

Gas Decarbonisation Pathways for the Baltic Regional Gas Market

Deliverable 6: Report on the sensitivity analysis of the scenarios for a decarbonised Baltic gas market

Final Report

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***Gas Decarbonisation Pathways for the Baltic Regional Gas Market Countries***

***Deliverable 6: Report on the sensitivity analysis of the scenarios for a decarbonised Baltic gas market***

**In association with:**





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# Introduction

This sensitivity analysis report aims to complement the output of Deliverables 3 and 4 by evaluating factors of uncertainty regarding the development of clean gas facilities in the Baltic Regional Gas Market. To this end, 8 sensitivity scenarios were analysed each one treating a different dimension of uncertainty: capital costs and investment requirements, EU ETS price and electricity network fees. The sensitivity analysis provides additional insights to the results obtained in Deliverables 3 and 4 by presenting a plausible range of results regarding the investment requirements for the development of clean gas facilities, the LCOEs and their repercussions in economic output levels and employment. Chapter 2 provides a description of the analysed sensitivities, Chapter 3 includes the impacts on the energy system modelling results and Chapter 4 the impacts on the economic analysis results.

# Methodology and data inputs

## Sensitivity analysis of the energy system modelling

The sensitivity analysis has been performed for the three decarbonisation scenarios: REN-Methane, REN-Hydrogen, and Cost Minimal scenario. These scenarios are evaluated using different values for selected parameters to evaluate the sensitivity of the energy system modelling outcomes to changes in these input parameters. The business-as-usual scenario is excluded from the sensitivity analysis because the main objective is to compare the performance of the scenarios that target full decarbonisation of the regional gas system under different energy system modelling assumptions. The analysed sensitivity parameters are the following:

1. Technology CAPEX: Biomethane production systems
2. Technology CAPEX: Renewable hydrogen production systems
3. EU ETS price
4. Network fee (grid charge) for renewable electricity

### Technology CAPEX

The technology CAPEX assumptions used in Deliverable 3 for the scenario modelling are consistent with those presented in Table 2‑1 as base case values. The considered values are derived from [IEA, 2020][[1]](#footnote-2), [BIOSURF][[2]](#footnote-3), and [IEA, 2021][[3]](#footnote-4).

Table ‑ Renewable gas production technology CAPEX - base case values considered

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|   | Technology | Current (2021) | 2030 | 2040 | 2050 |
| **Hydrogen** | PEM Electrolyser (Euro/kW) | 1750 | 440 | 390 | 340 |
| PEM Electrolyser (% cost reduction from 2022) |   | 75% | 78% | 80% |
| **Biomethane** | AD wastewater + Upgradation\* (Euro/kW) | 865 | 865 | 865 | 865 |
| AD biowaste/Agri waste + Upgradation\* (Euro/kW) | 825 | 825 | 825 | 825 |

*\***For Upgradation, the CAPEX value is averaged for four different technologies: Pressure water scrubber, Amine scrubber, Pressure swing adsorption, and Membrane separation*

### EU ETS price change

In the sensitivity analysis, the impact of changes in the European Emission Trading System (EU ETS) prices on the overall natural gas (NG) cost is taken into account. The base case ETS price projections presented in Figure 2‑1 align with those utilized in Deliverable 3 for the scenario modelling and are derived from [S&P Global, 2022][[4]](#footnote-5) and [REUTERS, 2022][[5]](#footnote-6). Considering the historical incremental trend, two sensitivities related to EU ETS prices (+20% and +40%) are considered.

Figure ‑ EU ETS price projections (base case)

Based on the project team’s estimation considering the historical natural gas price data obtained from GET Baltic[[6]](#footnote-7) and Bloomberg[[7]](#footnote-8), and along with the ones used in Deliverable 3 for the scenario modelling, the natural gas price assumption is presented in Figure 2‑2.

Figure ‑ NG price projections (base case)

### Network fee for electricity

The tariffs for network fees, which apply to the electricity supplied through the grid for use in electrolysers, are specific to each country and can also vary depending on the voltage level of the transmission grid. The ENTSO-E 2020[[8]](#footnote-9) report provides a detailed breakdown of the network tariffs for the EU 27 countries, categorizing them based on transmission voltage. In the RGMCG region, the network tariffs range from 5 to 21 EUR/MWh (with the higher-end values including regulatory charges not directly related to TSOs' activities).

To ensure a fair comparison of renewable hydrogen production considerations among the four countries, a flat rate of 5 EUR/MWh is adopted as the base network fee case for all of them. This flat base rate is a common benchmark for analysing network fee sensitivities and comparing their impacts on the Levelised cost of energy (LCOE) for renewable hydrogen production in these countries. Two sensitivity analyses are conducted for the base network fee: +20% and -20%. No additional taxes are accounted for in relation to the renewable electricity consumed for hydrogen production.

### Sensitivity scenarios

A total of four sensitivity parameters have been chosen for analysis, with two different sensitivity levels for each parameter, resulting in eight sub-sensitivities. These sub-sensitivities are applied to the three decarbonisation scenarios (REN-Methane, REN-Hydrogen, and Cost Minimal scenario), leading to a total of 24 modelling simulation runs. Table 2‑2 provides an overview of all the sensitivity parameters and their corresponding sensitivity levels.

Table ‑ Sensitivity parameters and the corresponding sensitivity levels

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Sensitivity analysis | CAPEX of H2 technologies | CAPEX of BM technologies[[9]](#footnote-10) | ETS price[[10]](#footnote-11) | Network fees for electricity |
| **Sensitivity 1 (S1)** | **S 1.1** | **+20%** | **-** | **-** | **-** |
| **S1.2** | **-20%** | **-** | **-** | **-** |
| **Sensitivity 2 (S2)** | **S 2.1** | **-** | **+20%** | **-** | **-** |
| **S 2.2** | **-** | **-20%** | **-** | **-** |
| **Sensitivity 3 (S3)** | **S 3.1** | **-** | **-** | **+20%** | **-** |
| **S 3.2** | **-** | **-** | **+40%** | **-** |
| **Sensitivity 4 (S4)** | **S 4.1** | **-** | **-** | **-** | **+20%** |
| **S 4.2** | **-** | **-** | **-** | **-20%** |

## Sensitivity analysis of the macro-economic modelling

The macroeconomic modelling quantifies the impact of alternative assumptions regarding cost developments and investment needs on the economy. The macroeconomic analysis is performed for the S1 and S2 set of scenarios and computes the output and employment changes. Uncertainty regarding the evolution of costs associated to the deployment and the production of clean fuels makes these sensitivities most relevant from a macroeconomic perspective.

The model takes as inputs the CAPEX and the LCOE from the energy model. Investments provide a demand stimulus in the economy and direct economic gains. Gas prices on the other hand, influence production costs and change demand for domestically produced goods through income and substitution effects.

# Sensitivity analysis of the energy system modelling

## Results of the sensitivity analysis

### S1: Effect of CAPEX fluctuation of biomethane (BM) Technologies on the Capital Investment

This sensitivity parameter examines the impact of fluctuations in the investment cost per kW of biomethane production technology on the overall required capital expenditure (CAPEX) for biomethane production systems in the region. It analyses sensitivity cases of a 20% increase and a 20% decrease in biomethane production technology CAPEX (measured in EUR/kW). The results of the sensitivity analysis are presented in **Table 3‑1**, which compares the base case CAPEX values with the CAPEX sensitivities for all four countries under different scenarios.

Due to the large investments in biomethane production systems in different decades, the **REN-Methane scenario is the most affected scenario** by the CAPEX sensitivity. Under the REN-Methane scenario, all four countries exhibit notable differences in overall CAPEX volumes between the base case and the sensitivity cases. Specifically, Estonia shows a difference of 66 million EUR, Latvia 43-49 million EUR, Lithuania 226 million EUR, and Finland 244-326 million EUR.

**The Cost Minimal scenario is the least affected** by the CAPEX sensitivity as it deploys all the required biomethane production capacities before 2030. Consequently, the overall difference in CAPEX volumes between the base case and the sensitivity cases is relatively smaller: 9 million EUR for Estonia, 10 million EUR for Latvia, 30 million EUR for Lithuania, and 41 million EUR for Finland.

The scenarios REN-Methane (most affected) and Cost Minimal (least affected) exhibit both positive and negative aspects. The **REN-Methane becomes highly advantageous when the CAPEX of biomethane technology decreases, while the Cost Minimal scenario becomes comparatively more favourable when the CAPEX of biomethane technology increases** (as it shows the least increase in the overall required capital investment). Conversely, these scenarios can be considered unfavourable when the opposite conditions occur.

###  S2: Effect of CAPEX fluctuation of H2 Technologies on the overall Capital Investments

This sensitivity parameter examines the impact of fluctuations in the investment cost per kW of renewable hydrogen production technology on the overall required capital expenditure (CAPEX) for renewable hydrogen production systems in the region. It analyses sensitivity cases of a 20% increase and a 20% decrease in renewable hydrogen production technology CAPEX (measured in EUR/kW). The results of the sensitivity analysis are presented in **Table 3‑2**, which compares the base case CAPEX values with the CAPEX sensitivities for all four countries under different scenarios.

**The REN-Hydrogen scenario is the most affected scenario** in terms of the overall capital investment requirement for renewable production systems due to the sensitivity in CAPEX. Under the REN-Hydrogen scenario, all four countries exhibit significant differences in overall CAPEX volumes between the base case and the sensitivity cases. Specifically, Estonia shows a difference of 84-150 million EUR, Latvia 134-137 million EUR, Lithuania 869-887 million EUR, and Finland 343 million EUR.

**The Cost Minimal and REN-Methane scenarios are both relatively less affected** by the CAPEX sensitivity as the total required investment in their base cases is less than the REN-Hydrogen scenario resulting in a smaller overall CAPEX volume difference between the base case and the sensitivity cases.

Table ‑ Impact of technology CAPEX fluctuations on the total capital investment (Million EUR) needed for biomethane production systems

|  |  |
| --- | --- |
|  |  |
|  |  |

Table ‑. Impact of technology CAPEX fluctuations on the total capital investment (Million EUR) needed for renewable hydrogen production systems

|  |  |
| --- | --- |
|  |  |
|  |  |

### S1: Effect of CAPEX fluctuation of biomethane (BM) Technologies on the Levelised Cost of BM

This sensitivity parameter investigates the increase and decrease in biomethane’s (BM) Levelised cost of energy (LCOE) with the increase and decrease of biomethane production technology’s CAPEX in the region. The sensitivity of biomethane LCOE to CAPEX changes is assessed with the baseline biomethane LCOE values in each scenario. In addition, the impact of the sensitivity parameter on biomethane’s LCOE level is compared with the baseline NG price.

The modelling findings for the sensitivity parameters are the following:

1. Increase in BM production technology CAPEX by 20%:
	* In 2030 and 2050, the Cost Minimal scenario is the least effected scenario for all the countries in terms of the BM LCOE increase due to the sensitivity parameter corresponding to 1-2% BM LCOE increase between countries.
	* In 2030, Estonia experiences a 3% increase in BM LCOE for both REN-Methane and REN-Hydrogen scenario, Latvia has a 4% BM LCOE increase in REN-Methane and a 6% increase in REN-Hydrogen scenario, Lithuania has a similar BM LCOE increase of 5% in REN-Methane and REN-Hydrogen scenario, and Finland has a 9% BM LCOE increase in REN-Methane and 4% increase in REN-Hydrogen scenario.
	* In 2050, Estonia and Latvia exhibit a 4-5% increase in BM LCOE for both REN-Methane and REN-Hydrogen scenarios, Lithuania shows a 6% BM LCOE increase in REN-Methane and 5% increase in REN-Hydrogen scenario, and Finland has a 6% BM LCOE increase in REN-Methane and 2% increase in REN-Hydrogen scenario.
2. Decrease in BM production technology CAPEX by 20%:
	* In 2030 and 2050, the Cost Minimal scenario is the least affected scenario for all the countries in terms of the BM LCOE increase due to the sensitivity parameter corresponding to a 1-2% BM LCOE decrease between countries.
	* In 2030, Estonia experiences a 3-4% decrease in BM LCOE for both REN-Methane and REN-Hydrogen scenario, Latvia has a 4% BM LCOE decrease in REN-Methane and 6% decrease in REN-Hydrogen scenario, Lithuania has a similar BM LCOE decrease of 6% in REN-Methane and REN-Hydrogen scenario, and Finland has a 4-5% BM LCOE decrease in REN-Methane and increases in REN-Hydrogen scenario.
	* In 2050, Estonia experiences a 3% decrease in BM LCOE for both REN-Methane and REN-Hydrogen scenario, Latvia exhibits a 2% BM LCOE decrease in REN-Methane and a 7% decrease in the REN-Hydrogen scenario, Lithuania shows a 3-4% decrease in BM LCOE for both REN-Methane and REN-Hydrogen scenario, and Finland has a 6% BM LCOE decrease in REN-Methane and 4% increase in REN-Hydrogen scenario.

Comparing BM’s LCOE sensitivity to CAPEX changes with NG price with ETS:

* It is evident that the magnitude of change in BM LCOE due to CAPEX is relatively smaller, and BM LCOE remains consistently lower across all decades, indicating its cost competitiveness compared to NG prices.

**Figure 3‑1** presents the overall impact analysis of the sensitivity parameter.

**Key take aways:**

* The analysis indicates that adjusting the CAPEX values has a clear impact on the BM LCOE in the region.
* The Cost Minimal Scenario is the least affected pathway by the CAPEX sensitivity among all scenarios.
* Adjusting the BM CAPEX has a relatively larger effect on the REN-Methane & REN-Hydrogen scenarios in 2030 and 2050 for all four countries than the cost minimal scenario.
* BM LCOE fluctuations due to CAPEX sensitivity are relatively smaller in comparison to NG prices and BM stays competitive against NG in all decades till 2050.

Figure ‑. BM LCOE fluctuations for CAPEX sensitivity and Comparison with NG Base Price



### S2: Effect of CAPEX fluctuation of H2 Technologies on the Levelised Cost of H2

This sensitivity parameter analyses the increase and decrease in renewable hydrogen LCOE with the increase and decrease of hydrogen production technology’s CAPEX in the region. The sensitivity of renewable hydrogen LCOE to CAPEX changes is assessed with the baseline renewable hydrogen LCOE values in each scenario. In addition, the impact of the sensitivity parameter on renewable hydrogen LCOE level is compared with the baseline NG price and average baseline BM LCOE in the region.

The findings based on the sensitivity modelling are the following (indicated in Figure 3‑2):

Increase in renewable hydrogen production technology CAPEX by 20%:

* + In 2030 and 2050, Cost Minimal scenario is the least effected scenario for all the countries in terms of the renewable hydrogen LCOE increase due to the sensitivity parameter corresponding to 1-3% renewable hydrogen LCOE increase between countries.
	+ In 2030, Estonia exhibits a 10% increase in renewable hydrogen LCOE for both REN-Methane and a 5% increase in REN-Hydrogen scenario, Latvia shows a 9% renewable hydrogen LCOE increase in REN-Methane and a 4% increase in REN-Hydrogen scenario, Lithuania has a similar renewable hydrogen LCOE increase of 3% in both REN-Methane and REN-Hydrogen scenario, and Finland has a 3-4% increase in renewable hydrogen LCOE for both REN-Methane and REN-Hydrogen scenario.
	+ In 2050, Estonia experiences a 5% increase in renewable hydrogen LCOE for both REN-Methane and 1% increase in the REN-Hydrogen scenario, Latvia and Lithuania have a 4-5% renewable hydrogen LCOE increase for REN-Methane and REN-Hydrogen scenario, and Finland has a similar renewable hydrogen LCOE increase of 3% in REN-Methane and REN-Hydrogen scenario.

Decrease in renewable hydrogen production technology CAPEX by 20%:

* + In 2030 and 2050, the Cost Minimal scenario is the least affected scenario for all the countries in terms of the renewable hydrogen LCOE decrease due to the sensitivity parameter corresponding to 1-3% renewable hydrogen LCOE decrease between countries.
	+ In 2030, Estonia experiences a 10% decrease in renewable hydrogen LCOE for both REN-Methane and a 5% decrease in the REN-Hydrogen scenario, Latvia has a 9% renewable hydrogen LCOE decrease in REN-Methane and a 6% decrease in REN-Hydrogen scenario, Lithuania has a similar renewable hydrogen LCOE decrease of 3% in both REN-Methane and REN-Hydrogen scenario, and Finland has a 3-4% decrease in renewable hydrogen LCOE for both REN-Methane and REN-Hydrogen scenario.
	+ In 2050, Estonia experiences a 5% decrease in renewable hydrogen LCOE for both REN-Methane and a 1% increase in the REN-Hydrogen scenario, Latvia has a 5-6% renewable hydrogen LCOE decrease for REN-Methane and REN-Hydrogen scenario, Lithuania has a 3% renewable hydrogen LCOE decrease for REN-Methane and 5% REN-Hydrogen scenario, and Finland has a 3-4% renewable hydrogen LCOE decrease for REN-Methane and REN-Hydrogen scenario.

Comparing renewable hydrogen’s LCOE sensitivity to CAPEX changes with NG price with ETS and average baseline BM LCOE in the region:

* When comparing the changes in renewable hydrogen LCOE due to CAPEX adjustments with the baseline NG prices, it is evident that by 2050, even with the CAPEX increase, renewable hydrogen’s LCOE is still less than the NG price. On the other hand, with the CAPEX decrease, renewable hydrogen’s LCOE is still more than the average baseline BM LCOE in the region.

**Figure 3‑2** presents the overall impact analysis of the sensitivity parameter.

**Key take aways:**

* The Cost Minimal Scenario is the least affected pathway among all scenarios.
* Estonia and Latvia have a relatively large effect of sensitivity measure under REN-Methane & REN-Hydrogen scenarios in 2030.
* By 2050, renewable hydrogen's LCOE remains lower than NG prices, even with increased CAPEX. Conversely, with decreased CAPEX, renewable hydrogen's LCOE still exceeds the average baseline biomethane LCOE in the region.

Figure ‑. Renewable hydrogen’s LCOE fluctuations for CAPEX sensitivity and comparison with the baseline NG price and average baseline BM LCOE in the region



### S3: Effect of ETS price change on Levelised costs of renewable gases

The sensitivity parameter examines the impact of rising EU ETS prices on natural gas (NG) costs. It plays a crucial role in assessing whether the upward trend in ETS prices can positively influence the competitiveness of renewable gases. Higher ETS prices can lead to a significant increase in NG costs, thereby improving the financial viability of renewable gases in the region. Two sensitivities are evaluated based on the base ETS projections: a 20% increase and a 40% increase (Figure 3‑3).

Figure ‑. EU ETS price projections (base case and two sensitivity cases of +20% and +40% respectively)

Figure 3‑4 presents the NG costs fluctuations based on the EU ETS sensitivities presented in Figure 3‑3.

Figure ‑. NG cost fluctuations based on the EU ETS price sensitivities

Figure 3‑4 compares NG cost projections based on the EU ETS price sensitivities against the average baseline BM and renewable hydrogen’s LCOEs. It shows that in 2030, NG in across all scenarios is expected to be more expensive than BM but is expected to perform better by a large margin against renewable hydrogen. By 2040, the competitiveness of renewable hydrogen's LCOE against the price of NG will reach a critical point in the region. This transitional year marks the convergence of both gaseous energy carriers, and the winner will be determined by the fluctuation of NG prices influenced by the sensitivity of EU ETS (REN-Methane and REN-Hydrogen in favour of renewable hydrogen whereas Cost Minimal scenario in favour of NG). While BM LCOE still performs the best against the other two gaseous energy carriers across three decades, renewable hydrogen due to the technology learning curve will become more competitive than the expected NG price projection for 2050[[11]](#footnote-12).

Figure ‑. Effect of ETS price fluctuation on NG cost levels and a comparison with the LCOEs of renewable gases

|  |
| --- |
| *REN-Hydrogen scenario**REN-Methane scenario**Cost Minimal scenario* |

### S4: Effect of Network Fee (for REN-Electricity) on the Levelised Costs of renewable hydrogen

The grid fee is specifically analysed in relation to hydrogen production because hydrogen production often relies on renewable electricity sources, such as wind or solar power, which are connected to the electricity grid. The grid fee, also known as the network fee, is the cost associated with the transmission and distribution of electricity through the grid infrastructure.

This sensitivity parameter analyses the impact of the fluctuation of Network Fee (grid fee for renewable electricity supply) on the renewable hydrogen’s Levelised costs. Two sensitivities of the base network fee (i.e., 5 EUR/MWh) are analysed; +20% and -20%. Figure 3‑6 shows that the effect of the Network Fee on the Levelised costs of renewable hydrogen is very minimum +/- 1–2 EUR/MWh and the reason for this is that the base network fee, which is set at 5 EUR/MWh, constitutes only a small fraction of the total Levelised cost of energy (LCOE) for renewable hydrogen. As a result, the sensitivity of this minor component will have a minimal impact on the overall LCOEs of renewable hydrogen.

Figure ‑. Effect of Network Fee (for REN-Electricity) on the Levelised Costs of renewable hydrogen

## Impact assessment of the energy modelling scenarios considering the sensitivity analysis

The assessment of the energy system impacts of the decarbonisation scenarios in Deliverable 3 considered a number of criteria (further details provided in the report)[[12]](#footnote-13):

* Costs of the gas system
* Costs for specific gas users categories
* Market integration and competition
* Investment needs
* Decarbonisation of the energy system
* Resource availability and efficient/sustainable use
* Energy import dependence
* Robustness

The analysis of Deliverable 4 indicated that under the baseline decarbonisation scenarios, **the Cost Minimal scenario was preferred according to most criteria.** It exhibits the lowest total long-term gas system cost as well as cost advantages to commercial and household users, improved market integration and competition compared to the other scenarios, faster decarbonisation of the gas system and reduced energy import dependence, as well as robustness to uncertainties given its leveraging of different renewable gas sources. The Cost Minimal scenario still presents a number of comparative disadvantages and risks, especially related to the need to realise significant investments in renewable gas production already in the 2022-2030 period (potentially leading to high costs in the short-term to some consumers, depending on how the investment costs are recovered), and the availability of both biomass feedstocks for biogas/biomethane production and renewable electricity for electrolysis.

The question addressed by this section is what are change (if any) in the assessment of the decarbonisation scenarios considering the results of the energy system modelling sensitivity analysis. For this, the main impacts on the assessment criteria are considered. Note that the analysis presented focuses on the difference between the ‘sensitivity analysis’ scenarios versus the base case decarbonisation scenarios, without aiming to present a full comparison between the scenarios (which is available in the Deliverable 4).

The main impacts of the sensitivity analysis on the decarbonisation scenarios are the following:

**REN-Biomethane scenario**

* **Impact of sensitivities:** As could be expected, of all sensitivities assessed the REN-Biomethane scenario is most sensitive to changes in the CAPEX of biomethane technologies. But due to the strong competitiveness of biogas/biomethane, it remains the preferred gas for decarbonisation of the system. A 40% increase in ETS prices compared to the base case could make hydrogen slightly more competitive than natural gas in the 2030 horizon, accelerating the deployment of hydrogen for hard-to-decarbonise localised applications in this scenario.
* **Effect on scenario assessment:** Changes in unit CAPEX will impact the costs to the gas system as well as specific users, and the total investment needs of the scenario. Moreover, accelerated hydrogen deployment in case high ETS prices materialise would positively impact the ‘decarbonisation of the energy system’ as well as ‘energy import dependence’ by phasing out LNG imports more quickly, which would however require increased investments. The sensitivity analyses should not have a significant impact on the other criteria, such as market integration and competitiveness.

**REN-Hydrogen scenario**

* **Impact of sensitivities:** The REN-Hydrogen scenario is most sensitive to changes in the assumed unit CAPEX for hydrogen technologies. Moreover, as in the REN-Biomethane scenario increased ETS prices of the order of +40% would improve the competitiveness of hydrogen compared to natural gas already in 2030. However, in this scenario hydrogen is already slightly more competitive than natural gas (but not biomethane) in that horizon. Hence, limited additional deployment could be expected compared to the base case.
* **Effect on scenario assessment:** The main impacts of the sensitivities should be on the investment needs of the scenario, and the associated cost to the system and specific users. The other criteria should not be affected, as there is no change in the order of preference between the alternative gases.

**Cost Minimal scenario**

* **Impact of sensitivities:** The Cost Minimal is generally the decarbonisation scenario less sensitive to changes in the assumed CAPEX for biomethane/hydrogen or ETS prices (while all decarbonisation scenarios exhibit low sensitivity to changes in network fees). Furthermore, the sensitivities do not lead to a change in the preference order (relative to the base case) between biomethane, hydrogen and natural gas in any time horizon. Moreover, the concentration of investments in the 2020-2030 period for the CM scenario means that these investments are subject to a lower uncertainty regarding CAPEX and ETS prices in the first place.
* **Effect on scenario assessment:** The Cost Minimal scenario is robust to the sensitivities considered in this report. Nonetheless, other risks are relevant to the scenario, and even if an increase in renewable gas CAPEX would not change the scenario results much, it would still increase short-term financing needs which are already high in the base CM scenario. Thus the costs and investment criteria are the most affected by the sensitivities, while the assessment for the other criteria should not be affected significantly.

In summary, the sensitivity analyses indicate investment needs in all decarbonisation scenarios would be affected by unit CAPEX values different to the base case. Furthermore, the REN-Biomethane scenario could respond positively to increased ETS prices by accelerating the decarbonisation of the gas system. However, those considerations do not impact the Deliverable 4[[13]](#footnote-14) assessment that the Cost Minimal scenario is the preferred one from an energy systems perspective. In case of unit CAPEX increases there would need to be additional attention to the investment needs under this scenario, but without affecting the recommendation.

Another interesting analysis is the consideration of whether the combination of two or more sensitivities would alter the comparative performance of the scenarios. For example, increased unit CAPEX for hydrogen technologies combined with reduced unit CAPEX for biomethane production technology could make the REN-Biomethane more competitive to the other scenarios. However, the difference in the LCOE of biomethane and hydrogen is very large, and the preference order would not be altered by such CAPEX changes (at least in the ranges considered in this sensitivity analysis report). Moreover, as all three decarbonisation scenarios make use of biogas/biomethane and hydrogen to different extents, the impacts of the sensitivities analyses are not very high which leads to a low probability that either the REN-Hydrogen or REN-Biomethane would under some sensitivity assumptions become more attractive than the Cost Minimal scenario.

# Sensitivity analysis of the macro-economic modelling

The assessment is performed for two alternative financing options: external financing and self-financing as in Deliverable 4. The results are presented in the following sections.

### S1: Effect of CAPEX fluctuation of biomethane (BM) Technologies

### S1: 20% increase

Higher investments in biomethane imply higher output gains. The multiplier effect of biomethane investments is higher compared to that of other clean gas and in many countries higher than the average multiplier of non-gas investments meaning that increased expenditures for the development of such facilities deliver higher benefits. The 4 countries in total, record output gains (associated to increased investments) compared to the central case of approximately 3.7% in the REN-Methane scenario and of 1.2% in the REN-Hydrogen and 0.9% in the Cost minimal scenario. Compared with the BAU, the Cost-minimal pathway continues to out-perform the other two pathways in terms of output changes. However, the REN-Methane under the S1 setup implies now higher output gains due to higher investments compared to the Cost minimal scenario (Figure 10).

Figure ‑: Investments – output changes (cumulative)

Figure ‑: Investments – output changes in comparison to the BAU scenario

At the country level, the impacts are higher in Finland, where cumulative output increases on average (between scenarios) by 2.7% and in Latvia by 2.5% compared to their Deliverable 4 counterparts. Output changes are higher in both countries in the REN-Methane scenario; in Finland output increases by 784 million € and in Latvia by 159 million €.

Figure ‑: Investments – output changes in comparison to the BAU scenario

In the self-financing setup, increased investments in biomethane lead to smaller crowding-out effects and all pathways perform better compared to their central case counterparts. For example, REN-Methane under the *S1-20% increase* leads to cumulative regional output gains of 465 million € compared to 456 million € in the central case (+1.8%). So, under S1 output increases by 9 million €. The respective changes for the REN-hydrogen and the Cost minimal scenario are 25 (-8.7%) and 27 million € (+2.5%).

Figure ‑: Investments – output changes (self-financing)

Figure ‑: Investments – output changes in comparison to the BAU scenario (self-financing)

Output gains from increased investments are higher in Lithuania in the Cost minimal pathway (+13.1%) and in Latvia in the REN-Methane scenario (+6.5%). Compared to their central case counterparts, the economic output in Lithuania is higher by 2.2 million € and in Latvia by 8.5 million €.

Figure ‑: Investments – output changes in comparison to the BAU scenario (self-financing)

With respect to prices, increased CAPEX lead to higher gas prices which in turn drives upwards production costs. Higher production costs have a direct effect on demand, which decreases (compared to the Deliverable 4 counterpart). In the REN-Methane scenario, cumulative regional output increases by 1.52 billion € (-18% from central case scenario), in the REN-Hydrogen by 0.3 billion € (-21%) and in the Cost minimal by 3.8 billion € (-3.9%). At the country level, the impact of new prices is more significant in Estonia in the REN-Methane scenario where output gains are lower by 136 million € (compared to the central case) and in Finland in the REN-Methane scenario where output is lower by 182 million €.

Figure ‑: Price effect at regional level

Figure ‑: Price effect by country

In total the S1 sensitivities lead to higher economic output in the external financing case compared to their central case counterparts. However, in the self-financing case cumulative output is lower as the average multiplier of gas investments is lower than that of the non-energy sectors; higher investments lead to stronger crowding-out effects and the output of the economy falls.

Table : Output changes compared to the Base case

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|   |   | REN-Methane | REN-Hydrogen | Cost Minimal |
| Estonia | External financing | -22 | -9 | -21 |
| Self-financing | -135 | -42 | -68 |
| Finland | External financing | 601 | 191 | 125 |
| Self-financing | -191 | -30 | -77 |
| Latvia | External financing | 155 | 40 | 51 |
| Self-financing | 4 | 10 | -1 |
| Lithuania | External financing | 405 | 145 | 163 |
| Self-financing | 4 | 6 | 18 |

In terms of employment, job creation associated with investments in clean gas capacities is higher compared to the central case for all pathways. As far as prices are concerned, the impact of price differentials on employment is rather small compared to the central case. On average at the regional level, additional investments will generate each year approximately 1600 more jobs (compared to the BAU) in the Cost minimal scenario and 1100 more jobs in the REN-Methane scenario.

Figure ‑: Investments – job creation

Figure ‑: Prices – job creation (compared to the BAU)

### S1: 20% decrease

Lower investments lead to lower economic output gains. Cumulative output changes at the regional level and compared to the Base case are higher in the REN-Methane scenario (-2.6%) and lower in the REN-Hydrogen (-1.3%) and in the Cost minimal scenario (-1 %). The changes are in line with the investment differentials and investment mix.

Figure ‑: Investments – output changes

Figure ‑: Investments – output changes in comparison to the BAU scenario

At the country level, the impacts are higher in Finland, where cumulative output decreases on average (between scenarios) by 1.9% and in Latvia by 2.5% compared to their Deliverable 4 counterparts. Output changes are higher(-3% and -4% respectively) in both countries in the REN-Methane scenario; in Finland cumulative output decreases compared to the Base case scenario by 410 million € and in Latvia by 161 million €. In Estonia and Lithuania, changes are equal in magnitude and of opposite sign as in the scenario assuming a 20% increase in CAPEX.

Figure ‑: Investments – output changes compared to the BAU scenario

In the self-financing case, the performance of alternative gas decarbonization pathways in terms of output changes is lower compared to their Deliverable 4 counterparts. Compared to the BAU scenario, the REN-Methane leads to cumulative output gains of 0.43 billion € (vs. 0.46 billion € in the Central case), the REN-Hydrogen scenario to cumulative losses of 0.31 billion € (vs. 0.29 billion €) and the Cost minimal to cumulative gains of 1.06 billion € (vs. 1.09 billion €).

Figure ‑: Investments – output changes (self-financing)

Figure ‑: Investments – output changes in comparison to the BAU scenario (self-financing)

At the country level the highest changes are observed in the REN-Methane scenario. In Estonia, cumulative output decreases by 0.78 billion € compared to the BAU, in Finland -7.8 billion € in Latvia -8.3 billion €. In Lithuania changes are more significant in the Cost minimal scenario (-19.4 billion €).

Figure ‑: Investments – output changes in comparison to the BAU scenario (self-financing)

With respect to energy prices, the lower CAPEX levels lead to lower gas costs which in turn drive competitiveness gains and lead to higher demand. In the REN-Methane scenario, the cumulative regional economic output increases by 1.88 billion € (+2.5% from central case scenario), in the REN-Hydrogen by 0.4 billion € (+5.3%) and in the Cost minimal by 4.0 billion € (0.1%).

Figure ‑: Price effect at regional level

Figure ‑: Price effect by country

In total the ***S1- 20% decrease*** sensitivities lead to lower economic output in the external financing due to lower investments. However, in the self-financing case the cumulative output is higher due to the beneficial impact of lower gas prices on products demand.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|   |   | REN-Methane | REN-Hydrogen | Cost Minimal |
| Estonia | External financing | -119 | -48 | -35 |
| Self-financing | -6 | -15 | 12 |
| Finland | External financing | -356 | -257 | -212 |
| Self-financing | 46 | 32 | -10 |
| Latvia | External financing | -163 | -22 | -61 |
| Self-financing | -10 | 8 | -3 |
| Lithuania | External financing | -410 | -167 | -164 |
| Self-financing | -9 | -30 | -20 |

In terms of employment, on average 1800 more jobs are created each year in the REN-Methane pathway (+882 compared to the BAU), 1500 in the REN-Hydrogen (-315 compared to the BAU) and 3100 in the Cost minimal scenario (+1604 compared to the BAU).

Figure ‑: Investments – job creation

Figure ‑: Prices – job creation (compared to the BAU)

### S2: Effect of CAPEX fluctuation of H2 Technologies

### S2: 20% increase

Higher investments in hydrogen leads to higher output gains compared to the Base case. The effects are higher in the REN-Methane and in REN-Hydrogen where regional cumulative output increases by 1.7 billion € and by 1.9 billion € compared to the base case. This also leads to higher output gains compared to the BAU; in the REN-Methane regional cumulative output increases by 2.3 billion €. In the REN-Hydrogen by 1.9 billion € and in the Cost minimal pathway by 13.2 billion € (Figure 10). In terms of economic efficiency in the REN-Methane pathway each euro invested leads to an increase of 1.59€ in output levels, in the REN-Hydrogen to an increase of 1.55€ and in the Cost minimal scenario of 1.63 €.

Figure ‑: Investments – output changes

Figure ‑: Investments – output changes in comparison to the BAU scenario

At the country level and compared to the base case, in Estonia output changes are higher in the REN-Hydrogen (+155 million €), in Finland and in Latvia in the REN-Methane scenario (+714 million € and +160 million € respectively) and in the Lithuania in the Cost minimal scenario (+1073 million €).

Figure ‑: Investments – output changes in comparison to the BAU scenario

In the self-financing setup, increased investments in hydrogen leads to higher crowding-out effect. This is because the average multiplier of investments in hydrogen is lower than that of the non-gas investments. Cumulative regional output decreases by 1.3 billion € in the REN-Methane scenario, by 2.1 billion € in the REN-Hydrogen scenario and by 0.68 billion €in the Cost minimal scenario.

Figure ‑: Investments – output changes (self-financing)

Figure ‑: Investments – output changes in comparison to the BAU scenario (self-financing)

At the country level Finland and Lithuania experience higher output changes due to the crowding out effect. For example, in Finland in the REN-Hydrogen scenario cumulative output decreases by 56 million € compared to the Base case, while in Lithuania by 82 million €.

Figure ‑: Investments – output changes in comparison to the BAU scenario (self-financing)

With respect to energy prices, increased CAPEX lead to higher gas costs which have a negative impact on the overall economic output and employment levels in the REN-Methane and in the Cost minimal pathway. On the other hand the REN-Hydrogen scenario under the *S2- 20% increase* setup produces positive results (i.e. higher output in comparison to the Base case counterpart) due to the LCOE developments in Finland in 2040.

Figure ‑: Price effect at regional level

Figure ‑: Price effect by country

In total the S1 sensitivities lead to higher output in the external financing case compared to their central case counterparts. However, in the self-financing case cumulative output is lower as the average multiplier of gas investments is lower than that of the non-energy sectors; higher investments lead to stronger crowding-out effects and the output of the economy falls.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|   |   | REN-Methane | REN-Hydrogen | Cost Minimal |
| Estonia | External financing | -59 | 96 | -14 |
| Self-financing | 15 | -13 | 20 |
| Finland | External financing | 563 | 905 | 374 |
| Self-financing | -9 | 223 | -80 |
| Latvia | External financing | 155 | 143 | 42 |
| Self-financing | -13 | -26 | -10 |
| Lithuania | External financing | 724 | 933 | 1069 |
| Self-financing | -63 | -104 | -67 |

In terms of employment, job creation associated to investments in clean gas capacities is higher compared to the central case for all pathways. As far as prices are concerned, the impact of price differentials on employment is rather small compared to the central case. On average at the regional level, additional investments will generate each year approximately 1600 more jobs (compared to the BAU) in the Cost minimal scenario and 1100 more jobs in the REN-Methane scenario.

Figure ‑: Investments – job creation

Figure ‑: Prices – job creation (compared to the BAU)

### S2: 20% decrease

Lower investments lead to lower output gains. Cumulative output changes at the regional level and compared to the Base case are higher in the REN-Methane scenario (-2.4%) and lower in the REN-Hydrogen (-4.9%) and in the Cost minimal scenario (+2.8%). Changes in the cost minimal scenario are driven by higher investments in SNG facilities in Lithuania.

Figure ‑: Investments – output changes

Figure ‑: Investments – output changes in comparison to the BAU scenario

At the country level, the REN-Hydrogen scenario in Estonia and in Finland is mostly affected by changes in H2 capex, leading to a cumulative output loss of 196 million € and 655 million € respectively compared to its Deliverable 4 counterpart, while in Latvia the REN-methane scenario records losses of 156 million € and in Lithuania the Cost minimal scenario leads to output gains of 2.1 billion €.

Figure ‑: Investments – output changes in comparison to the BAU scenario

Assuming self-financing of investments and compared to the BAU scenario, the REN-Methane leads to cumulative output gains of 0.52 billion € (vs. 0.46 billion € in the Central case), the REN-Hydrogen scenario to cumulative losses of 0.13 billion € (vs. 0.28 billion €) and the Cost minimal to cumulative gains of 1.2 billion € (vs. 1.09 billion €).

Figure ‑: Investments – output changes (self-financing)

Figure ‑: Investments – output changes in comparison to the BAU scenario (self-financing)

At the country level the highest changes are observed in the REN-Hydrogen scenario. In Estonia, cumulative output decreases by 5.2 million € compared to the BAU, in Finland cumulative output increases by 56 million € and in Latvia 24 million €. In Lithuania in the Cost minimal scenario output changes in comparison to the central case by 98 million €.

Figure ‑: Investments – output changes in comparison to the BAU scenario (self-financing)

With respect to energy prices, the lower CAPEX levels lead to lower gas costs which in turn drive competitiveness gains and lead to higher demand. In the REN-Methane scenario, the cumulative regional economic output increases by 1.82 billion €, in the REN-Hydrogen by 0.9 billion € and in the Cost minimal by 3.9 billion €.

Figure ‑: Price effect at regional level

Figure ‑: Price effect by country

In total the ***S1- 20% decrease*** sensitivities lead to lower output in the external financing due to lower investments. However, in the self-financing case, the cumulative output is higher due to the beneficial impact of lower gas prices on products’ demand and the lower crowding out effect generated by gas-related investments.

Table : Output changes in comparison to the Base case

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|   |   | REN-Methane | REN-Hydrogen | Cost Minimal |
| Estonia | External financing | -78 | -159 | -49 |
| Self-financing | -10 | 47 | -27 |
| Finland | External financing | -54 | -180 | -584 |
| Self-financing | -33 | 500 | 66 |
| Latvia | External financing | -157 | -137 | -71 |
| Self-financing | 13 | 28 | 13 |
| Lithuania | External financing | -678 | -902 | 2098 |
| Self-financing | 59 | 99 | 119 |

On average at the regional level (in the external financing case), in the *S2 – 20% decrease* each year approximately 1700 more jobs (compared to the BAU) in the Cost minimal scenario and 900 more jobs in the REN-Methane scenario. In the REN-hydrogen scenario, job losses are equal to 425.

Figure ‑: Investments – job creation

Figure ‑: Prices – job creation (compared to the BAU)

# Key findings and conclusions

The sensitivity analysis aims at evaluating different aspects of uncertainty regarding the evolution of key cost elements associated with the development of clean gases.

The impacts of the considered changes in the sensitivity analysis are not very high:

* + As the LCoE differences between gases are high (particularly between biomethane and hydrogen), the preference order would generally not be altered by CAPEX changes (even if combining two parameters);
	+ The investment needs would in all decarbonisation scenarios nonetheless be affected by changes in CAPEX values;
	+ The REN-Biomethane and REN-Hydrogen scenarios would respond positively to increased ETS prices by accelerating the decarbonisation of the gas system, in particular through early deployment of hydrogen in local applications.

The Cost Minimal scenario remains the preferred pathway from an energy system’s perspective

* + The probability is low that either the REN-Hydrogen or REN-Biomethane scenario would become more attractive than the CM scenario;
	+ In case of unit CAPEX increases specific attention would need to be paid to the investment needs under the CM scenario, but the overall recommendations would not be changed.

The macro-economic analysis reveals that higher investment levels (due to assumed CAPEX increases) lead in general to higher economic output gains. However, this effect is lessened by the impact of energy prices; higher energy prices lead to lower demand for products and hence lower economic output. If we rank the decarbonisation scenarios in terms of their economic efficiency, the Cost minimal pathway remains the best option, if we consider only the investment and price effects, as for each € spent the regional economic output increases by approximately 1.63 €. Additionally, job creation is in the Cost minimal scenario on average higher at the regional level compared to the other scenarios. The cumulative output varies compared to the Base case (in the external financing case) by -2.8% to 4.3% in the REN-Methane scenario, by -4.9% to 4.9% in the REN-Hydrogen scenario and by -1% to 3.3% in the Cost minimal pathway.

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1. https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth/sustainable-supply-potential-and-costs [↑](#footnote-ref-2)
2. https://www.ergar.org/wp-content/uploads/2018/07/BIOSURF-D3.4.pdf [↑](#footnote-ref-3)
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8. https://eepublicdownloads.entsoe.eu/clean-documents/mc-documents/l\_entso-e\_TTO-Report\_2020\_03.pdf [↑](#footnote-ref-9)
9. Increase/decrease as per the base Technology considerations [↑](#footnote-ref-10)
10. As ETS prices are only trend, only an increasing trend makes sense for the sensitivity analysis [↑](#footnote-ref-11)
11. By the year 2050, all three modelled scenarios (REN-Methane, REN-Hydrogen, and Cost Minimal scenarios) achieve complete decarbonisation. The NG price levels for 2050 are presented solely for the purpose of comparing their financial competitiveness with renewable gases. [↑](#footnote-ref-12)
12. E3Modelling, Trinomics and SEI (2023) Gas Decarbonisation Pathways for Estonia - Deliverable 4: Impact assessment of the scenarios for a decarbonised Baltic gas market [↑](#footnote-ref-13)
13. E3Modelling, Trinomics and SEI (2023) Gas Decarbonisation Pathways for Estonia - Deliverable 4: Impact assessment of the scenarios for a decarbonised Baltic gas market [↑](#footnote-ref-14)