Transitioning to a climate-neutral electricity generation

Summary report

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Trinomics

Contents

1 Introduction

The Estonian Government, 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 need to assess how plausible technologies and policies can be brought forward over the next three decades in order to decarbonise electricity.

This is the summary Report for the project "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 with 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).

Based on the deliverables of this assignment, and on the analysis carried out, the scenarios considered can be divided in:

Recommended

- **RES+storage:** scores positively on contributing to security of supply, limiting fossil fuel usage, socio-economic impacts and reducing CO2 emissions; aligns well with deployment in neighbouring countries; is based on proven technologies; the actions required are relatively straightforward
- **All Technologies:** achieves only a couple of very positive results across any of the aspects considered; however, it also does not have any strong negative point;
- **Renewable gas (modified):** the pathways scores well across several indicators, but with some changes to total biogas deployment)

Also viable

- **All Technologies - No Net Imports:** scores well across several criteria, but foresees extended use of fossil gas throughout the period considered (to 2050) and is likely to require high support to renewable generation installations
- **All technologies + 1000 MW:** overall this scenario achieves similar results to the base case AT – but the requirement to keep high reserve capacity (rather than relying on the market) is likely to result in unnecessary costs
- **Biogas (as modelled):** while the use of the 1 GW of biomass capacity is very limited, and investment costs in biogas quite high, building up high dispatchable capacity may reduce the risk on relying so extensively on batteries as in other scenarios

Not recommended

- **Nuclear:** the analysis shows that this pathway is expected to have some good outcomes (reducing the use of fossil fuel and keeping prices low in the long term). However, given the timeline involved, it is too risky to rely on the technology to achieve the decarbonisation objectives. Nuclear may be part of a balanced mix, but cannot be the "core" of a decarbonisation strategy
- **CCUS:** opting for a technology for which only very limited investments are possible does not make sense. However, CCUS should be revaluated if new outlet channels are found.

However, this analysis also identified several the actions that are likely to be needed across all pathways:

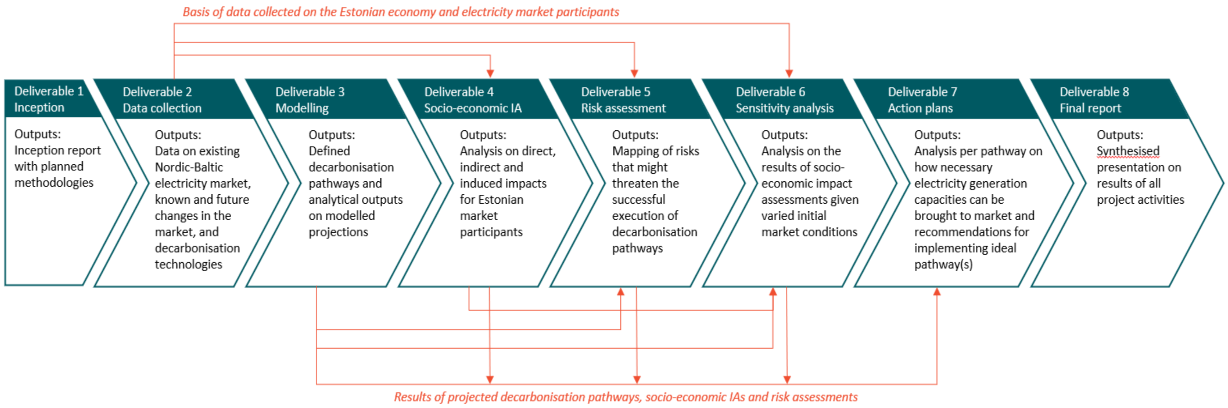
- Actions to streamline the planning process
- Actions to reduce risks on renewable and low carbon investments
- Setup a market for reserve capacity, flexibility and ancillary services that is open to different technologies, to nearby countries and to prosumers
- Actions to facilitate the diffusion of PPAs
- Increased funding and limits for Kredex guarantees
- Actions to support vulnerable households, including economic, technical and informational support

2 Summary of project activities and results

2.1 Summary of the project activities

The project activities consisted of eight interlinked tasks. The figure 1-1 shows overview of our approach, deliverables, activities, and sequence of tasks. The project includes eight deliverables, which are explained in further detail in the following sections.

Figure 2-1 The project activities



2.2 Deliverable 3: Main results from modelling pathways

Deliverable 3 aimed at defining and analysis the potential routes to 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.

This deliverable showed that in all climate-neutral (non-baseline) pathways, Estonian electricity production **shifts from oil shale toward wind and solar**. Fluctuations in wind and solar output are **balanced primarily by built-up dispatchable generation and storage, with some demand-side management (DSM) and electricity imports**. 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 results represent the base pathways for the analysis and the results are presented in the next section.

2.3 Deliverable 6: Main results from the sensitivity analysis

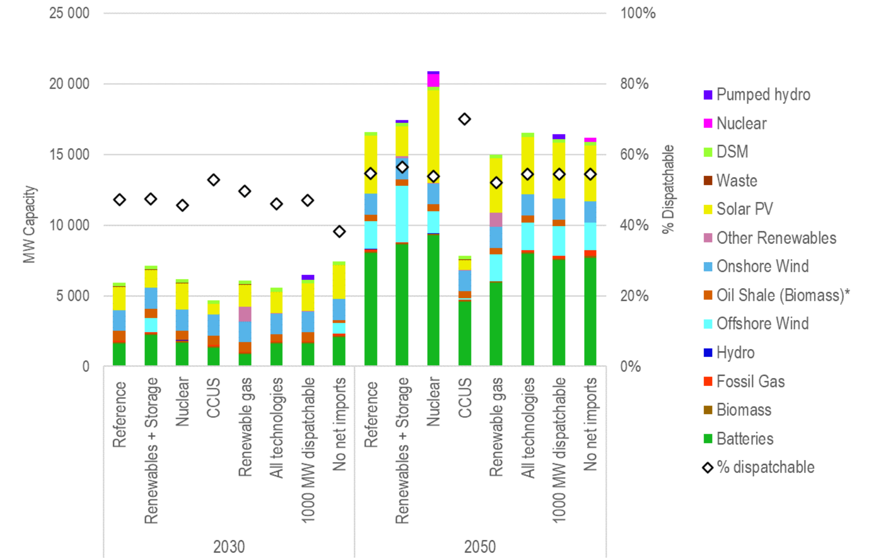
The aim of Deliverable 6 was to assess the robustness of the critical assumptions underlying the modelling of the decarbonisation pathways (Deliverable 3). This assessment is done by investigating four sensitivities, the first of which became the new base case for the pathway modelling, replacing the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

1. *(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;
2. *(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.
3. *(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.
4. *(S4) Test all sensitivities in the All technologies - No net import [AT-NIMP] pathway:* For the pathway with the most positive socio-economic impacts, test all sensitivity changes applied together to gauge the potential impacts: i.e., using the revised wind curves; assuming a higher price for biomass; enforcing a higher (90%) nuclear dispatch rate. Analyse changes to highlight the potential impacts of these sensitivities, including noting whether nuclear is adopted in this pathway and how renewables adjust to higher biomass prices.

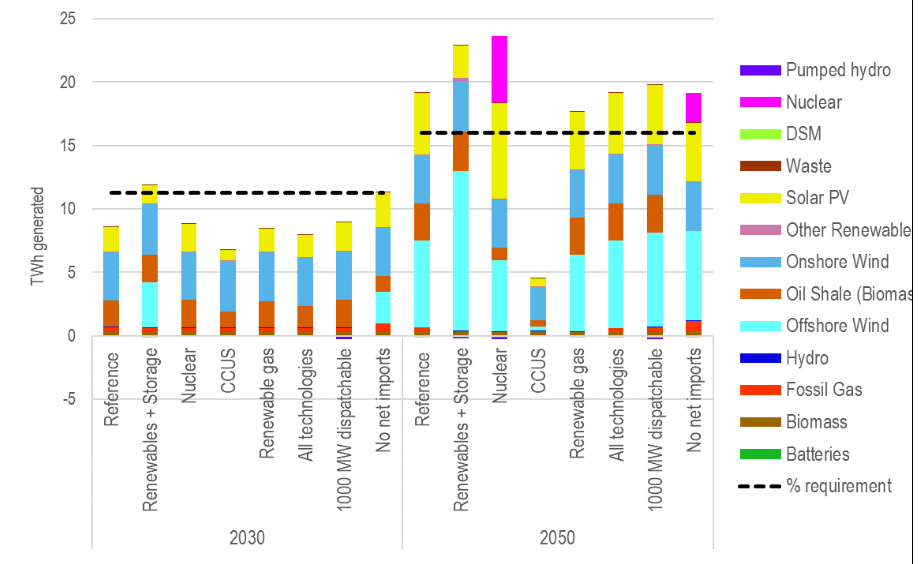
The full 2050 results for S1 are presented below in Table 2-1.

Table 2-1 Key pathway results for Deliverable 6 S1 using alternate wind curves

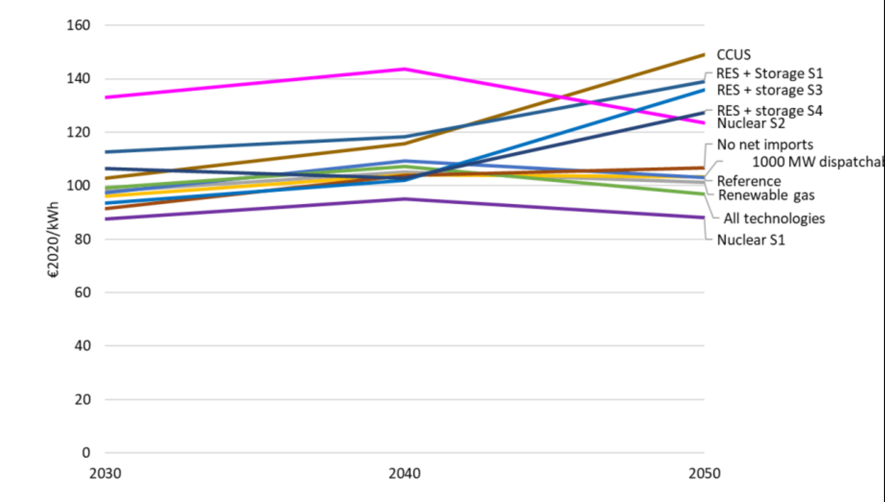
Capacity (MW)



Generation (TWh)



Prices (EUR/MWh)



Emissions (ktCO$_2$e)

GHG emissions	2020	2030	2040	2050	Total cumulative 2020-2050
Reference	2 667	763	98	187	24 306
RES+STORAGE	2 667	782	84	79	23 761
Nuclear	2 667	754	41	30	22 780
CCUS	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 CCUS the oil shale plants are converted to run on biomass in the 2030's

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 CCUS. 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 CCUS 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 CCUS 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 prices1 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 in the RES-Storage (increasing to around 140 EUR/MWh) and especially CCUS (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 CCUS pathway able to achieve net positive emissions

[1] 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

through BECCS2 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 and solar PV capacity in 2030 and also via 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.

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.

2.4 Deliverable 4: Main results from 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 2-2 below. This shows that the highest investments are needed in the RES-Storage, Nuclear and RES-Gas pathways, the least in the CCUS pathway.

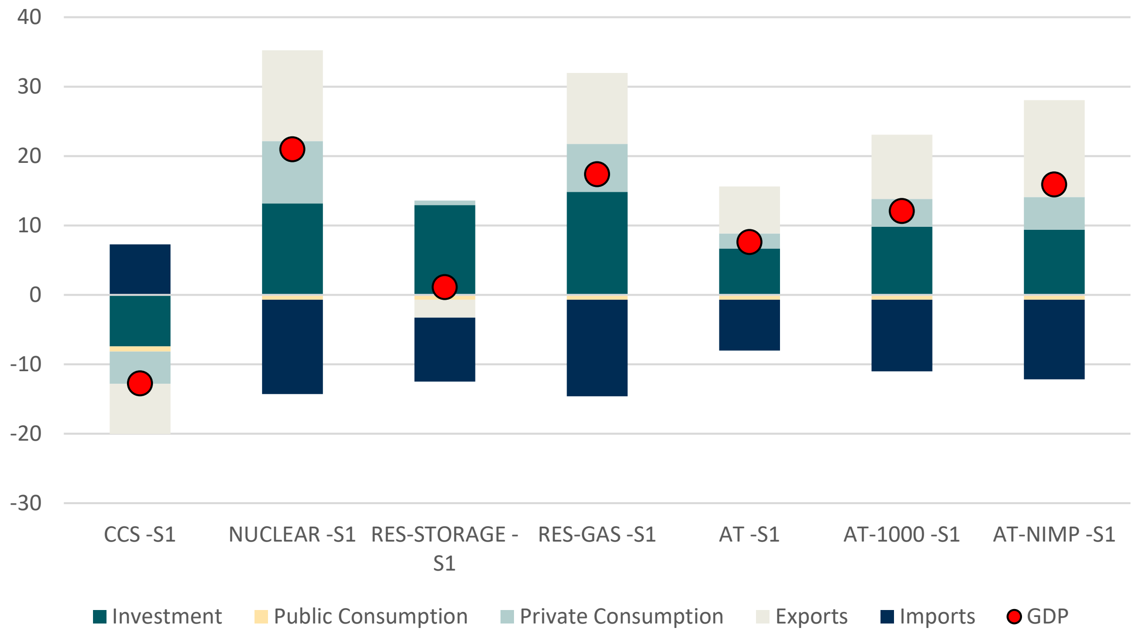
[2] A note of caution, by GHG accounting Estonian power sector emissions would be positive in the CCUS pathway, however the fact that nearly 70% of electricity would be imported means that potentially significant emissions would be caused indirectly by Estonian needs.

Table 2-2: Investment per pathway including Capital Costs and Interest rates (mil. €)

	Sensitivity case	Capital	Interest rate	Total	Post 2050 remaining payments
Reference	S1	6871	2027	8899	3295
All Technologies (AT)	S1	6959	2053	9013	3327
AT-1000	S1	7610	2245	9855	3311
AT - No Net Imp	S1	8062	2379	10441	2540
RES - Storage	S1	11027	3253	14280	2182
RES - Gas	S1	8930	2635	11564	2983
Nuclear	S1	9325	2751	12077	3193
CCUS	S1	3052	901	3953	344

These investments were used to model economic impacts, with figure 2-2 presenting the overall cumulative macroeconomic adjustment for each pathway for 2025-2050, this shows that all except the CCUS 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), with this leading to the highest economic positive turning negative as it drives price increases, undermining competitiveness.

Figure 2-2: S1- Macroeconomic adjustment of the different scenarios (demand & price effects) - GDP - cumulative (2025-2050)



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 CCS 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. CCS 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 CCUS 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.

2.5 Deliverable 5: Main results from 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 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.

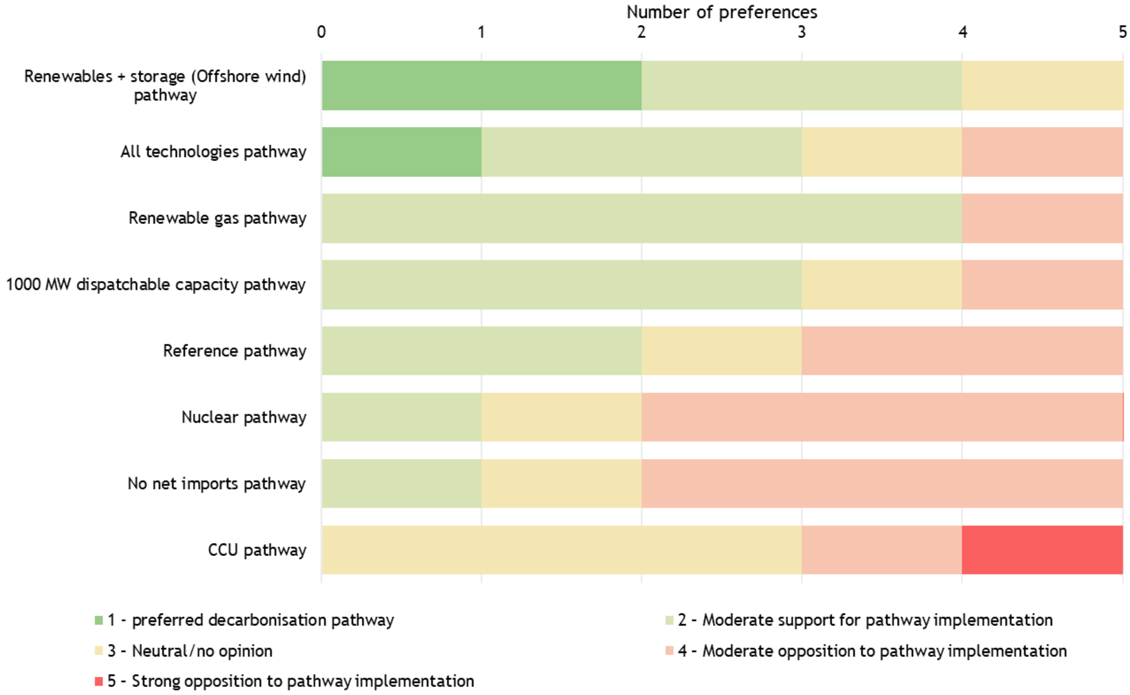
Stakeholders consider the nuclear pathway as the riskiest (a medium-high level of risk), while Renewable gas is the less risky one – although marginally less than all other pathways. The average score across all respondents and all categories of risks (Table 2-3) shows how the scenarios' scores compare for likelihood and severity across all risks.

Table 2-3 Average risk score by pathway (all risks)

	Likelihood	Severity	Total
Renewable gas	2.61	2.67	2.64
All technologies	2.88	2.82	2.85
Reference	2.88	2.98	2.93
1000 MW dispatchable capacity	2.93	3.00	2.96
CCU	2.94	3.16	3.05
Renewables + storage (Offshore wind)	2.92	3.23	3.07
No net imports	3.24	3.27	3.26
Nuclear	3.52	3.83	3.67
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 2-3 Pathway by preference



The survey was followed by a series of 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.

2.6 Deliverable 7: Action plans

Figure 2-4 lists the actions considered for the different pathways. How the actions relate to each pathway is shown in Annex.

Figure 2-4 List of actions

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

Action set	Actions
3. Risk reduction instruments	3.A actions to stimulate the uptake of Power Purchase Agreements (PPAs)
	3B. Amendment to the current renewable electricity auction scheme
	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
	3E. Public co-investing and sharing risks
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
	5B. Review the approach for balancing the electricity system
	5C. Improve batteries' economic viability and access to finance
	5D. Remove the double network charges for network-connected storage
	5E. Create a demand side management framework
	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
6. Involvement of the civil society	6A. Information campaign to be launched together with a new renewable energy strategy
	6B. Setup One-stop shops
	6C. Local action groups
	6D. Facilitate the uptake of Citizens and Renewable Energy communities
7. Other actions	7A. Support for vulnerable households
	7B. Skills development

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.
- **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.
- **Actions to reduce risks on renewable or low carbon investments**. For the majority of renewables, market risks are the major factor stopping or delaying an investment decision. The recommended mechanism to overcome this barrier is an improvement on the current feed-in premium. Contracts for difference would provide a more balanced risk transfer between generators and consumers, and minimise support if energy prices stay high. Different budgets within the scheme would allow support tailored to the targeted technology mix. Other technologies, such as renewable gas, nuclear energy and CCU will instead need more tailored risk reduction instruments that address technology-specific risks if it is decided that these are desirable for strategic regions (cost:return ratios are otherwise too unattractive for market players to invest).
- **Setup of a 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.
- **Setup an Energy and Climate Agency**, in charge of supporting various ministries with the implementation of energy and climate programmes.
- **Increased funding and limits for Kredex guarantees**, 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.

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 to the deployment of storage solutions, and on protecting vulnerable consumers from possible increases in energy bills.
- **Nuclear:** 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.
- **CCUS:** this is the scenario which requires the lowest investment and that will allow Estonia to continue exploiting its fossil fuel reserves 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 that is modelled to be worst for the economy and employment, and would leave Estonia most dependent on power imports in future. CCUS 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.
- **Renewable gas:** 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.
- **All technologies:** 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.

3 Summary of key results

3.1 Summary assessment

Table 3-1shows 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, but it should be noted that indicators presented should not be "added up", as this would imply they are given the same weight.

Table 3-1 Summary assessment across criteria

Criteria	RES+Storage	Nuclear	CCUS	Renewable Gas	All technologies (AT)	No net imports	1000 MW dispatchable capacity
Security of supply (year power req. are met)	++	+	--	0	0	0	++
Limit of fossil use (fossil gas gen. in 2050)	++	++	--	++	-	--	-
Electricity from Biomass in 2050	--	0	++	--	--	++	--
CO2 emissions by 2050 (ktCO2)	0	0	++	0	0	-	0
Avg. electricity prices in 2050 (EUR/kWh)	-	++	--	+	+	+	+
Total cumulative investment costs (2022-2050)	--	--	++	--	0	0	0
Total network reinforcement costs	--	-	+	+	+	+	+
Renewable subsidies costs in 2030 (low-high est.)	--	0	++	0	0	--	0
Socioeconomic impacts	++	-	--	++	0	++	0
Risk analysis	0	--	--	++	++	--	++
Sensitivity analysis	++	++	--	++	0	++	0
Main implementation challenges	0	--	-	0	++	0	0
Stakeholders' preference	++	-	--	+	++	-	0

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

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 the assessment of how challenging the implementation of the pathway is, the indicators should be given a strong implicit weight, as the chances of failing or falling behind with the

The contractors recommendation, based on the above analysis, is that the *All technologies, Renewable gas* and the *RES + Storage* scenarios are those to be preferred.

3.2 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.

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 show that Estonia will need to deploy between 860 MW and 2,235 MW of batteries by 2030 and between 4,570 MW and 9,300 MW by 2050. 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 set up a transparent flexibility market that is able to send the right long-term signals to investors.

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. Exceptions to this are the CCUS (continues with oil shale), No net imports (substitutes for fossil gas and then nuclear), and nuclear (substitute for nuclear) pathways.

Among the alternatives considered, the CCUS 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 CCUS 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 required investments are substantial in all scenarios, and amount on average to €7.9 billion up to 2050. Total investment in the scenarios considered vary between €3.2 billion for the CCUS pathway and €11 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.

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.

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.

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 other needs to be aligned to the expected capacities to be deployed.

Four actions are a priority in every scenario considered. Review of the planning process; Renewables support; expand the electricity system balancing market to encourage investments in flexibility technologies; reinforcement to the transmission network (reinforcement to the distribution network, while not assessed in this assignment, are also likely to be required).

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 improvement 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. The estimated costs for the four most relevant actions are:

	Stakeholder responsible	RES+Storage	Nuclear	CCUS	Renewable Gas	All technologies (AT)	No net imports	1000 MW dispatchable capacity
Cumulative investment to 2050	Private and state-controlled investors	**€14,280M**	**€12,077M**	**€3,953M**	**€11,564M**	**€9,013M**	**€10,441M**	**€9,855M**
Cost of reviewing the planning process	Central and local government	Low (administrative resources)	Low (administrative resources)	Low (administrative resources)	Low (administrative resources)	Low (administrative resources)	Low (administrative resources)	Low (administrative resources)
Cost of expanding balancing market	System operator / TSO	Low (administrative resources, software)	Low (administrative resources, software)	Low (administrative resources, software)	Low (administrative resources, software)	Low (administrative resources, software)	Low (administrative resources, software)	Low (administrative resources, software)
Total network reinforcement costs to 2050	TSO	€355M	€230M	€135M	€141M	€155M	€135M	€155M
Renewable subsidies in 2030 (low-high est.)	Central government	€105-209M	€39-78M	€28-55M	€37-73M	€36-71M	€94-189M	€41-82M

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.

3.3 Recommendations

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

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 the 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

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 (Table 3-1 and Annex). 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. Refer to Table 3-1 for the synthetic score and the Annex for the underlying justification for the scores.

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 *CCUS* 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.

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.

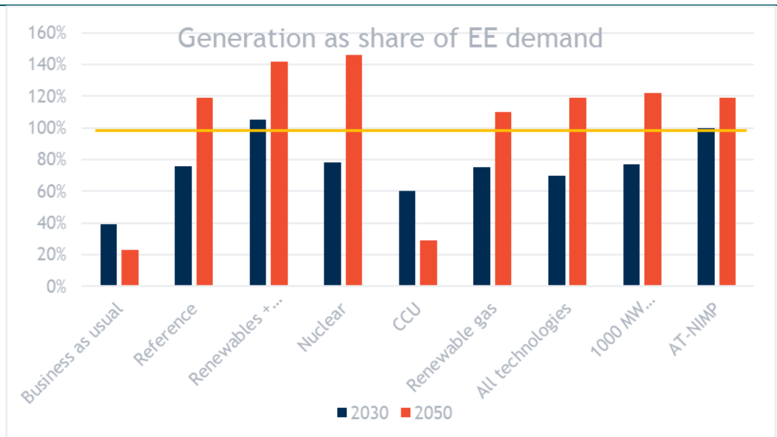
Once a scenario has been chosen, and before the decarbonisation strategy has been defined, the government should perform an analysis of the chosen scenario under a system integration perspective. This analysis should examine the implications for other sectors of the trajectories and actions associated with the preferred scenario, and the implications for the 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.

4 Answers to additional study questions

Based on the results of the previous project deliverables, the study questions are answered in Table 4-1 below.

Table 4-1 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.
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[3]. 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 CCUS 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 CCUS 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.

[3]See example of studies carried out by the Belgian government to facilitate potential developers of offshore sites: https://economie.fgov.be/en/themes/energy/belgian-offshore-wind-energy/preliminary-studies-carried

<table>
<tr><td>11. Which would be the spatial distribution of capacities and their impacts in every pathway?</td><td>Modelling 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</td></tr>
<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></tr>
<tr><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, chapter 3.</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 defence 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, prioritisation 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 equalisation 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;

</td></tr>
</table>

	○ Create possibilities for municipalities to benefit from renewable energy investments in their jurisdictions. This could take the form of profit/revenue sharing with municipalities, co-financing via local authorities or energy communities, or direct purchase contracts; ○ 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 3-1 for the synthetic score and the Annex for the underlying justification for the scores.

Annex - Actions list and summary table

Table 0-1 Action list

Action set	Actions	Renewables + storage	Nuclear	CCUS	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	7A. Support for vulnerable households	P	P	P	P	P	P	P
	7B. Skills development	✓	P	✓	✓	✓	✓	✓

P = priority action ✓ = supporting actions

Table 0-2 Summary table

DLV		RES+Storage	Nuclear	CCUS	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. CCUS 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.*		
	Conclusion	**RECOMMENDED**	**NOT RECOMMENDED**	**NOT RECOMMENDED**	**RECOMMENDED (with changes)**	**RECOMMENDED**	**Also viable**	**Also viable**
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. Growing use of biomass-fuelle doil shale plants, providing more than 3 TWh of power by 2050.	+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 biomass-fuelled oil shale plants after 2030, these provide around 1 TWh of power by 2050. Offshore wind only added after 2040.	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. Results in major import dependency.	+ 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 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.	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-fuelled oil shale plants, providing almost 3 TWh of power by 2050.	+ 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 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.	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 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)	RES+Storage 2030		RES+Storage 2050		Nuclear 2030		Nuclear 2050		CCUS 2030		CCUS 2050		Renewable Gas 2030		Renewable Gas 2050		AT 2030		AT 2050		No net imports 2030		No net imports 2050		1000 MW 2030		1000 MW 2050	
	MW	GWh	MW	GWh	MW	GWh	MW	GWh	MW	GWh	MW	GWh	MW	GWh	MW	GWh	MW	GWh	MW	GWh	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	1,479	3,944	1,479	2,640	1,479	3,833	1,479	3,750	1,479	3,819	1,479	3,812	1,479	3,781	1,479	3,821	1,479	3,847	1,479	3,885
Offshore	1,000	3,542	4,000	12,550	0	0	1,576	5,594	0	0	123	321	0	0	1,883	6,079	0	0	1,968	6,881	726	2,447	1,967	7,008	0	0	2,098	7,417
PV	1,249	1,444	2,094	2,504	1,864	2,160	6,573	7,549	725	833	725	647	1,572	1,830	3,837	4,555	1,507	1,746	4,057	4,811	2,390	2,768	3,933	4,615	1,940	2,247	3,920	4,681
Batteries	2,235	-55	8,617	-127	1,677	-40	9,288	-114	1,330	-38	4,571	-13	860	-26	5,907	-88	1,607	-42	7,970	-102	2,075	-48	7,705	-97	1,616	-38	7,533	-97
Other techs	1,155	2,965	1,235	3,775	1,155	2,936	1,975	6,545	1,155	2,021	923	989	2,155	2,831	1,901	3,316	963	2,411	1,045	3,676	782	2,349	1,125	3,648	1,446	2,692	1,424	3,646
Total	**7,118**	**11,839**	**17,425**	**22,697**	**6,174**	**8,803**	**20,892**	**23,369**	**4,688**	**6,760**	**7,821**	**4,585**	**6,066**	**8,467**	**15,007**	**17,612**	**5,556**	**7,934**	**16,519**	**19,078**	**7,452**	**11,297**	**16,209**	**18,995**	**6,480**	**8,748**	**16,453**	**19,532**
% dispatchable	48%		55%		46%		53%		53%		70%		50%		52%		46%		55%		38%		54%		47%		52%	

	RES+Storage	Nuclear	CCUS	Renewable Gas	All technologies (AT)	No net imports	1000 MW dispatchable capacity
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
	Cumulative investment to 2050	€14,280M	€12,077M	€3,953M	€11,564M	€9,013M	€10,441M	€9,855M
	Total network reinforcement costs	€355M	€230M	€135M	€141M	€155M	€135M	€155M
	Renewable subsidies in 2030 (low-high est.)	€105-209M	€39-78M	€28-55M	€37-73M	€36-71M	€94-189M	€41-82M

DLV		RES+Storage	Nuclear	CCUS	Renewable Gas	All technologies (AT)	No net imports	1000 MW dispatchable capacity
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	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 employment impact, positive with open finance, negative under self-finance + Price impact, small reduction ++ Distributional impact, especially with open finance	0 GDP impact, slight positive with open, slight negative with closed financing - Employment small negative impact -- Prices large negative impact + Distributional impact, small positive	-- GDP negative impact -- Employment negative impact --- Prices large negative impact - Distributional negative impact	++ GDP impact, especially with open financing ++ employment impact, especially with open finance, neutral under self-finance - Price impact, small increase ++ Distributional impact, especially with open finance	+ GDP impact, small positive with open financing - employment impact, small negative + Price impact, small reduction 0 Distributional impact, negligible	++ GDP impact, especially with open financing ++ employment impact, especially with open financing - Price impact, small increase + Distributional impact, positive	+ GDP impact, small positive with open financing - 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	**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	**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**	**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**	**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	**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	**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.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 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	**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 7.B. Skills development	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	5.E. Create a demand side management framework 7.A. Support vulnerable households	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	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	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**
	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 (--)