking	**2**	**1**	**7**	**4**	**2**	**6**	**5**
2	Model description	Evaluates a large deployment of offshore wind	Climate-neutral electricity production via +900 MW nuclear capacity	Adding carbon capture to two large oil shale generators	Implementation of 1 GW of new biogas capacity	Least constrained pathway, allows for investment in the most cost optimal electricity generation technology	AT pathway + requirement for Estonia's electricity imports and exports to be balanced	AT pathway + constraint to have at least 1000 MW dispatchable capacity in Estonia
3	Pathway analysis	+1 GW of offshore wind by 2030, up to 4000 MW by 2050, >50% of all generation. Also expands batteries, onshore wind and solar PV similar to REF. Achieves RES shares of 100% from 2040.	+0.9 GW nuclear by 2040. This provides around 1/3 of total supply in 2040. Nuclear complements major battery and solar PV additions - highest of each across all pathways. Declining use of	Continues to operate oil shale plants fuelled by oil shale after 2030 with adoption of CCS technology, however at significantly lower scale, only 0.5 TWh p.a. by 2040. Batteries and onshore wind are other major additions.	+ 1 GW of biogas capacity by 2030, but this is too expensive to run and makes virtually no actual contribution to generation. Otherwise similar to reference, (+ battery, solar PV and onshore wind). Battery additions are	Builds new capacity with a focus on Batteries, Solar PV and Onshore Wind. Also adds small fossil gas plant after 2040. +2 GW offshore wind follows only after 2040. Growing use of biomass-	+ 348MW pumped hydro facility by 2030. This helps to always provide 1000MW of dispatchable capacity. Builds new capacity with a focus on Batteries, Solar PV and Onshore Wind. Also adds	Builds new capacity with a focus on Batteries, Solar PV and Onshore Wind. Also adds medium fossil gas capacity (400MW) after 2030. This acts as a transition power source prior to the nuclear

DLV	RES+Storage				Nuclear			
	Growing use of biomass-fuelled oil shale plants, providing more than 3 TWh of power by 2050.				biomass-fuelled oil shale plants after 2030, these provide around 1 TWh of power by 2050. Offshore wind only added after 2040.			
Capacity (MW) & generation (GWh)	**2030**		**2050**		**2030**		**2050**	
	MW	GWh	MW	GWh	MW	GWh	MW	GWh
Onshore	1,479	3,944	1,479	3,994	1,479	3,748	1,479	3,795
Offshore	1,000	3,542	4,000	12,550	0	0	1,576	5,594
PV	1,249	1,444	2,094	2,504	1,864	2,160	6,573	7,549
Batteries	2,235	-55	8,617	-127	1,677	-40	9,288	-114
Other techs[19]	1,155	2,965	1,235	3,842	1,155	2,936	1,975	6,545
Total	**7,118**	**11,839**	**17,425**	**22,764**	**6,174**	**8,803**	**20,892**	**23,480**
% dispatchable	48%		55%		46%		53%	

DLV	CCU				Renewable Gas			
	Results in major import dependency.				lowest of all pathways until after 2040. Growing use of biomass-fuelled oil shale plants, providing almost 3 TWh of power by 2050. Offshore wind only added after 2040.			
Capacity (MW) & generation (GWh)	**2030**		**2050**		**2030**		**2050**	
	MW	GWh	MW	GWh	MW	GWh	MW	GWh
Onshore	1,479	3,944	1,479	2,640	1,479	3,833	1,479	3,750
Offshore	0	0	123	321	0	0	1,883	6,079
PV	725	833	725	647	1,572	1,830	3,837	4,555
Batteries	1,330	-38	4,571	-13	860	-26	5,907	-88
Other techs[19]	1,155	2,021	923	989	2,155	2,831	1,901	3,316
Total	**4,688**	**6,760**	**7,821**	**4,585**	**6,066**	**8,467**	**15,007**	**17,612**
% dispatchable	53%		70%		50%		52%	

DLV	All technologies (AT)				No net imports			
	fuelled oil shale plants, providing almost 3 TWh of power by 2050.				small fossil gas plant after 2030. +2.1 GW offshore wind follows only after 2040. Growing use of biomass-fuelled oil shale plants, providing almost 3 TWh of power by 2050.			
Capacity (MW) & generation (GWh)	**2030**		**2050**		**2030**		**2050**	
	MW	GWh	MW	GWh	MW	GWh	MW	GWh
Onshore	1,479	3,819	1,479	3,812	1,479	3,781	1,479	3,821
Offshore	0	0	1,968	6,881	726	2,447	1,967	7,008
PV	1,507	1,746	4,057	4,811	2,390	2,768	3,933	4,615
Batteries	1,607	-42	7,970	-102	2,075	-48	7,705	-97
Other techs[19]	963	2,411	1,045	3,676	782	2,349	1,125	3,648
Total	**5,556**	**7,934**	**16,519**	**19,078**	**7,452**	**11,297**	**16,209**	**18,995**
% dispatchable	46%		55%		38%		54%	

DLV	1000 MW dispatchable capacity			
	power unit coming online by 2050 (300MW). 725MW offshore wind already by 2030, expands to 2000MW after 2040. Declining use of (biomass-fuelled) oil shale plants.			
Capacity (MW) & generation (GWh)	**2030**		**2050**	
	MW	GWh	MW	GWh
Onshore	1,479	3,847	1,479	3,885
Offshore	0	0	2,098	7,417
PV	1,940	2,247	3,920	4,681
Batteries	1,616	-38	7,533	-97
Other techs[19]	1,446	2,635	1,424	3,636
Total	**6,480**	**8,991**	**16,453**	**19,723**
% dispatchable	47%		52%	

	DLV	RES+Storage	Nuclear	CCU	Renewable Gas	All technologies (AT)	No net imports	1000 MW dispatchable capacity
3	Security of supply (year power req. are met)	2030	2040	Does not meet requirement	2050	2050	2030	2050
	Limit of fossil use (fossil gas gen. in 2050)	0.01 TWh	0.01 TWh	0.48 TWh (shale oil)	0.0 TWh	0.3 TWh	0.89 TWh	0.4 TWh
	Electricity from Biomass in 2050	3.8 TWh	1.4 TWh	0.4 TWh	3.2 TWh	3.3 TWh	0.4 TWh	3.4 TWh
	CO2 emissions by 2050 (ktCO2)	79 ktCO_2	30 ktCO_2	-147 ktCO_2	68 ktCO_2	167 ktCO_2	324 ktCO_2	199 ktCO_2
4	Avg. electricity prices in 2050 (EUR/kWh)	0.139 EUR/kWh	0.088 EUR/kWh	0.149 EUR/kWh	0.101 EUR/kWh	0.097 EUR/kWh	0.107 EUR/kWh	0.103 EUR/kWh
	Total cumulative investment costs (2022-2050)	€14,293M	€12,089M	€3,966M	€11,577M	€9,025M	€10,454M	€9,868M
	Total network reinforcement costs	€355M	€230M	€135M	€141M	€155M	€135M	€155M
	Renewable subsidies costs in 2030 (low-high est.)	€105-209M	€39-78M	€28-55M	€37-73M	€36-71M	€94-189M	€41-82M
	Socioeconomic impacts	++ GDP impact, especially with open financing	0 GDP impact, slight positive with open, slight negative with closed financing	-- GDP negative impact -- Employment negative impact --- Prices large negative impact	++ GDP impact, especially with open financing	+ GDP impact, small positive with open financing	++ GDP impact, especially with open financing	+ GDP impact, small positive with open financing

[19] All remaining technologies, including Oil shale. Oil shale provides a significant contribution to generation still in 2030, after which it is replaced by biomass in all but the CCU pathway.

		0 employment impact, positive with open finance, negative under self-finance + Price impact, small reduction ++ Distributional impact, especially with open finance	- Employment small negative impact -- Prices large negative impact + Distributional impact, small positive	- Distributional negative impact	++ employment impact, especially with open finance, neutral under self-finance - Price impact, small increase ++ Distributional impact, especially with open finance	- employment impact, small negative + Price impact, small reduction 0 Distributional impact, negligible	++ employment impact, especially with open financing - Price impact, small increase + Distributional impact, positive	- employment impact, small negative - Price impact, small increase 0 Distributional impact, negligible
5	Risk analysis	Perceived as risky by stakeholders, although it is the most supported. Exposed to high energy market risk	Riskiest scenarios, stakeholders moderately negative about it. Main risks are related to citizens opposition, regulation, and technological delay.	Medium risk scenario, but disliked by stakeholders. Main risk is technological	Less risky scenario, overall liked by stakeholders. Very exposed to international energy prices but less exposed to the risk of competition for rare materials needed for batteries.	Low risk scenario with good stakeholder support.	Second highest risk, overall disliked by stakeholders. High regulatory risks	Second best scenario, liked by stakeholders.
	Environmental risk (severity/likelihood, 1-5)	2/2.5	4/2.5	2.7/2.3	2/2	3/2.5	3/2.5	3/3
6	Sensitivity analysis	++ GDP impact, especially in case of higher biomass prices (S3) + employment impact, small positive but only in case of higher biomass prices (S3) -- Price impact, highest prices by 2050 +++ Distributional impact	++ GDP impact, except in case of enforced 90% dispatch (S2), then small negative + employment impact, except in case of enforced 90% dispatch (S2), then negative + Price impact, lowest prices by 2050, except in case of enforced 90% dispatch (S2), then negative + Distributional impact, except in case of enforced 90% dispatch (S2), then negative	-- GDP negative impact - Employment negative impact - Prices negative impact - Distributional negative impact	++ GDP impact, positive +++ employment impact, positive + Price impact, small positive ++ Distributional impact, positive	+ GDP impact, small positive + employment impact, small positive + Price impact, small reduction 0 Distributional impact, minimal impact	++ GDP impact, positive ++ employment impact, positive 0 Price impact, minimal impact 0 Distributional impact, minimal impact	+ GDP impact, small positive ++ employment impact, positive 0 Price impact, minimal impact + Distributional impact, small positive impact
7	Priority actions **(shared priorities in bold)**	**1.A. streamline the infra. planning approval process** 1.B. add resources for planning & permissions 1.C. Speed-up approval process 2.D. Increase cross border cooperation 3.A. Actions to stimulate the uptake of PPAs 3.B. Amendment to RES auction scheme **3.D. Expand state guarantees & develop broader framework for gov. guarantees** **5.B. Review the approach for balancing the electricity system** 5.C. Improve batteries' economic viability and access to finance 5.D. Remove the double network charges for network-connected storage	**1.A. streamline the infra. planning approval process** 2.A. Set up a nuclear regulator 2.B. Review the mandate of the Estonian National Regulatory Agency 3.B. Amendment to RES auction scheme **3.D. Expand state guarantees & develop broader framework for gov. guarantees** 3.E. Public co-investing and sharing risks **5.B. Review the approach for balancing the electricity system** 5.C. Improve batteries' economic viability and access to finance 5.D. Remove the double network charges for network-connected storage 5.E. Create a demand side management framework 6.A. Info. Campaign 7.A. Support vulnerable households	**1.A. streamline the infra. planning approval process** 2.B. Review the mandate of the Estonian National Regulatory Agency 2.D. Increase cross border cooperation **3.D. Expand state guarantees & develop broader framework for gov. guarantees** 3.E. Public co-investing and sharing risks **5.B. Review the approach for balancing the electricity system** 5.E. Create a demand side management framework 6.A. Info. Campaign 7.A. Support vulnerable households	**1.A. streamline the infra. planning approval process** 3.B. Amendment to RES auction scheme **3.D. Expand state guarantees & develop broader framework for gov. guarantees** **5.B. Review the approach for balancing the electricity system** 5.E. Create a demand side management framework 7.A. Support vulnerable households	**1.A. streamline the infra. planning approval process** 1.B. add resources for planning & permissions 1.C. Speed-up approval process 3.A. Actions to stimulate the uptake of PPAs 3.B. Amendment to RES auction scheme **3.D. Expand state guarantees & develop broader framework for gov. guarantees** **5.B. Review the approach for balancing the electricity system** 5.E. Create a demand side management framework 7.A. Support vulnerable households	**1.A. streamline the infra. planning approval process** 1.B. add resources for planning & permissions 1.C. Speed-up approval process 3.A. Actions to stimulate the uptake of PPAs 3.B. Amendment to RES auction scheme **3.D. Expand state guarantees & develop broader framework for gov. guarantees** **5.B. Review the approach for balancing the electricity system** 5.E. Create a demand side management framework 7.A. Support vulnerable households	**1.A. streamline the infra. planning approval process** 1.B. add resources for planning & permissions 1.C. Speed-up approval process 3.A. Actions to stimulate the uptake of PPAs 3.B. Amendment to RES auction scheme **3.D. Expand state guarantees & develop broader framework for gov. guarantees** **5.B. Review the approach for balancing the electricity system**

		5.E. Create a demand side management framework 5.H. Reinforcement to transmission and interconnection infra. 6.A. Info. Campaign 7.A. Support vulnerable households	7.B. Skills development					
	Main implementation challenges	Highest investments required, but in known technologies. The success may depend on few key offshore project being successful. Challenging actions to deploy sufficient battery capacity	Relies on unproven technologies, for which Estonia has no history. This may force Estonia to take expensive remedial actions in the mid 2030s Challenging amount of battery deployment. Positive socio-economic results occur in sensitivity analysis only at low load factors (50-60%) for nuclear, enforcing higher loads leads to negative impacts.	Lowest investment required, but it could be one of the more challenging to implement in the short term. Cost savings come with high socio-economic costs and energy security risks, i.e. relies on imports for more than 60% of domestic requirements.	Biggest challenges is the financing of biogas capacity in the short term. While this reduces the risks of relying only on batteries for flexibility, for flexibility purposes is cheaper investing in batteries or pumped hydro.	Relatively low total investment needs (€ 7 billion by 2050), most of which is expected to be required after 2040 and in proven technology means actions do not need to be too complex or expensive	Main challenge is associated with high capacity required by 2030, with associated high investment	The 1000 MW capacity requirement increases investment needs and strength of associated actions, in particular subsidies

Very favourable (++); moderately favourable (+); neutral/no impact (0); moderately unfavourable (-); very unfavourable (--)

Annex I: List of participants at workshops

List of participating organisations in the Pathway modelling Workshop (12/5/21)

- Tartu Regional Energy Agency
- Estonian Heat Pump Union
- EE Environmental Investment Centre
- University of Tartu
- AS Tootsi Turvas
- Estonian University of Life Sciences
- Estonian Green Movement
- Estonian Environmental Research Centre
- EE Hydrogen Association
- Nomine Consult
- Eesti Energia
- Estonian Private Forest Centre
- National Audit Office of Estonia
- Estonian Power Plants and District Heating Association
- Port of Tallinn
- PwC
- EE Ministry of Environment
- EE Electricial Industry Association
- Eesti Gaas
- Viru Keemia Grupp
- Permanent Representation of Estonia to the EU
- Association of Estonian Cities and Municipalities
- City of Tallinn
- KPMG
- Estonian Cell
- Estonian Investment Agency
- LHV
- Fermi Energy
- Cleantech For Estonia
- Baltic Bioenergy Association

List of participants in the Final Results Presentation Workshop (11/5/22)

- Ain Laidoja
- Aire Rihe
- Airiin Liisbet Strandson
- Ando Möldre
- Andrea Demurtas
- Andres Levald
- Anna Volkova
- Ants Kippasto Varmata

- Antti Roose
- Anu Ainsaar
- Argo Rosin
- Arvi Hamburg
- BERGER Nathalie (REFORM)
- Bert.Louke
- Birgit Parmas
- Enn Lust
- Eva-Ingrid Rõõm
- Gowtham Muthukumaran
- Hannes
- Heidi Koger
- Helen Saarmets
- Helena Gailan
- Helle Truuts
- Imre Bnysz
- Ingrid Nielsen (Eestimaa Looduse Fond)
- Irje Möldre
- Ivan Sergejev
- Ivo Krustok
- Jaanus Arukaevu
- Jaanus Uiga
- Jelena Šuvalova
- Johanna Lehtmets
- JOVOVIC KOMNENIC Jovana (REFORM)
- Julia Vahtraorg
- Kaarel Jänes
- Kädi Ristkok
- Kadi Steinberg
- Kaia Oras
- Kaie Küngas
- Karin Kondor-Tabun
- Karl Annus
- Karmo Kübarsepp
- Koen Rademaekers
- Kristiina Joon
- Kristiina Toots
- Kristin Puusepp
- Kristjan Kalda
- Kristo Kaasik
- Kulno Kesküla
- LAANISTE Madis (ENER)
- Laura Remmelgas
- Lauri Tammiste
- Lembe Reiman
- Liis Kasemets
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