Transitioning to a climate-neutral electricity generation

Deliverable 4 Report: Socio-economic impact assessment of pathways for reaching climate-neutral electricity generation

Contract details
European Commission – DG Reform

Transitioning to a climate-neutral electricity generation

REFORM/SC2020/068

Presented by
Trinomics B.V.

Westersingel 34

3014 GS, Rotterdam

the Netherlands

Contact person
Mr. Koen Rademaekers

T: +31 6 2272 5505

E: koen.rademaekers@trinomics.eu

Date
November 29. 2021

Acknowledgement
This study was carried out with funding by the European Union via the Structural Reform Support Programme and in cooperation with the Directorate General for Structural Reform Support of the European Commission.

Rotterdam, November 29, 2021

Client: European Commission – DG Reform.
REFORM/SC2020/068

Transitioning to a climate neutral electricity generation

Ioannis Charalampidis – E3M
Leonidas Paroussos – E3M
Matthew Smith – Trinomics
Natalie Janzow – Trinomics
Koen Rademaekers – Trinomics
Lauri Tammiste – SEI
Jason Veysey – SEI
Silvia Ulloa – SEI
Andrea Demurtas – Trinomics
Hardi Koduvere – TalTech

In association with:

CONTENTS

1 Introduction

There are multiple technological options that would facilitate the decarbonisation of Estonia's power generation sector. Each option / combination of options has different implications for the economy, employment and the security of supply of the country. This report presents the methodology and findings regarding the socio-economic impact assessment of different climate-neutral electricity generation pathways. These pathways are summarised in chapter 3[1]. The focus is on the economic and employment implications of the different configurations of the Estonian power generation system. The alternative power mix scenarios quantified with the LEAP model in Deliverable 3 are further evaluated regarding their socio-economic consequences using the GEM-E3 model and static Leontief economic and employment multipliers. The modelling approach is described in chapter 2, the modelled scenarios defined in chapter 3, and the socio-economic impact analysis presented in chapter 4.

An Excel annex is provided to accompany this report which provides the data underlying the figures in this report.

Addendum: following this report the sensitivity analyses (for the Deliverable 6 report) identified important necessary modifications to the climate-neutral electricity generation pathways, particularly in respect of the wind energy availability curves. The sensitivity analysis report includes updated pathway results and socio-economic analyses reflecting these changes and other sensitivities. The results in this D4 report are superseded by the results in the sensitivity analysis report. **Whilst the results in this report provide useful insights, the socio-economic impact results of the sensitivity analysis report will be the primary outputs used for determining the action plans (deliverable 7).**

[1] A full explanation and analysis of the pathways can be found in Deliverable 3 of this work 'Development of pathways for reaching climate-neutral electricity generation' available at https://energiatalgud.ee/sites/default/files/2021-11/D3_Pathway_modelling_report_final_v10.pdf.

2 Modelling methodology and data inputs

The selection of a country's power generation mix is not straightforward, as it depends on multiple interrelated factors that go beyond cost optimisation. Electricity supply should be uninterrupted, affordable, and ensure security of supply, but also should address the environmental objectives of a country. The specificities of each country regarding to the availability of national energy resources, production capacity of power generation technologies and fuels, access to finance and labour skills scarcity largely define power generation choices.

The focus of this study is to assess the socio-economic implications of alternative configurations of the Estonian power generation mix. To this end we employ a two-stage methodology. The first stage (described in detail in 2.1.1) is a static analysis of the impact on investments on the Estonian economy where the first order impacts are identified and quantified. The key contribution of this stage to the analysis is to show how the demand stimulus effect varies across power mix options according to economic and employment multipliers. The second stage is a full system analysis that includes the feedback loops of the economy (described in detail in 2.1.2). At this stage, for each scenario examined, the impact of power choices on electricity prices, production costs, competitiveness, households'

Two stage methodological approach

- ✓ **Stage I** - Static Leontief Input Output Analysis: At this stage we calculate the output and employment multiplier impact of the investments required to decarbonize the Estonian electricity system. The analysis, based on the IO multipliers, accounts both for import dependency and industry inter-dependencies, but does not capture feedback loops in the economy driven by competitiveness and resource scarcity (labour or finance). Beyond its limitations this stage provides clear indications regarding the expected employment and economic impacts from shifting demand to RES power generation.
- ✓ **Stage II** – Dynamic Computable General Equilibrium (CGE) Analysis: At this stage the full dynamic and economy-wide impacts are considered. Changes in competitiveness due to changes in electricity prices and production costs and changes in household's disposable income are accounted for when the impact on GDP, value added and trade are computed. The role of financing is identified and discussed.

disposable income and employment are considered simultaneously in a consistent representation of multiple countries in a dynamic modelling framework.

The economic impacts of the BAU scenario were not assessed. The BAU scenario, from the point of view of the general equilibrium analysis, is a “constructed” scenario, calibrated to reproduce exogenous projections regarding the population and GDP dynamics. The economic repercussions of alternative power generation systems for the rest of the scenarios were assessed both in the static and the dynamic framework. The results of the seven alternative carbon neutral pathways are presented as deviations from the solution of the reference scenario.

2.1 Modelling methods

2.1.1 Leontief Multipliers

The static analysis of the zero-emission pathways is based on the Leontief multipliers and aims at providing insights on the potential benefits from the shift of demand to RES power generation. The analysis aims to determine the economic effects from increased investments in power generation, considering both forward and backward linkages, as well as import dependence of the sectors for which demand is expected to increase. This type of analysis does not account for changes in capital and labour markets nor for the changes of electricity prices which influence production cost and yields changes in the competitiveness of domestic activities.

The starting point of the analysis is the Input-Output table of Estonia from which the following multipliers are calculated:

a) Output - Type I: Captures the direct and indirect effects of an increase in sectorial demand,
b) Output - Type II: Captures the direct and indirect and the induced (income) effect, i.e., due to changes in households’ income and expenditures.
c) Employment (Type I & II): Captures the number of jobs generated by the increased demand for investment goods and services.

The output and the employment multipliers[2] for the sectors of interest as computed from the Input-Output table are presented in Table 1 and Table 2 respectively.

Table 1: Output Multipliers

	Type-I	Type-II
Gas	2.34	2.62
Power supply	2.97	3.19
Ferrous metals	1.37	1.61
Metal products	1.85	2.18
Computer, electronic and optical products	1.80	1.96
Electrical equipment	1.67	1.87
Machinery and equipment	1.51	1.70
Other Equipment Goods	1.71	1.99
Construction	2.03	2.56
Financial services	1.61	2.02
Other Market Services	1.63	2.01
Equipment for wind power technology	1.20	1.28
Equipment for PV panels	1.21	1.28
Equipment for CCS power technology	1.71	1.99

Source : Author's calculations

Table 2: Employment Multipliers

	Type I	Type II
Power supply	0.15	0.18
Gas	0.19	0.23
Construction	0.36	0.43
Metal products	0.22	0.26
Computer electronic and optical products	0.11	0.13
Other Equipment Goods	0.18	0.22
Equipment for CCS power technology	0.18	0.22
Electrical equipment	0.14	0.16
Other Market Services	0.26	0.31
Financial services	0.28	0.33
Machinery and equipment	0.13	0.15
Ferrous metals	0.16	0.20
Equipment for PV panels	0.05	0.06
Equipment for wind power technology	0.05	0.06

[2] Output multipliers show by how many euros the output of the economy will increase if one euro is spent on a specific industry (if the demand for the product of an industry increases by one euro by how much the economy wide output will increase). The employment multipliers show how many working hours will be used to provide a product of a specific monetary value. Both output and employment multipliers are calculated using the Input-Output table of Estonia. The output multipliers are calculated using the sectorial input coefficients (inputs/supply) while the employment multipliers take into account also the sectorial employment requirements. The calculation of the multipliers considers the domestic\imported content of products together with the degree of industrial interconnections. These multipliers are used to assess by how much the Estonian output and employment will increase once spending on specific power generation capital goods takes place.

2.1.2 The GEM-E3 model

The GEM-E3[3] model is a multi-regional, multi-sectoral, recursive dynamic computable general equilibrium (CGE) model which provides details on the macro-economy and its interaction with the environment and the energy system. The version used for this study represents Estonia as a separate economy fully linked with the external sector through endogenous bilateral trade transactions. The GEM-E3 model incorporates micro-economic mechanisms and institutional features within a consistent macro-economic framework and avoids the representation of behaviour in reduced form. Particularly valuable are the insights the model provides regarding the distributional aspects of climate and energy policies. The model is modular allowing the user to select among a number of alternative closure options and market institutional regimes depending on the issue under study (e.g., selection of national or global interest rates to balance savings-investments or taxes to balance public budgets).

The model features perfect competition market regimes, discrete representation of power producing technologies, semi-endogenous learning by doing effects, equilibrium unemployment, option to introduce energy efficiency standards, formulates emission permits for GHG and atmospheric pollutants. The environmental module includes flexibility instruments allowing for a variety of options when simulating emission abatement policies, including different allocation schemes (grandfathering, auctioning, etc.), user-defined bubbles for traders, various systems of exemptions, various systems for revenue recycling, etc. Its scope is general in two terms: it includes all simultaneously interrelated markets and represents the system at the appropriate level with respect to geography, the sub-system (energy, environment, economy) and the dynamic mechanisms of agent’s behaviour. It formulates separately the supply or demand behaviour of the economic agents which are considered to optimise individually their objective while market derived prices guarantee global equilibrium, allowing the consistent evaluation of distributional effects of policies. It considers explicitly the market clearing mechanism and the related price formation in the energy, environment, and economy markets: prices are computed by the model as a result of supply and demand interactions in the markets and different market clearing mechanisms, in addition to perfect competition, are allowed.

---

[3] Full model documentation is available at https://e3modelling.com/modelling-tools/gem-e3/.

The model formulates production technologies in an endogenous manner allowing for price-driven derivation of all intermediate consumption and the services from capital and labour. In the electricity sector a bottom-up approach is adopted for the representation of the different power producing technologies. For the demand-side the model formulates consumer behaviour and distinguishes between durable (equipment) and consumable goods and services. The model is dynamic, recursive over time, driven by accumulation of capital and equipment. Technology progress is explicitly represented in the production function, either exogenous or endogenous, depending on R&D expenditure by private and public sector and taking into account spill overs effects. Moreover, it is based on the myopic expectations of the participating agents. The design of GEM-E3 model has been developed following four main guidelines:

1) Model design around a basic general equilibrium core in a modular way so that different modelling options, market regimes and closure rules are supported by the same model specification.
2) Fully flexible (endogenous) coefficients in production and in consumer's demand.
3) Calibration to a base year data set, incorporating detailed Social Accounting Matrices as statistically observed.
4) Dynamic mechanisms, through the accumulation of capital stock and learning effects.

GEM-E3 is built on the basis of a Social Accounting Matrix (SAM). Technical coefficients in production and demand are flexible in the sense that producers can alternate the mix of production not only regarding the primary production factors but also the intermediate goods. Production is modelled through KLEM (capital, labour, energy and materials) production functions involving many factors (all intermediate products and three primary factors –capital, natural resources and labour). At the same time consumers can also endogenously decide the structure of their demand for goods and services. Their consumption mix is decided through a flexible expenditure system involving durable and non-durable goods.

The GEM-E3 model is built in a modular way around its central CGE core. It supports defining several alternative regimes and closure rules without having to re-specify or re-calibrate the model. The most important of these options are presented below:

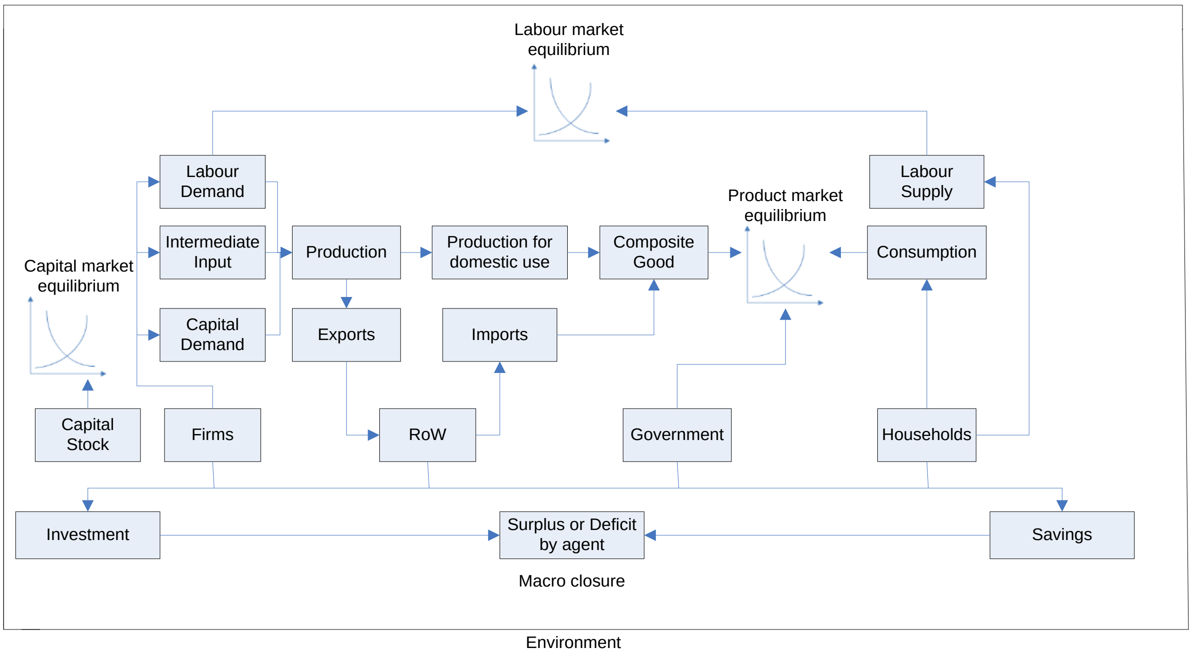
- ✓ Capital mobility across sectors and/or countries
- ✓ Flexible or fixed current account (with respect to the foreign sector)
- ✓ Flexible or fixed labour supply
- ✓ Market for GHG allowances national/international, environmental constraints

- ✓ Fixed or flexible public deficit

The model is dynamic in the sense that projections change over time. Its properties are mainly manifested through stock/flow relationships, technical progress, capital accumulation and agents' (myopic) expectations. Total demand (final and intermediate) in each country is optimally allocated between domestic and imported goods, under the hypothesis that these are considered as imperfect substitutes (the "Armington" assumption of imperfect substitution between locally produced goods and imports). Economies in the model are linked through bilateral trade flows taking into account trade margins and transport costs. Consumption and investment is built around transition matrices linking consumption by purpose to demand for goods and investment by origin to investment by destination. Figure 1 provides a schematic representation of the key linkages among the economic agents of the GEM-E3 model.

Institutional regimes, that affect agent behaviour and market clearing, are explicitly represented, including public finance, taxation and social policy. The model represents goods that are external to the economy as for example damages to the environment.

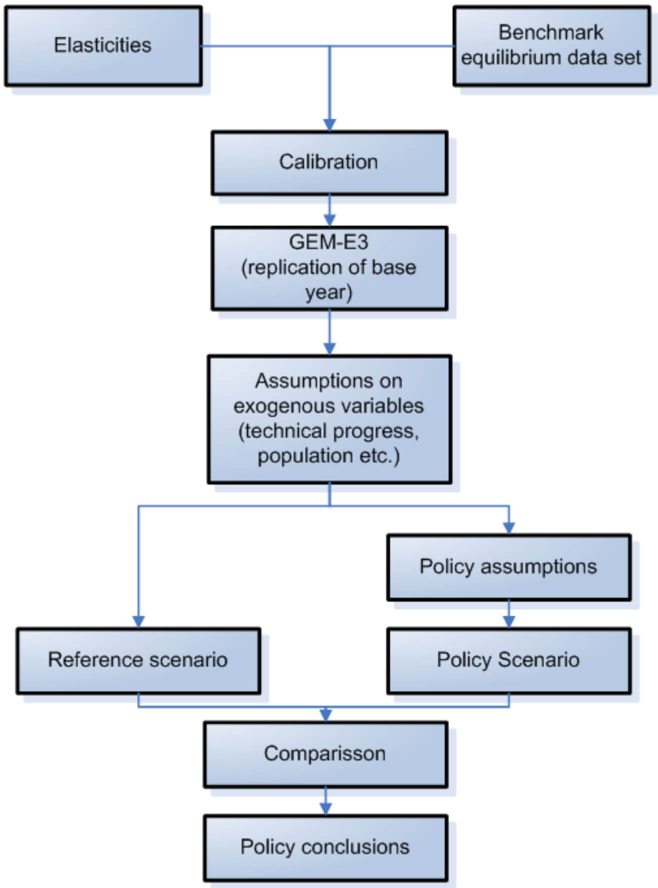
Figure 1: GEM-E3 economic circuit



Source: The GEM-E3 manual

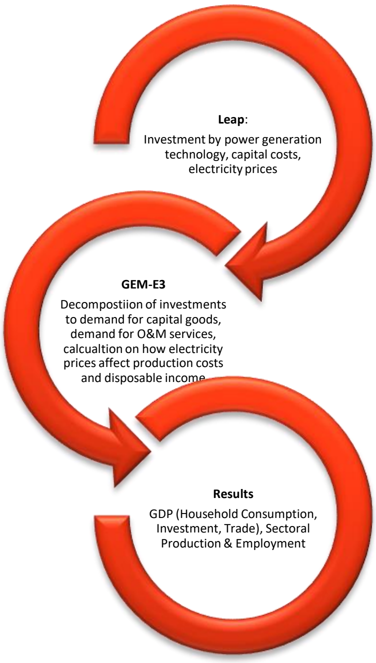
The internalisation of environmental externalities is achieved either through taxation or global system constraints, the shadow costs of which affect the decision of the economic agents. In the *GEM-E3* model global/regional/sectoral constraints are linked to environmental emissions, changes in consumption or production patterns, external costs/benefits, taxation, pollution abatement investments and pollution permits. The model evaluates the impact of policy changes on the environment by calculating the change in emissions and damages and determines costs and benefits through an equivalent variation measurement of global welfare (inclusive environmental impact).

Once the model is calibrated, the next step is to define a reference case scenario. The reference case scenario includes all already decided policies. The key drivers of economic growth in the model are labour force, total factor productivity and the expectations on sectoral growth. The "counterfactual" equilibria can be computed by running the model under assumptions that diverge from those of the reference scenario. This corresponds to scenario building. In this case, a scenario is defined as a set of changes of exogenous variables, for example a change in the tax rates. Changes of institutional regimes, that are expected to occur in the future, may be reflected by changing values of the appropriate elasticities and other model parameters that allow structural shifts (e.g., market regime). These changes are imposed on top of the assumptions of the reference scenario thereby modifying it. To perform a counterfactual simulation, it is not necessary to re-calibrate the model. The different steps for performing a counterfactual simulation in GEM-E3 are depicted in the figure above.



A counterfactual simulation is characterised by its impact on consumer's welfare or through the equivalent variation of his welfare function. The equivalent variation can be, under reasonable assumptions, directly mapped to some of the endogenous variables of the model such as consumption, employment, and price levels. The sign of the change of the equivalent variation gives then a measure of the policy's impact and burden sharing implications.

In this specific study the policy scenarios have been quantified using the inputs of the LEAP model. For each of the nine scenarios examined the LEAP model has generated a specific power mix for the years up to 2050. The power generation mix considered in each scenario, requires different levels of investments, address different capital goods & fuels and requires different O&M expenses. The GEM-E3 model received from LEAP the investments pathway for each power generation technology until 2050. Then the model decomposed these investments to demand for specific sectors. The financing of this investment is considered alternatively in GEM-E3 either through loans or out of pocket money. The GEM-E3 model was also calibrated to be consistent with the changes in electricity prices of the LEAP model for each scenario.



The range of results (the results of this study are presented in 4.3) provided by GEM-E3, are as follows: i) Dynamic annual projections in volume, value and deflators of national accounts by country, ii) Full Input-Output tables for each country/region identified in the model, iii) Distribution of income and transfers in the form of a social accounting matrix by country, iv) Employment by economic activity and unemployment rate by country, v) Capital and investment by country and sector, vi) Greenhouse gasses, atmospheric emissions, pollution abatement capital, purchase of pollution permits, vii) Consumption matrix by product and investment matrix by ownership branch, viii) Public finance, tax incidence and revenues by country, ix) Full bilateral trade matrices.

Data

The GEM-E3 model is calibrated on the Social Accounting Matrix (SAM). The SAM includes information regarding all transactions between agents (firms, households, government, world) within the economy in a given period of time. The model's main data source is the GTAP 10 database which provides the full set of Input-Output tables along with bilateral trade, duties and transport margins tables for 141 countries/regions and 65 economic sectors. Other main data sources include consumption and investment matrices, energy balances and employment statistics.

The investment matrix is used to disaggregate sectorial investments into demand for specific goods and services. For the decomposition of power generation investments to deliveries of capital goods a number of sources have been used including the most recent data on power plants cost-structure published by EIA (Energy Information Agency of the U.S.) and engineering information regarding the power plants equipment, while for the rest of the sectors the decomposition of investments is based on the published input-output statistics.

As far as it concerns the decomposition of consumption by purpose categories to demand for products, we use the set of consumption matrices published by the Joint Research Center (JRC) of the European Commission. Institutional transfers are based on Eurostat's institutional transfer accounts for the EU27 member states, while for the rest of the world we draw information from the United Nations and World Bank's databases.

With respect to energy and environment, the data from GTAPe, Eurostat, GAINS, etc. are used.

Employment statistics are based on the National Statistics Estonia and Eurostat regarding the overall employment by occupation and of the sectorial employment. In particular for the aggregate labour market statistics (labour force, active population, unemployment rate, employment) the following data from Eurostat have been used: demo_pjan, lfsa_pganws, lfsi_emp_a)[4]. Aggregate employment by skill type and sector is based on ILO statistics[5]. Data from Estonian National Statistics Estonia are used in the regional modelling.

[4] https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=demo_pjan&lang=en

https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=lfsa_pganws&lang=en

https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=lfsi_emp_a&lang=en

[5] EMP_2EMP_SEX_OCU_NB_A

3 Scenario Definition

The scenarios evaluated in this study are described in detail in the "*Deliverable 3: Development of pathways for reaching climate-neutral electricity generation*" report. This section focuses on the scenarios aspects and key variables that are used as input to the GEM-E3 and the static multiplier analysis.

This study quantifies seven alternative carbon-neutral pathways. Each of these pathways achieves carbon neutrality of the power generation system by 2050. Power generation investments peak in 2030 (except for the scenario assuming increased storage for renewables), then slow in the decade between 2030 and 2040 and recover in the last decade of the projection period. The time-profile of investment requirements depends on factors such as the electrification of transport and heating, the adoption of hydrogen which increases significantly in the last decade of the projection period, as well as on the assumptions regarding the lifetime of renewables. The additional investments are further split-out per technology in Table 4. These tables are both based on the outputs of Deliverable 3.

Table 3: Investments in power generation by scenario (million. €)

	Capital	Investments Additional to Reference
Reference	3838	
AT-1000	4043	205
AT - No Net Imports	4943	1105
RES Storage	8995	5157
RES Gas	6361	2523
Nuclear	5839	2001
CCS	3475	-363
All_technologies	4132	294

Source: LEAP inputs, summarised in Annexes B and C of the Deliverable 3 report

Table 4 Additional investments in power generation technologies and storage (in million €)

	RES-STORAGE	RES-GAS	AT	AT-NIMP	AT-1000	CCS	NUCLEAR
Batteries	184	-187	-76	241	-167	-218	104
Shale oil fired*	0	0	725	327	219	-80	0
Gas fired	0	0	0	0	201	0	0
Nuclear	0	0	0	0	0	0	2329
Biomass	46	2635	0	0	0	-2	0
Hydro	0	0	0	0	184	0	0

Wind	5540	71	-85	551	-88	-1164	-1105
PV	-613	5	-270	-15	-144	-610	673
Other renewables	0	0	0	0	0	2	0
CCS Shale oil	0	0	0	0	0	1663	0
CCS Biomass	0	0	0	0	0	46	0
Total	**5157**	**2523**	**294**	**1104**	**205**	**-363**	**2001**

Source: LEAP inputs, summarised in Annexes B and C of the Deliverable 3 report

In terms of cumulative investments and compared to the reference, six scenarios require higher amounts for the energy system restructuring and one (*CCS)* requires less. In the *RES-Storage* scenario cumulative investments are found to be almost 2.4 times higher than the reference and equal to 1.7% of cumulative GDP, followed by the *RES-GAS* scenario where investments are found to be equal to 1.2% of cumulative GDP. However, as shown in Table 5, the allocation of investments in time is not uniform and investment expenditures in 2050 are lower compared to the Reference pathway.

Table 5: Total investments as % of GDP

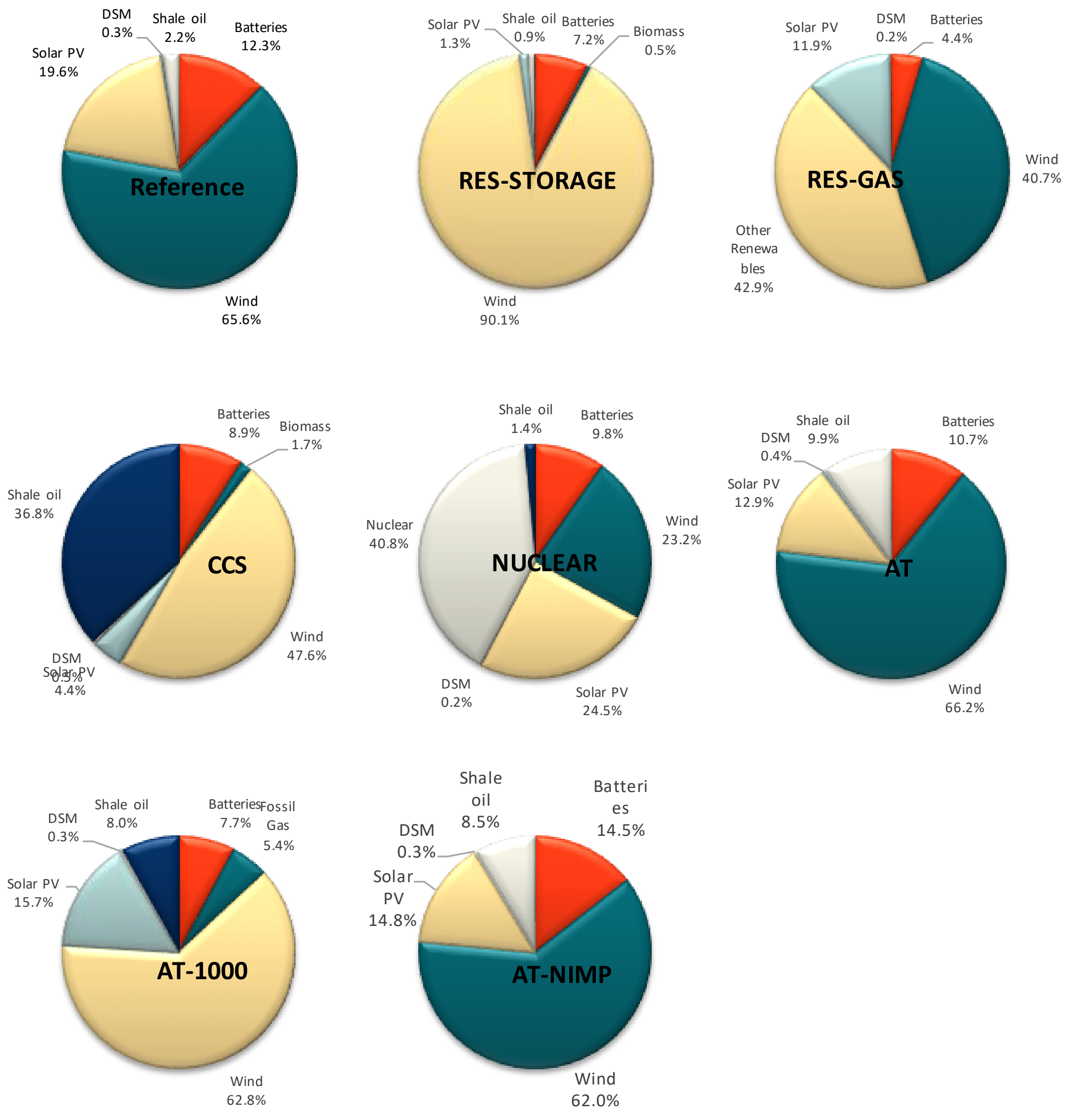
	2020	2030	2040	2050	Cumulative (2020- 2050)
Reference	0.1%	0.5%	0.0%	0.4%	0.7%
All Technologies (AT)	0.1%	0.5%	0.1%	0.4%	0.7%
AT-1000	0.1%	0.7%	0.1%	0.4%	0.7%
AT – No Net Imp	0.1%	0.9%	0.2%	0.3%	0.9%
RES - Storage	0.1%	0.8%	1.1%	0.5%	1.7%
RES - Gas	0.1%	1.3%	0.0%	0.4%	1.2%
Nuclear	0.1%	0.5%	0.7%	0.3%	1.1%
CCS	0.1%	0.8%	0.0%	0.0%	0.5%

Source: Based on LEAP results

Each scenario has a different driver of energy system investments. Demand side management expenditures remain virtually at their reference levels across all scenarios, while oil shale remains an option (with CCS and/or with biomass) in the power generation system as new oil shale investments take place between 2020 and 2030. In 2050 there is a decrease in expenditures for storage systems in most of the scenarios considered. The cases where oil shale remains as an option in the PG mix are the: AT scenario, the AT-NIMP and mainly in the CCS scenario.

In the reference scenario, investment resources are mainly directed towards wind and solar PV and storage options, while no resources are directed towards fossil fuelled power and biomass generation. In the zero-emission pathways, wind investments are lower except for the *Renewable storage* variant where the expansion of offshore wind is foreseen. In general, the portfolio of power generation investments is more diversified in the carbon neutral scenarios compared to the reference[6].

Figure 2: Distribution of cumulative investments in the Different Scenarios Examined



[6] The model accounts both for the intermittent and dispatchable capacity investments. The key importance is how much of the investments is delivered with domestic resources and how much with imported.

Electricity price depends on the power generation mix and on the evolution of capital costs of the clean energy technologies. Capital costs are reduced over time as a result of learning by doing, economies of scale and R&D expenditures. The cost reductions over time assumed in the GEM-E3 model are in line with those assumed in the LEAP model (Deliverable 3) and are reflected in the quantification of the Reference scenario. Variations in the power generation mix across the different scenarios has no impact on the capital costs as the size of the market and production is not sufficient to justify gains from economies of scale.

4 Socioeconomic Impacts

4.1 General Remarks

Shifting power generation from conventional (shale oil) sources to RES implies a redirection of demand across sectors delivering capital goods. Table 6 shows how the investment of each power generation technology is decomposed to demand for capital goods produced by different economic activities. In other words, this table shows the shares with which the economic activities contribute to the power generation investment projects (e.g., 53% of the Investment required to build a hydro power plant is directed as demand to the construction sector, whereas for the deployment of a wind turbine 69% is directed on the purchase of the equipment).

Table 6: Estonia's investment Matrix[7]: Contribution (%) of industries delivering the capital goods to total investments

	Power Plants							
% Shares	**Shale oil**	**Gas fired**	**Nuclear**	**Biomass**	**Hydro electric**	**Wind**	**PV**	**CCS shale**
Ferrous metals & Metal products	42	0	0	33	0	0	0	28
Computer, electronic and optical products	1	0	22	2	1	0	4	1
Electrical equipment	4	15	22	8	1	8	13	3
Machinery and equipment	8	60	8	15	15	0	0	10
Other Equipment Goods	0	0	0	0	0	0	11	0
Technology Specific Equipment (Wind turbine, PV panel etc.)	0	0	0	0	0	69	41	19
Construction	12	15	17	14	53	10	16	10
Financial Services	11	6	9	11	9	4	4	13
Other Market services	22	4	23	17	20	9	12	17
Total	100	100	100	100	100	100	100	100

Source: EIA, IRENA, author's calculations

[7] The data are drawn from EIA report (2020) "Capital Cost and Performance Characteristic Estimates for Utility Scale Electric Power Generating Technologies" and the IRENA report "Renewable Power Generation Costs in 2019"

The Estonian manufacturing industry accounts for approximately 14.7% of national gross value added (GVA) and employs almost 118 500 persons (in 2020). The most important sectors in terms of value added are wood and paper industries, consumer goods industries, producers of computer and optical products and electronic equipment. These industries are responsible for approximately 22%, 18.5% and 15% respectively of national manufacturing output (Eurostat, 2020).

The extent to which the domestic economy will benefit from the power sector transformation partly depends on the production structure of the sectors that will deliver the capital goods and the import dependency on high value-added capital goods. In Estonia, the structure of the manufacturing sector, which is oriented towards technology-related products, combined with the presence of small and medium-sized firms that operate in the field of renewable-equipment imply that there exist potential benefits for the domestic industry from the zero-emission transition. For example, firms such as ELEON, TUGE (small wind-turbine manufacturer), Tbhawt Manufacturing (manufacturer of wind generators), may benefit from the increased penetration of wind energy in the electricity mix depending on the type of installations. Considering the Aidu wind park where ELEON has planned to install 30 turbines of nominal capacity of 102 MW, ELEON's turbines account for 20% of installed wind-turbines in Estonia and approximately 25% of installed wind capacity[8]. Furthermore, other manufacturers (e.g., those associated to the production of boilers and turbines for industrial facilities) can benefit from the development of biomass facilities. With respect to import dependence the table below presents the import coverage of domestic demand as depicted in the Input-Output table of 2014[9]:

Table 7: Investment Matrix: Domestic and imported (%) of industries delivering the capital goods to total investments (2014)

% Shares	Domestically produced	Imported
Ferrous metals & Metal products	32%	68%
Computer, electronic and optical products	4%	96%
Electrical equipment	7%	93%
Machinery and equipment	16%	84%
Other Equipment Goods	36%	64%
Technology Specific Equipment (Wind turbine, PV panel etc.)	17%	83%

[8] Taking data from https://tuuleenergia.ee/?page_id=1373&lang=en and adding the Aidu wind farm. For the latter, data are drawn from https://www.thewindpower.net/windfarm_en_25421_aidu.php

[9] GTAP v.10

Construction	96%	4%
Financial Services	81%	19%
Other Market services	83%	17%

Source: GEM-E3

At the regional (NUTS3) level, the impacts will be determined by the location of production facilities and from the relevant contribution of the manufacturing to the local economy. Hence, regions with a high manufacturing share are expected to benefit more (e.g., Lääne-Eesti, Kesk-Eesti and Kirde-Eesti). Other (dynamic) factors that may affect regional performance are primary factor endowments and factor movement. Table 7 provides the relative contribution of each sector to the local economy.

Table 8: Regional Contribution to total Gross Value Added

	Põhja-Eesti	Lääne-Eesti	Kesk-Eesti	Kirde-Eesti	Lõuna-Eesti
Ferrous metals	0.5%	0.8%	0.9%	0.9%	0.7%
Metal products	1.7%	2.6%	2.9%	2.9%	2.2%
Computer electronic and optical products	3.9%	5.8%	6.6%	6.5%	4.8%
Electrical equipment	2.0%	3.0%	3.3%	3.3%	2.5%
Machinery and equipment	1.3%	2.0%	2.3%	2.3%	1.7%
Other Equipment Goods	1.0%	1.5%	1.7%	1.6%	1.2%
Total	10.5%	15.6%	17.7%	17.6%	13.0%

Source: GEM-E3

The regions with the highest manufacturing contribution to total output are Kesk-Eesti and Kirde-Eesti. The respective share for the two regions is equal to 45% and 49% respectively.

4.2 Static analysis: Economic & Employment Impacts

Key Insights of the Leontief Multiplier / Static Analysis

- The highest output multipliers of the Estonian economy are in the construction and market services sectors (2.02 and 1.6 respectively)
- Results on output and employment are driven by the size of investments and the choice of financing
- In the absence of financial and production capacity constraints the best performing case regarding total production is the RES-STORAGE that increases total sales by ~€ 8 bn cumulatively over the period 2025-2050
- When the size of investments is isolated then the best performing case in term of output is the CCS scenario. This indicates that it is beneficial to partly retain existing capacity/equipment while the mix of the sectors providing the capital goods has higher average multiplier than the other scenarios examined.
- The impact on employment by scenario is positive (particularly in the early years where the construction takes place) and ranges from 200 jobs (all technologies scenario) to 2 000 jobs (RES – Storage).
- In the case of self-financing where investments of equal value are cancelled to finance the power generation investments the net impact on the economy is negative. This indicates that the multiplier effect of the average capital good is higher by the multiplier of the capital goods used in the power generation.
- The static analysis does not consider price and productivity effects

4.2.1 Economic Impacts - Static

We consider two alternative financing schemes:

i) ***Loan Based (FINEXT)***: Investments are financed by external sources (e.g. FDI) and money are not paid back. Capital and labour are assumed to be in abundance and there are no production capacity bottlenecks (i.e. the additional demand for production does not create any inflation as idle production factors become active)

ii) ***Self – Financing (DOMEXT)***: Investments are financed from domestic resources - in this case the investments in the power generation sector deprive financial resources from other activities.

The loan-based financing (FINEXT) implies that the domestic economy takes full advantage of the resource's influx without an additional cost while the second financing option implies a re-orientation of domestic available funds towards energy-related investments yielding crowding-out effect.

Increased investments (as compared to the Reference scenario) are expected to generate a positive effect for the domestic economy, increasing the demand for the goods and services supplied by specific sectors. The size of total economic gains depends

i) on the selected financing scheme,

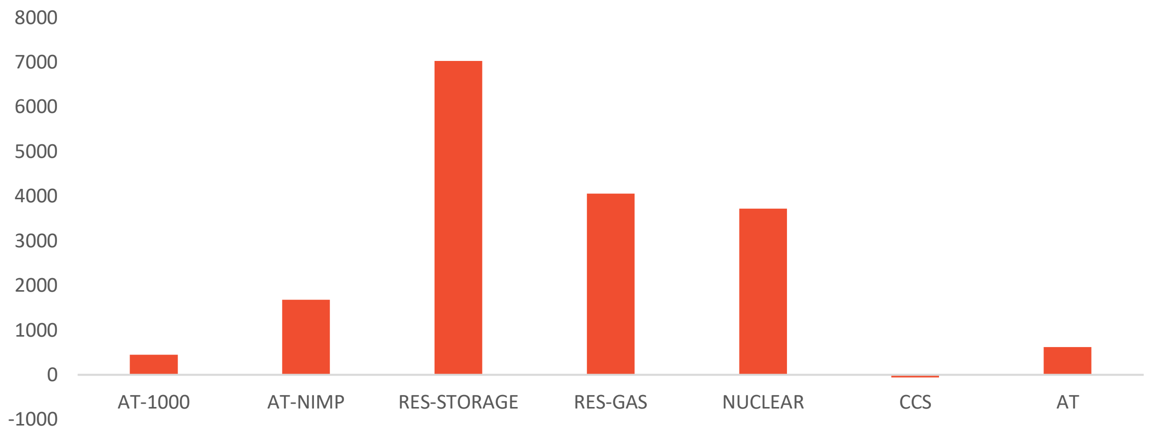
ii) on the structure of the gross fixed capital formation (which sectors will deliver the capital goods)

iii) on the import dependence of the sectors that are involved in the realization of energy-related projects.

Loan Based - FINEXT

In terms of cumulative output over the 2025-2050 period the scenario the RES-Storage scenario ranks first (production increases equal to 2.4%[10] of cumulative GDP). The lowest performance scenario is the CCS scenario (equal to 1% of cumulative GDP). The low performance of the CCS scenario is mostly attributed to the low level of investment expenditure as compared to the reference (limited demand driven stimulus effect).

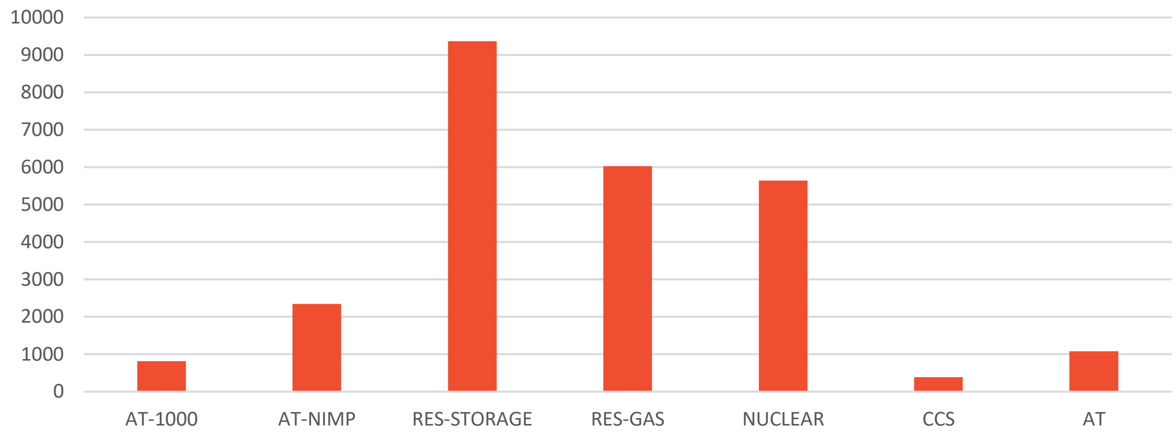
Figure 3: Cumulative (Type-I) output changes compared to the reference (in million €)



Source: Author's calculations

[10] The direct effect (investments) is equal to 1.7% of GDP and the multiplier effect is equal to 0.8%

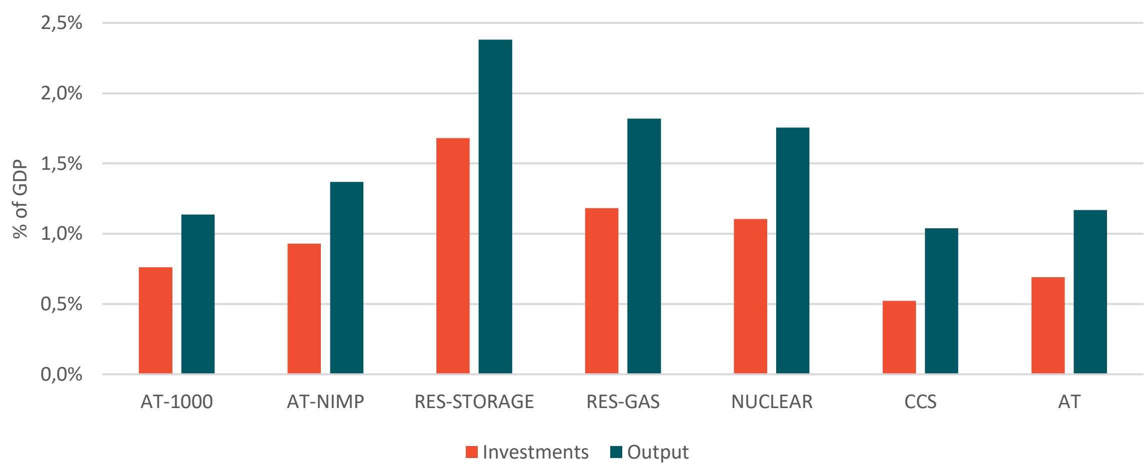
Figure 4: Cumulative (type-II) output changes compared to the reference (in million €)



Source: Author's calculations

In the absence of financing and production capacity constraints the higher the investment expenditure the better the performance of the scenario. Hence the ranking of the scenarios in terms of benefits[11] for the domestic economy, depends on the level of investments and does not necessarily coincide with the ranking as measured by the multiplier induced benefits. For example, in the RES - Storage scenario each euro spent (1 €) generates approximately one euro and forty cents (1.40 €) while in the RES - GAS scenario each euro spent generates approximately one euro and fifty-one cents (1.51 €) implying that the Estonian economy benefits more in the latter case as it mobilises more domestic activities that have stronger back/forth interlinkages with the rest of the economy.

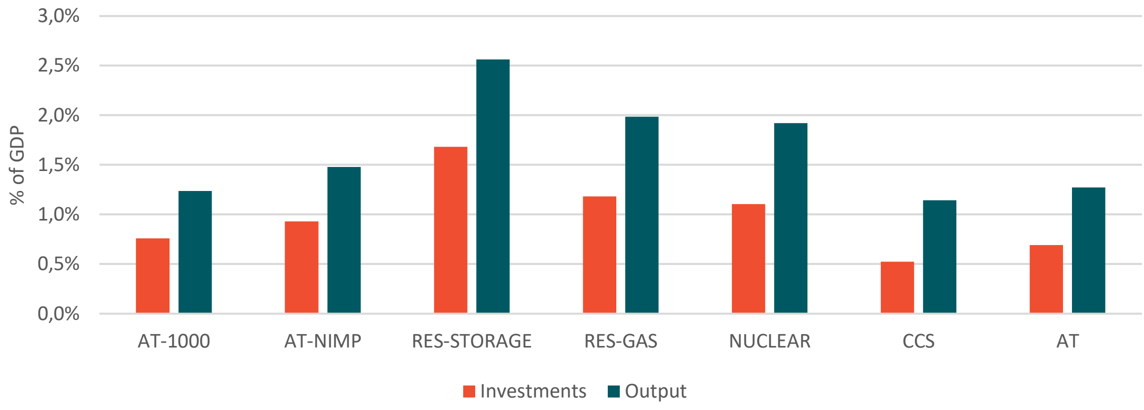
Figure 5: Cumulative investments and output changes for FINEXT– Type-I (% of GDP)



[11] Measured as output increase

Source : Author's calculations

Figure 6: Cumulative investments and output changes for FINEXT – Type-II



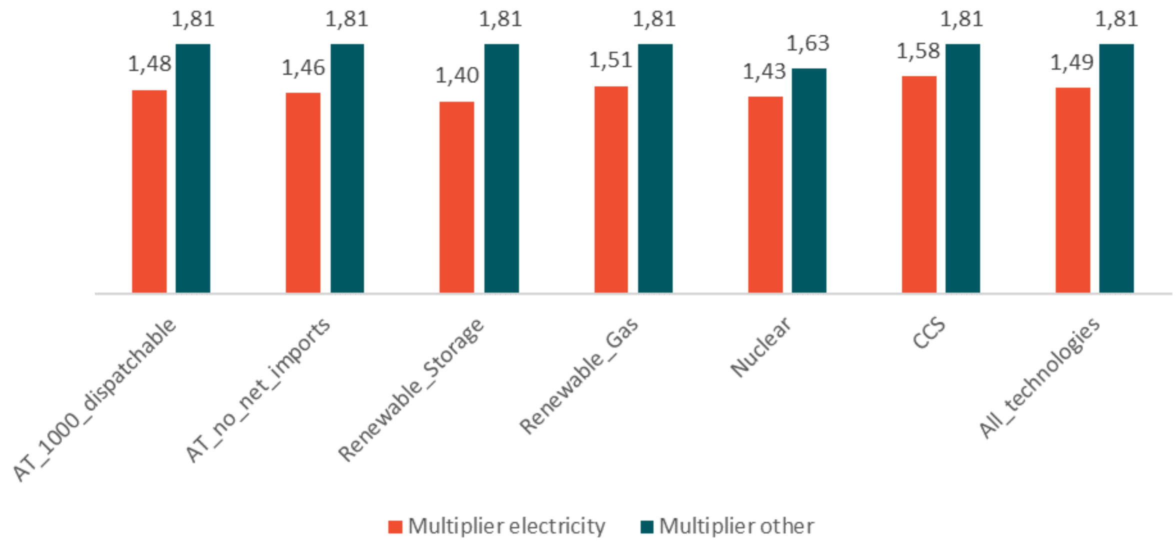
Source : Author's calculations

Compared to the reference case six out of seven scenarios imply higher cumulative gains for the period 2021-2050, while the *CCS* requires fewer total investments and delivers lower output than the reference.

Self-financing – Crowding Out

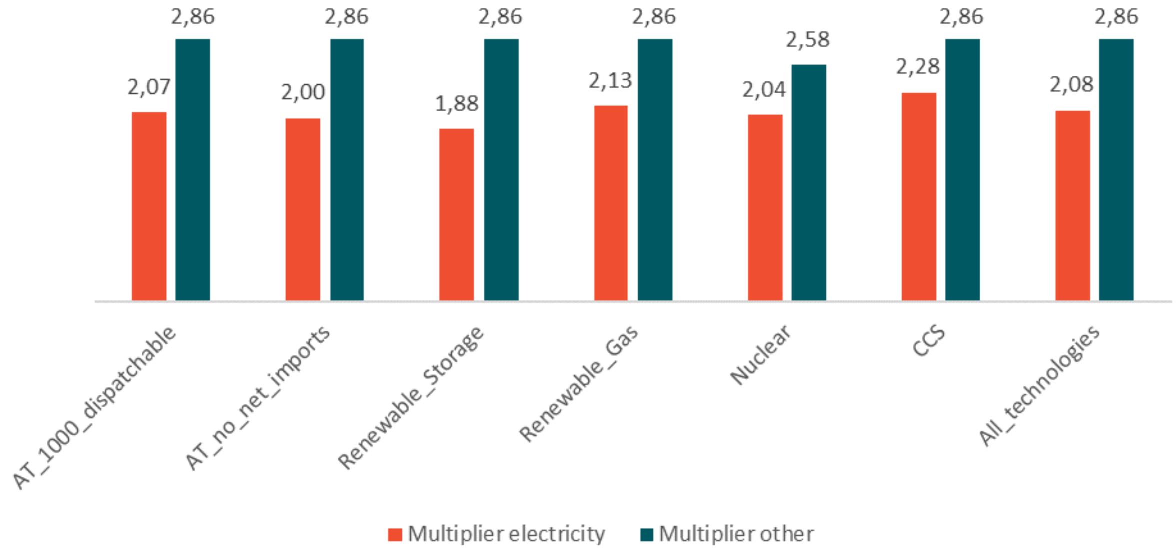
In the case of self-financing, it is assumed that the power generation investments are financed by cancelling out other investments in the economy of equal value (hence total investments in the economy remains unchanged). The multiplier-based analysis shows that in all scenarios examined the net impact on the economy is negative. This indicates that the multiplier effect of the average capital good is higher by the multiplier of the capital goods used in the power generation sector. When the amount of investments required to transform the electricity, system is re-oriented towards other productive investments, then, compared to the electricity investment- an additional of 30 cents (on average) is generated in the economy.

Figure 7: Type-I cumulative multiplier – Self Financing



Source: Author's calculations

Figure 8: Type-II cumulative multiplier – Self Financing



Source: Author's calculations

4.2.2 Impact on employment

The assessment on employment is based both on the IO derived employment multipliers and on the capacity and O&M multipliers derived by bottom-up engineering studies. The bottom-up multipliers for the different power generation technologies are extracted from the Paroussos and Fragkos (2018) study that assess the employment impacts associated to the expansion of renewables in the EU using the GEM-E3 model and compare their results with the implied job creation based on engineering bottom-up estimates (Table 8).

The number of jobs is disaggregated into three components:

i) jobs associated to the **construction of** the power generation utilities
ii) jobs associated to the **operation and maintenance** of power generation plants, which correspond to jobs within the regional borders
iii) jobs associated to the **manufacturing** of power generation equipment which refers to the global value chain.

Table 9: Literature Review generic estimations on Jobs per MW installed

	Construction (jobs per MW)		Manufacturing (jobs per MW)		O&M	
	Rutovitz, 2015	Rutovitz, 2015	Rutovitz, 2015	Wei 2011	USA, 2017	UNEP, 2008
Wind	0.5	4.7	0.3	0.24	0.05	0.08
Photovoltaics	6.4	6.7	0.7	0.52	0.13	0.17
Large hydro	7.4	3.5	0.2	0.34	0.06	
Biomass	14	2.9	0.65	0.12	0.08	0.16
Coal fired	11.2	5.4	0.18	0.4	0.16	0.38
Oil fired	1.3	1	0.14	0.1	0.16	0.16
Gas fired	1.3	1	0.14	0.1	0.15	0.15
Nuclear	11.8	1.3	0.6	0.7	0.46	

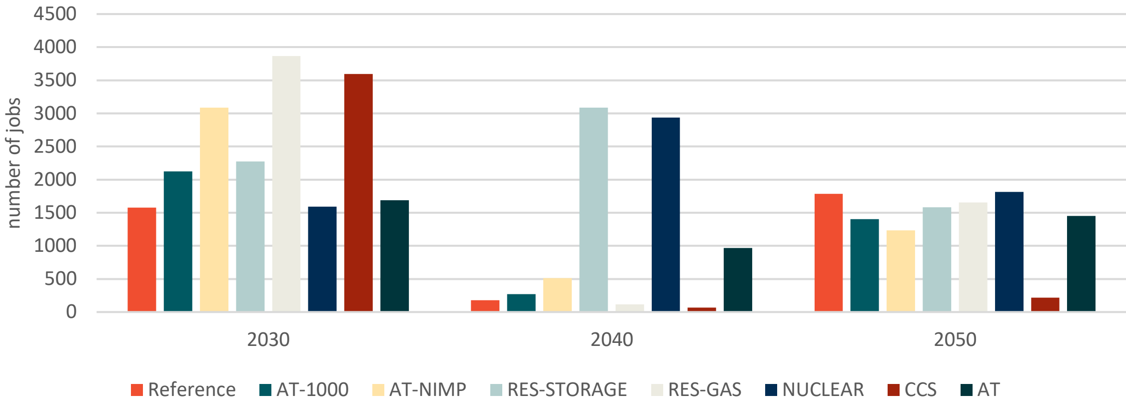
Source: Paroussos and Fragkos (2018)

Input-Output employment multipliers

The assessment of employment impacts using the IO derived multipliers approach shows higher employment gains for the carbon-neutral scenarios with respect to the reference case. In 2030, five out of six scenarios, record relative increases of employment with respect to the reference case. Towards the end of the projection period employment gains fall significantly and in 2050 employment gains are lower than in the reference case (except for the NUCLEAR scenario). The total employment[12] gains in the 2030 range from 2 280 jobs in the RES gas scenario to 200 jobs in the AT scenario.

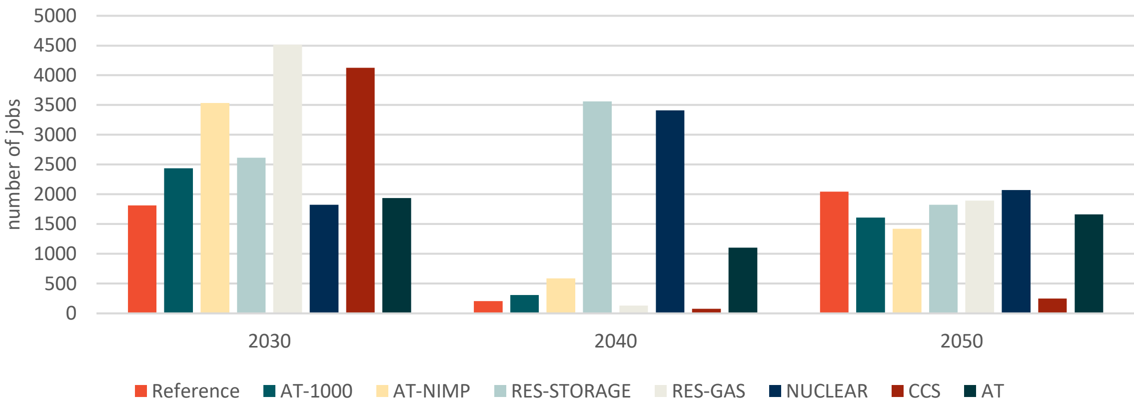
[12] The model does not allow for labour mobility across countries and there is no shortage of skills (i.e., labour skill requirements are supplied by the domestic pool of workers).

Figure 9: Type-I employment multipliers



Source: Author's calculations

Figure 10: Type-II employment multipliers

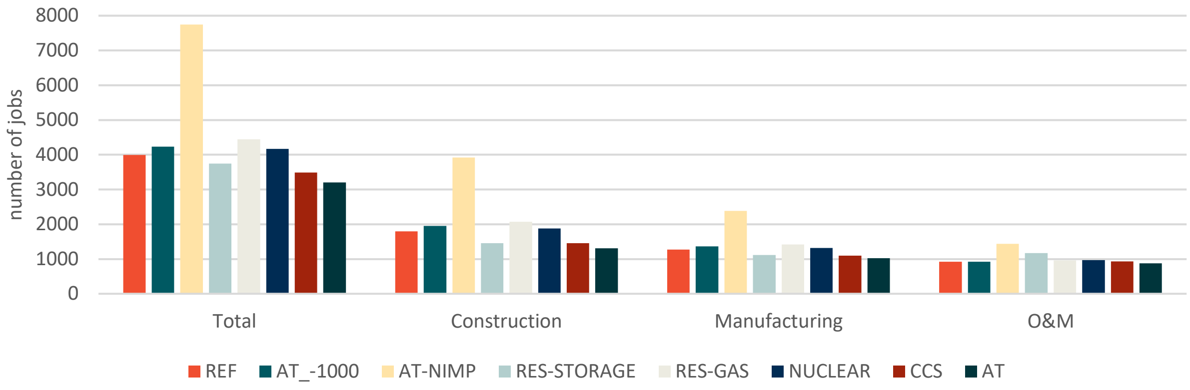


Source: Author's calculations

Literature based employment impacts

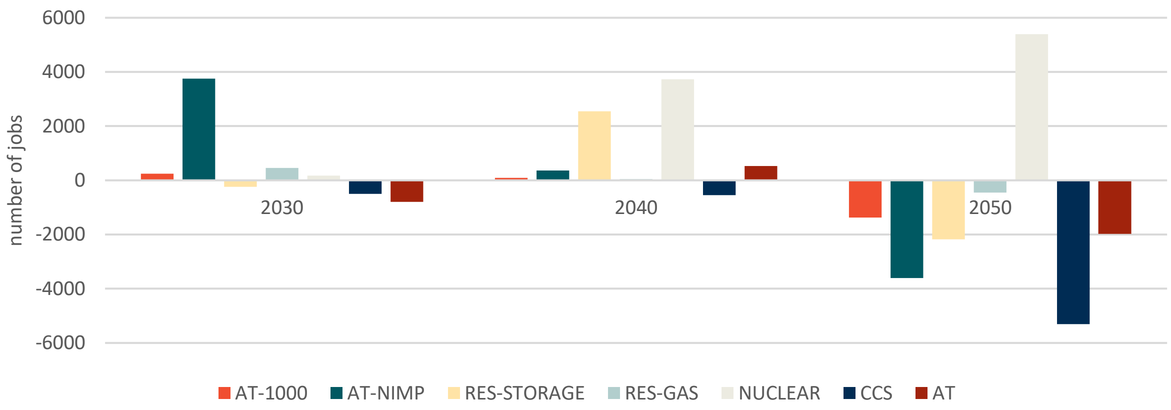
Using the annual added capacity and the power generation by source both in the reference and in the zero-emission pathways the number of jobs related to the power generation sector is calculated. In 2030, four out of seven scenarios generate a higher number of jobs with respect to the reference. In the AT no net imports scenario a total of 1 438 new jobs are created (518 when compared to the reference), while in the RES - Storage scenario 1 168 new jobs are created (247 additional to the reference). 51% of the jobs generated in the All Technologies no net imports scenario are created in the construction phase (these jobs are short lived as they are no longer required with the completion of the power plant).

Figure 11: Power generation related jobs in 2030 – literature based



Source: Author's calculations

Figure 12: Impact on Jobs (absolute difference from Reference)



Source: Author's calculations

4.3 Dynamic analysis using the GEM-E3 model

Key Insights of the Dynamic Analysis

- Moderate economic and employment impacts are expected from the implementation of the alternative pathways
- The choice of the financing option is key to the performance of the carbon neutral pathways.
- In the Loan based scenario the best performing pathway is the RES-Storage where (GDP increases by ~1.5% compared to the Reference Scenario)
- Construction, machinery, and equipment are the sectors that will benefit more during the transformation of the power generation sector
- In the self-financing scenario all/combined technologies scenarios perform better than any other cases examined. The best performing case examined is a combined technology (wind, shale oil and storage/batteries) scenario with zero net electricity imports
- The income distributional implications across household income classes are expected to be negligible. Small changes in electricity prices (-1% to +6%) have small impacts on both production costs and real disposable income hence not affecting considerably the income distribution among income classes. The small effects are in the direction of improving income distribution as in the best performing scenarios electricity prices are reduced and labour skills mostly available to low-income households are demanded.

The GEM-E3 model-based analysis differs from the static multiplier analysis presented in the previous section in the following respects:

i. It includes the feedback effects of the policy intervention. This means that any change that the new power generation system has on production costs, competitiveness, production, employment, wages and households' disposable income is taken into account;
ii. The financing schemes considered include more features such as the explicit loan repayment periods and interest rates;
iii. Long term dynamic effects through capital stock accumulation are better captured;
iv. Account for labor market imperfections – unemployment; and,
v. Account for distributional implications across income households.

As in the Leontief multiplier-based analysis two different financing schemes have been considered in order to assess the importance of financing availability:

i. ***Loan based***: Investors in the power generation sector receive loans on a 5% interest rate that need to be paid back on a ten years-time period.
ii. ***Full crowding out – Self Finance***: Power generation investments are financed by financial resources that are made available by cancelling investments of the same amount in other sectors of the economy (as in the static analysis described in the previous section),

The capital and interest payments that are assumed in each scenario are presented in Table 9. Since the repayment of the loans does not take fully within the examination period which means that the positive demand stimulus effects are partly overestimated. In addition, no stress on financial resources is modelled – this means that interest rate is kept constant irrespective of the level of requested funds (i.e. the AT-1000 and the RES Storage scenarios are financed with the same interest rate).

Table 10: Financing profile Capital Costs and Interest rates (mil. €)

	Capital	Interest Rate	Total	Post 2050 remaining payments	Investments Additional to Reference
Reference	3838	1132	4971	1363	
AT-1000	4043	1193	5237	1133	266
AT - No Net Imports	4943	1458	6401	980	1430
RES Storage	8995	2654	11649	1478	6678
RES Gas	6361	1877	8238	1328	3268
Nuclear	5839	1723	7562	1014	2592
CCS	3475	1025	4501	90	-470
All_technologies	4132	1219	5351	1143	380

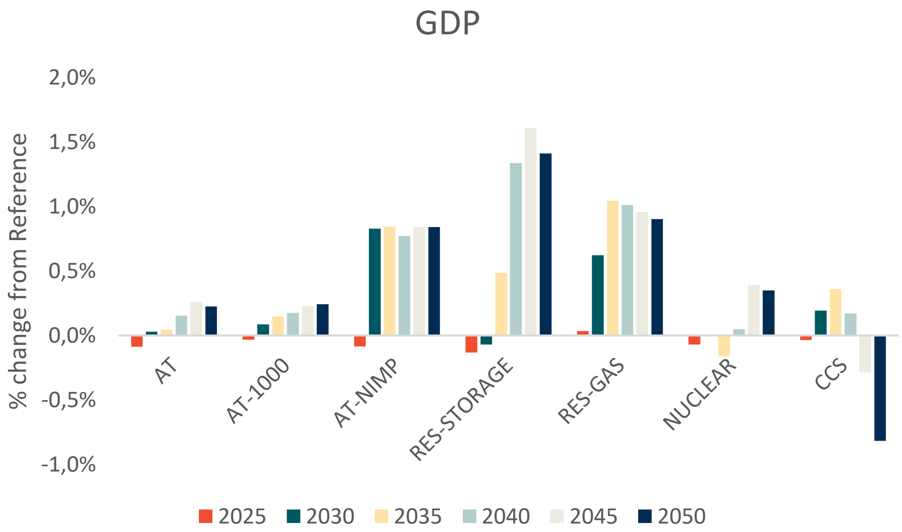
4.3.1 Loan Based

Macroeconomic Adjustment

GDP impacts are more likely to be on the positive side, as long as the scale of the required power generation investments does not act as a constraint on the overall economy, and as long as mitigating measures are in place to ensure that spare capacity and financial capital effectively flow into power generation investment in Estonia. The figure below (Figure 13) summarises GDP impacts in the Estonian across the policy scenarios.

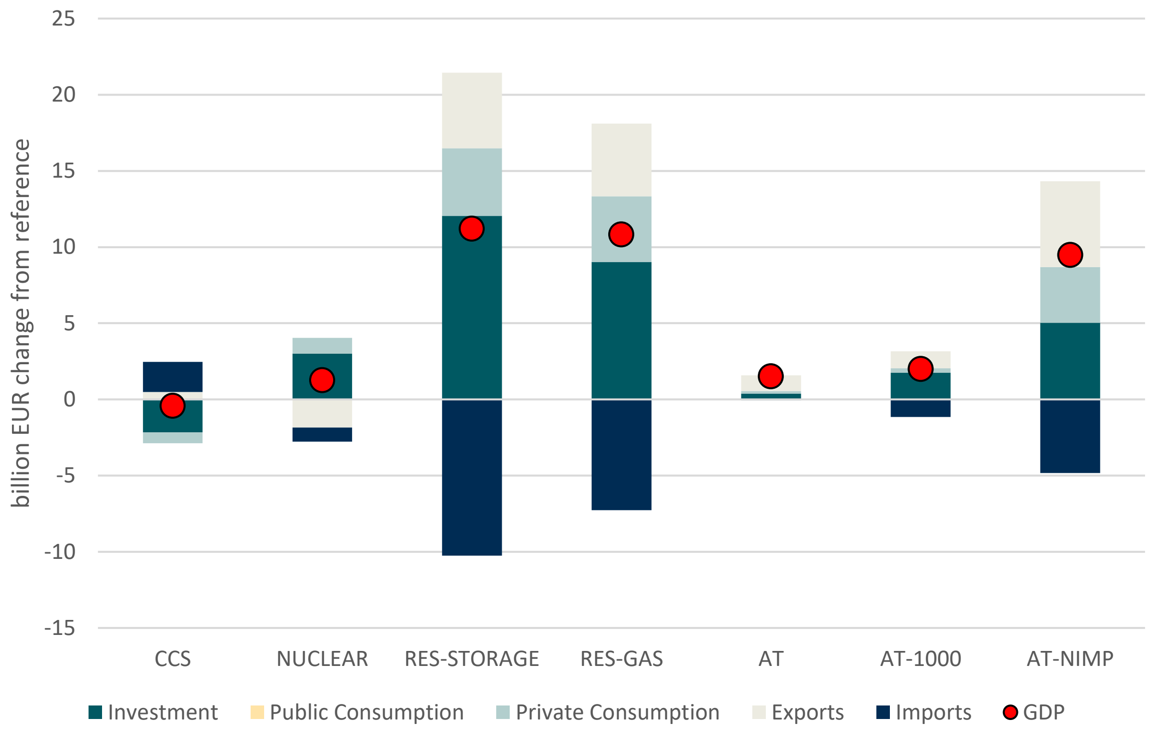
The GEM-E3 model shows positive impacts for most scenarios over the projection period. The GDP impacts are higher in the long run compared to the early years of transformation. The temporal profile of GDP changes can be attributed to the investment profile and the multiplier effects. The implementation of investments in the early years is associated with lower gains as the potential crowding out effects are higher (stemming from the increased capital requirements) and the fact that domestic production capacities are limited (compared to the increased demand) leading to higher imports of investment goods. This leads to a worsening of the trade balance for most scenarios up to 2035 (imports increase on average by 0.5% while exports fall by 0.1%). However, the ability of economic agents to borrow and smooth their consumption and investment spending, leads to higher benefits in the period from 2035 onwards. Demand stimulus (from increasing investments in clean energy technologies) has positive effects on private consumption as the increased activity leads to higher income levels. Private consumption increases on average by 0.21% in the period up to 2035 and by 0.34% in the period 2035-2050.

Figure 13: Macroeconomic adjustment of the different scenarios – GDP – dynamic



Source: GEM-E3

Figure 14: Macroeconomic adjustment of the different scenarios – GDP – cumulative (2025-2050)



Source: GEM-E3

The NUCLEAR scenario records lower GDP gains compared to the RES-GAS scenario with which they have comparable amounts of cumulative investments. In the NUCLEAR scenario, the increased electricity prices combined with the reduction in biomass use (which has high domestic content) hinders the gains from the investment stimulus in the economy. As far as it concerns the CCS scenario, the scenario records GDP gains in the period between 2030-2040 due to the demand associated to the increased spending in power generation facilities, but in the long run, i.e., after 2040, the negative pressure associated to the higher electricity and financial costs as well as the low level of investments (with respect to the reference case) leads to lower activity levels and GDP.

In the AT-NIMP the economy is benefited from the increased investments in the short-run. As the investments increase the productive capacity of the economy the economy benefits from the increased capital stock, which decreases capital rents and increase competitiveness, for all the preceding periods.

In AT, AT-1000 there is a more even distribution between investments during the decade 2020-2030 and 2040-2050. In both scenarios approximately 78.5% of the total amount due is paid during the examined period. The cumulative GDP gains in the two scenarios are equal to 1.6 bn.€ and 2 bn.€ respectively.

However, GDP gains per euro invested vary between alternative pathways as they depend on i) the multiplier effect of the investment mix, ii) loan costs and iii) electricity prices.

Comparing the RES-STORAGE with the RES-GAS scenario, cumulative investments are approximately 2 bn€ higher. However, when comparing the two scenarios in terms of cumulative GDP gains, we find that the RES-STORAGE scenario records 11.3 bn.€ and the RES-GAS 10.8 bn.€. The difference between the two scenarios is 0.5 bn.€ and the GDP gains per euro invested (with respect to the reference case) are equal to 2.2 for the RES-STORAGE scenario and 4.2 for the RES-GAS scenario. The reason is twofold: the RES-STORAGE scenario has higher repayment costs (87% of the loans are repaid by 2050 compared to 83% in the RES-GAS) and lower multiplier. In the RES-GAS scenario investments in the biogas facility generate higher demand for fabricated metal products and construction which have higher domestic content and multiplier effect than the manufacturing of wind turbines (which holds the predominant share between investment goods in the RES-STORAGE scenario.

At the regional level, see also the Annex, Lääne-Eesti records the highest total output gains under the RES-STORAGE scenario, while the highest output losses are recorded in Lõuna-Eesti under the CCS scenario. Excluding changes in electricity output, the highest increase in the RES-STORAGE scenario is recorded in Põhja-Eesti (+0.77% compared to the reference case), and is driven by increased manufacturing and service output (these two sectors are responsible for approximately 76% of total regional output change). The region accounts for more than 50% of total national manufacturing output (and 57% of the manufacturing related to clean energy technologies) and approximately 47% of total national services output. Hence, it benefits from the increased demand for goods and services related to power generation investments at a larger extent compared to other regions.

Sectoral Production

Increased power generation expenditures lead to increased demand in sectors providing goods and services to deliver the capital goods for the power generation utilities and construct the respective plants. Figure 15 presents the impacts by sector for different scenarios which clearly show that reducing GHG emissions drive expenditures towards sectors producing the respective equipment. Although the sectors most likely to benefit activity-wise are the construction sectors, engineering sectors, and some basic manufacturing sectors (such as non-metallic industries and the iron and steel sector). The direct positive effect of power generation expenditures on domestic activity, especially for sectors producing and installing the equipment, is further strengthened by multiplier effects that reflect the increased intermediate demand for goods and services due to sectorial interconnections and long supply chains. Sectors with low exposure to foreign competition record relatively higher increases in their activity (e.g., construction), while for sectors characterised by higher trade exposure (e.g., engineering and transport equipment), part of the increased demand is satisfied by imports, depending on the degree of exposure to foreign competition, thus the positive effect of increased expenditures on their activity is weakened.

Figure 15: Impact on Production

Employment

In general, **total employment is driven by employment multiplier effects and interactions between sectors** acting throughout the Estonian economy and put in motion under the power generation investment scenarios. These depend on the labour intensity of the sectors delivering inputs to power generation projects (relatively high for sectors like market services, high-tech manufacturing, construction) and that of the energy sectors (relatively low labour intensity), as well as on the share of domestically produced inputs to total inputs used in the production process (high shares of domestically produced inputs in the production process imply that an increase in the sectorial activity is associated with an increase in employment of sectors of domestic origin rather than that of sectors located outside Estonia). Net employment effects also depend on the "stickiness" of wages (the extent to which wages can adjust to changes in labour demand) and on the availability of skill formation and reorientation programs.

Figure 16: Impact on Aggregate Employment

Figure 17: Impact on Employment by Skill

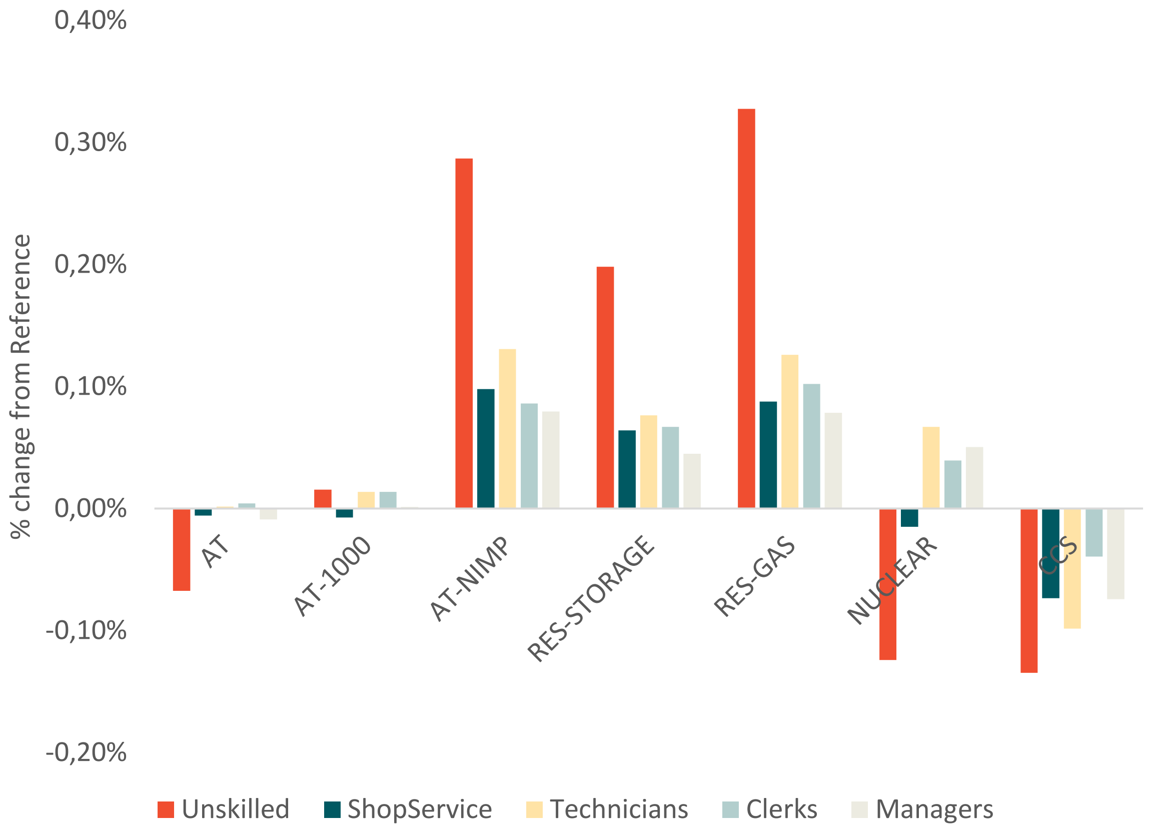
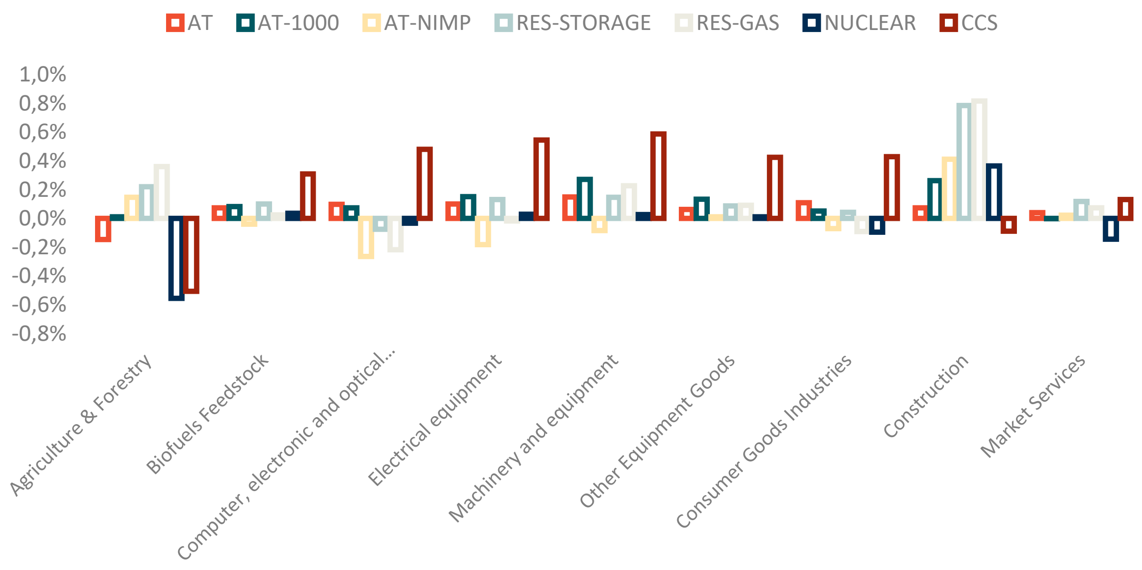
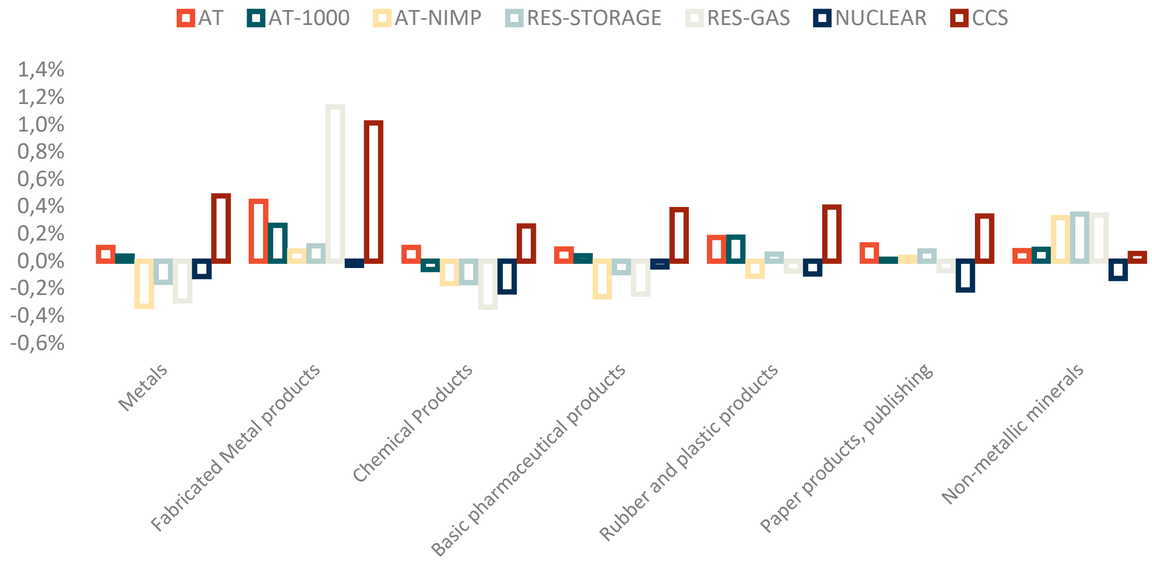


Figure 18 summarises employment impacts in the Estonia across the scenarios examined. In GEM-E3, employment is mostly affected by the projected changes in the activity of the more labour-intensive sectors. In GEM-E3, unused labour resources can be used in labour-intensive scenarios with only small effects on the equilibrium wage rates.

Figure 18: Impact on Employment



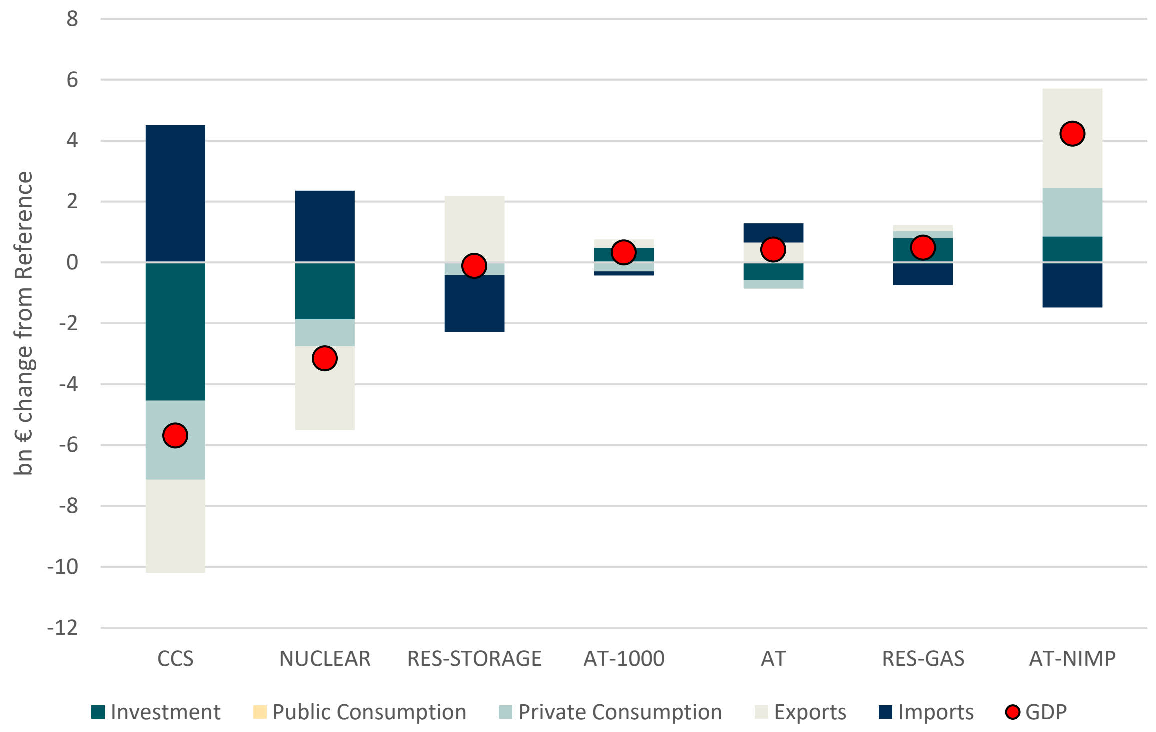


4.3.2 Self-financing

Assuming investments are self-financed, the Estonian economy records, see Figure 19, the highest GDP gains (compared to reference scenario) under the No Net Imports (AT-NIMP) scenario, while the lowest performance is recorded in the CCS scenario. In the AT-NIMP pathway, wind power generation is backed up by dispatchable fossil fuel-based electricity. This scenario is found to be beneficial in all components of GDP as this scenario is characterized by: i) a high domestic content in terms of delivering the capital cost of power generation equipment, ii) low cost of electricity (electricity prices are lower than the Reference) which reduces average production costs (improving competitiveness, increasing exports and reducing imports) and increases households disposable income (allowing for private consumption to increase). The latter has a significant positive multiplier effect in the economy and leads to GDP gains.

At the regional level, Lõuna-Eesti records the highest absolute cumulative output gains in the AT-NIMP scenario, and the same region records the highest absolute cumulative losses in the CCS scenario. Output changes in both cases are driven by the energy related sectors, by services, and by construction.

Figure 19: Macroeconomic adjustment of the different scenarios



Source: GEM-E3

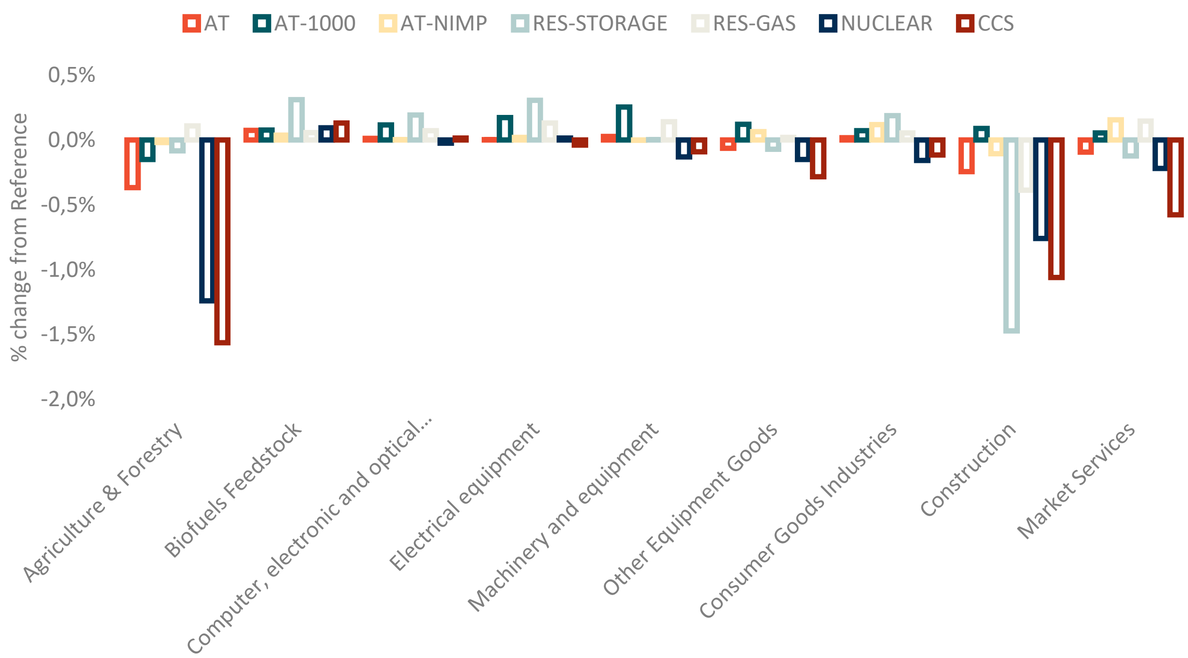
The CCS and Nuclear scenarios rank low regarding their performance on GDP for different reasons. CCS is a scenario where the investments on Wind, PV and batteries are reduced considerably, and the Nuclear scenario, whilst increasing investments in PV, sees a large decrease in wind investments, this decrease being the dominant effect in the low GDP performance of the scenario. The CCS pathway, although it assumes that fossil fuel plants are not phased out, leads to GDP losses due to higher electricity costs which are propagated to other the sectors implying increases in production costs and competitiveness losses and negative impacts on trade. The latter effect is also evident in the NUCLEAR scenario.

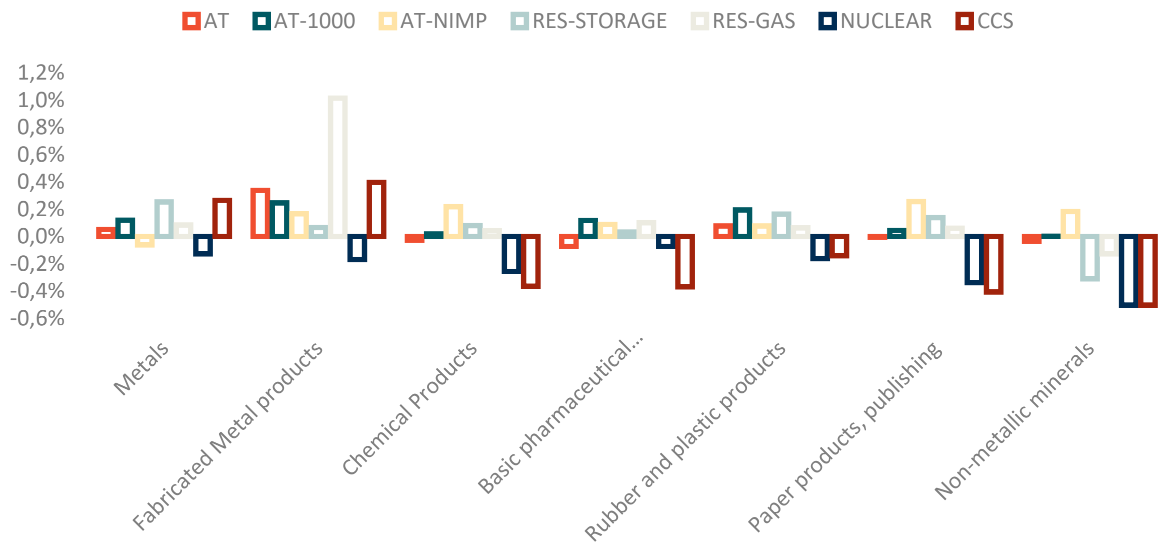
The power generation related investment mix of the AT_NIMP scenario leads to increased demand for domestically produced goods due to the increased demand for services and fabricated metal products. These increases are associated to the higher expenditures on oil-shale facilities. The higher demand for services has beneficial effects on the economy, due to its relatively high multiplier effect coupled with the relative importance of the sector for the Estonian economy. In addition to the positive impact of the investment mix, the scenario specification assumes an average decrease in electricity prices of approximately 2% which acts in favour of domestic activities, reducing production costs and providing competitiveness gains.

The RES-STORAGE scenario envisages an extensive deployment of wind coupled with additional storage facilities. Investments in wind generation are approximately 3 times higher than in the reference scenario, while investments in batteries almost double over the entire period. The additional expenditures are approximately equal to 0.97% of the cumulative (2025-2050) GDP or 2.3 times higher from the Reference case. However, the investment mix has low domestic content; benefits per euro invested are limited primarily due to the lower demand for fabricated metal products and construction and to a lesser extent due to the lower demand for market services. Demand for wind turbines increases substantially over the projected period.

The CCS scenario records small cumulative GDP losses compared to the reference case (-0.45%). These losses are driven by the higher electricity prices (+2% on average with respect to the reference case) and capital requirements (i.e., intensity) of the power generation sector. Higher demand for capital drives the economy wide capital rents higher, adding-up to the production costs increases caused by higher electricity differentials. Cost increases counterbalance the milder (to the reference) crowding out effects and the increased multiplier effect of the CCS scenario.

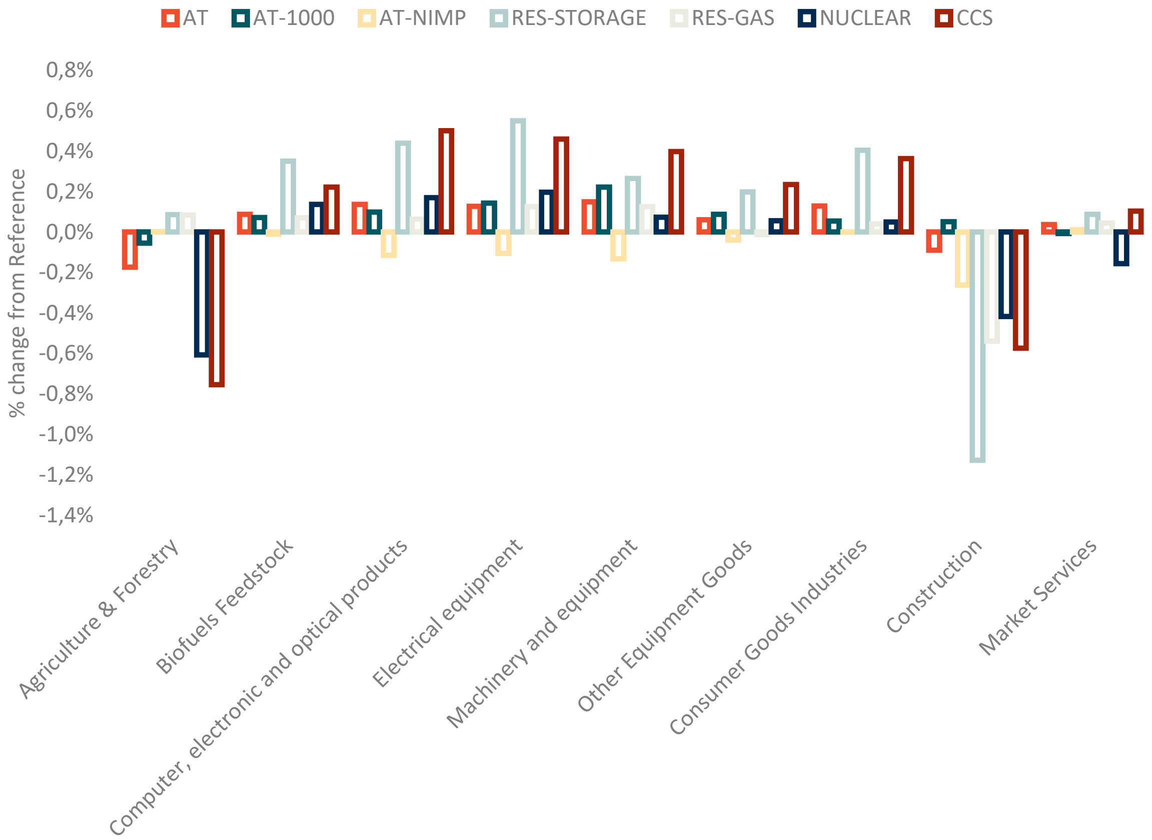
Figure 20: Impact on Sectoral Production

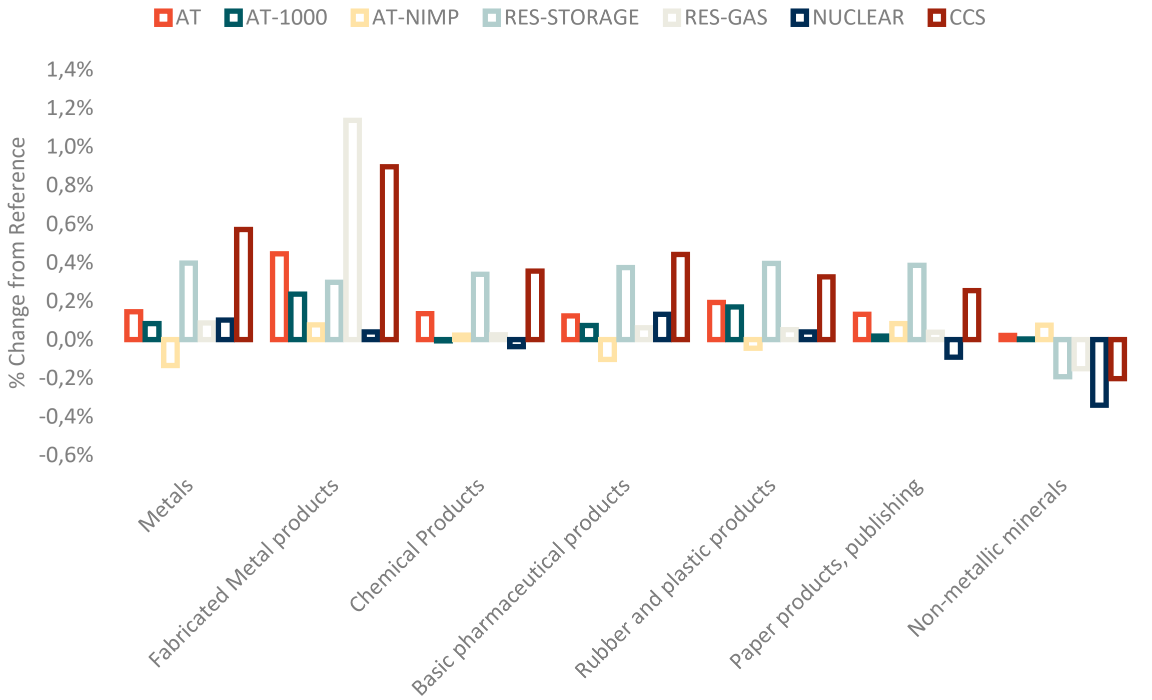




Source: GEM-E3

Figure 21: Impact on Employment





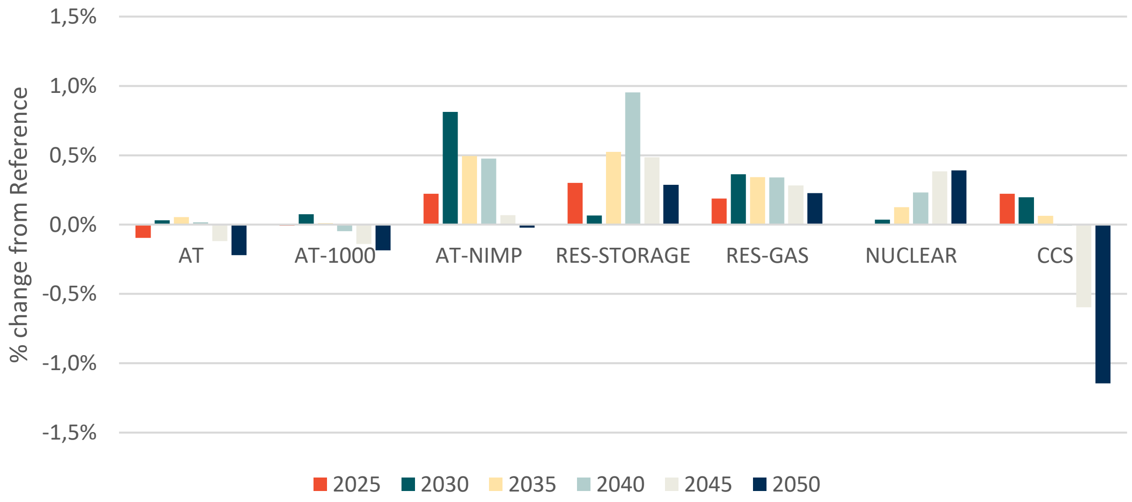
Source: GEM-E3

4.4 Distributional Implications

The distributional implications of the scenarios on different household income classes are decomposed by an income and a price effect. The income effect depends on the overall performance of the economy (whether it increases/decreases from the Reference scenario), the pattern of economic change growth (which sectors contribute to the economic change) and the impact on wages. The model has differentiated sources of income by household group according to the labour skills characteristics and occupation by economic activity. The price effect is mainly driven by the impact of electricity prices on production costs and households' consumption expenditure.

In the loan-based scenarios the impact on disposable income is small on scenarios examined (the range is +/- 1% over the 2025-2050 period). Positive effects are mainly found in the RES-Storage and RES – Gas scenarios. In the CCS scenario both the overall deceleration in economic growth and the increase in electricity & production costs reduce disposable income in the long term.

Figure 22: Impact on Disposable Income



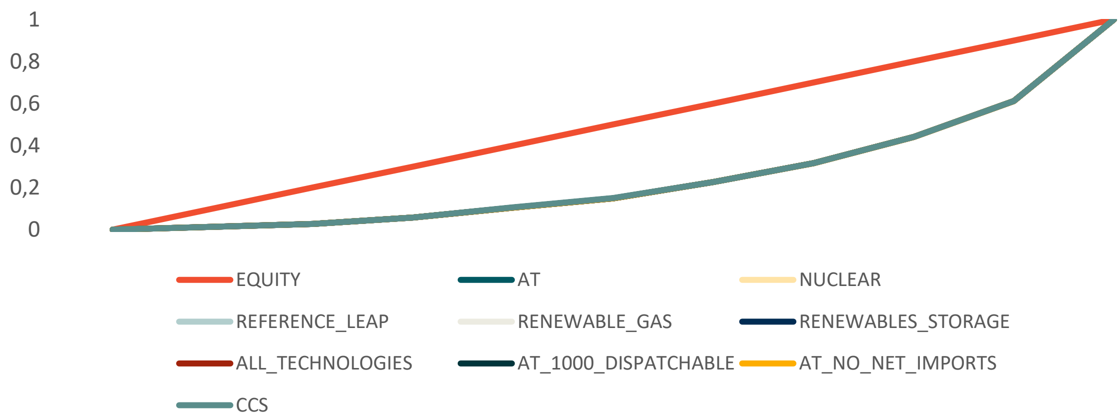
Source: GEM-E3

The impact on income distribution across the different scenarios is negligible as both the changes in prices and incomes are small (Figure 23). The changes in the Gini coefficient are negligible.

The distributional implications of the carbon neutral pathways do not alter in the self-financing case. The overall impacts on GDP are small in magnitude and the structural changes invoked by the transformation of the power generation system, specifically regarding job creation by skill type and thus income, do not alter significantly from the Reference scenario.

The alternative scenarios examined focus on the transformation of the power generation system and do not examine alternative pathways of other energy system components such as transport decarbonisation or energy efficiency in buildings. In which case, financing options could lead to different distributional impacts (e.g., financing policies/instruments could focus on alleviating the extra costs for low-income households by subsidizing expenditures in electric vehicles, renovation etc.).

Figure 23: Income distribution across income deciles



Note: The Lorenz curve for the different scenarios is almost identical and overlaps in the graph.

Source: GEM-E3

5 Comparison of scenarios

This chapter provides a brief summary comparison of the scenarios considering both the static and dynamic results and whether investments would be self or loan financed.

5.1 Impact on GDP

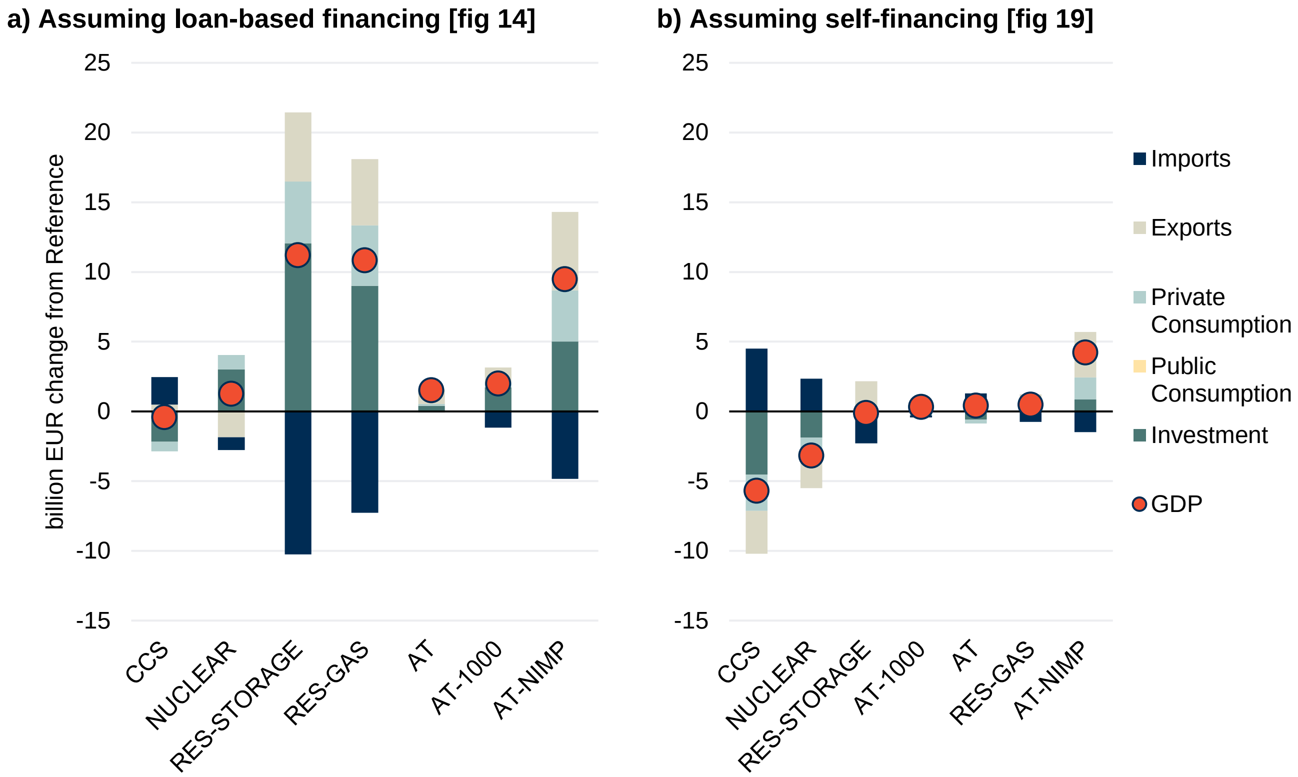
Building the power generation utilities requires the contribution of many economic activities. The extent to which investment in different power generation technologies will benefit the Estonian economy depends on i) the import dependence of the sectors providing the capital goods, ii) the output/employment multiplier of the sectors contributing to the investments, and iii) the cost of financing.

The Estonian economy imports a high share of the equipment goods that are necessary to deploy the different power generation technologies. However, there are potential benefits from the transition when shale-oil, biomass, or wind are deployed in larger shares. Shale-oil and biomass are sourced from largely domestic resources, and the country's wind production potential is more favourable compared to other renewable options such as solar PV.

Figure 24 presents the outputs of Figures 14 and 19 side-by-side to show the cumulative GDP impact and its drivers in both a loan-based and self-financing scenario. Assuming financing is loan-based, investments in power generation capacities, changing electricity prices, and resulting changes in competitiveness drive impacts on GDP. The loan-based scenarios result in higher net benefits than self-financing, highlighting the importance of financial constraints in determining the macroeconomic performance of the alternative pathways.

The figure shows that in the loan-based financing case, the RES-STORAGE, RES-GAS and AT-NIMP scenarios all generate around 10-11 billion EUR cumulative positive impact on GDP, whilst the other scenarios see only a much smaller positive impact, and even a small negative in the case of CCS. In the self-financing case the AT-NIMP scenario has the greatest positive effect on GDP of around 5 billion EUR, but most other scenarios have negligible cumulative net GPD impact, except for both the CCS and NUCLEAR scenarios which demonstrate negative impacts on GDP. A conclusion to draw from this is that the AT-NIMP scenario is highly likely to have a positive impact on GDP whichever way it is financed, the RES-STORAGE and RES-GAS scenarios can be positive, especially if loan financed, whilst the CCS, NUCLEAR, AT and AT-1000 scenarios are unlikely to have significant positive effects on GDP and the former two risk negative impacts if significant self-financing is required.

Figure 24 Cumulative impacts on drivers of GDP and on GDP compared to the reference scenario (2025-2050)



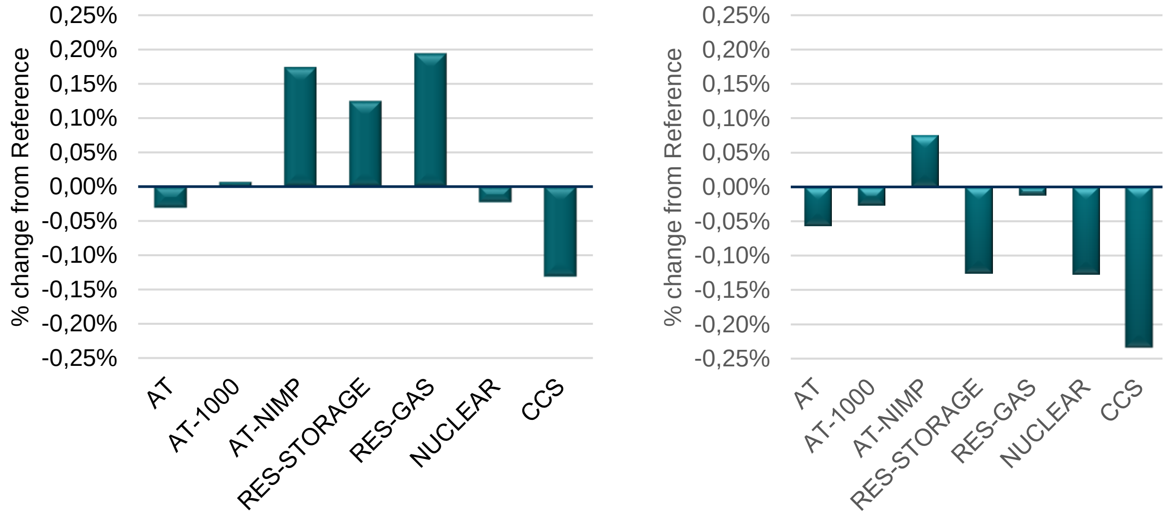
5.2 Impact on employment

In terms of employment, the comparison presented in Figure 25 shows that the highest numbers of additional jobs are generated in the Renewable Gas (RES-GAS) pathway (assuming loan-based financing) and in the All Technologies no net imports (AT-NIMP) pathway (assuming self-financing). The AT, NUCLEAR and especially CCS pathways leads to job losses under both financing options, whereas depending on the means of financing AT-1000 and RES-STORAGE can have either a positive or negative impact. On average in the RES-GAS scenario assuming loan-based financing, 1125 additional jobs are created between 2020-2050, most of which are associated with investments in the power generation and the manufacturing sectors. Assuming self-financing, the AT-NIMP pathway creates 434 additional jobs by 2050.

At a regional level, Lõuna-Eesti (in the RES-GAS scenario) and Põhja-Eesti (AT-NIMP) record the highest employment gains, while the highest employment losses in the CCS scenario are recorded in Kirde-Eesti (loan-based) and Lõuna-Eesti (assuming self-financing).

Figure 25 Impacts on aggregate employment compared to the reference scenario

a) Assuming loan-based financing [fig 16] b) Assuming self-financing



5.3 Impact on electricity prices

Changes in power generation systems leads to changes in electricity prices with respect to the reference scenario, as depicted in Table 11. Electricity prices in 2050 are lower than in the reference scenario for the No Net Imports, Renewables + storage, and All technologies pathways, but higher than the reference for all others.

Table 11 Average electricity prices (% change from the reference scenario, Estonia, 2050)

	Average price change over the simulation period
AT-NIMP	-2.26%
RES-STORAGE	-0.87%
AT	-0.64%
RES-GAS	0.40%
AT-1000	0.78%
NUC	2.03%
CCS	2.05%

Source: LEAP model D3 "Development of pathways for reaching climate-neutral electricity generation"

5.4 Impact on disposable income

Changes in disposable income correspond to aggregate-level GDP changes. Under loan-based financing, the Renewables + Storage (RES-STORAGE) scenario yields the highest impact, with cumulative disposable income increasing by 2.5 billion EUR compared to the reference case. Contrastingly, the CCS scenario leads to a marginal decrease of cumulative income. Under self-financing, the No Net Imports (AT-NIMP) pathway leads to a disposable income gain of 0.8 billion EUR, while the CCS pathway results in cumulative losses of 1.4

billion EUR over the projected period. Impacts on disposable income over time (assuming loan-based financing) were shown in Figure 22 and demonstrated only small impacts over time, the most significant variation was observed for CCS which had small positive impacts 2025-2040 but large negative impacts thereafter.

Table 12: Cumulative disposable income changes compared to the reference scenario

	Loan-based financing		Self-financing	
	Billion EUR	**%**	**Billion EUR**	**%**
AT	0.1	0.0%	-0.2	0.0%
AT-NIMP	1.9	0.4%	0.8	0.2%
AT-1000	0.0	0.0%	-0.3	-0.1%
RES-STORAGE	2.5	0.5%	-0.5	-0.1%
RES-GAS	2.2	0.5%	0.1	0.0%
NUCLEAR	1.0	0.2%	-0.2	0.0%
CCS	-0.7	-0.1%	-1.4	-0.3%

Source: GEM-E3

5.5 Summary conclusions

Across these different energy system pathways, using different modelling techniques and different assumptions on financing the following conclusions can be drawn on the socio-economic impacts of different choices.

- The financing assumption plays a crucial role in determining the socio-economic impact. In the case of closed (self-) financing the potential socio-economic benefits are much lower, and the risk of negatives much higher. To support socio-economic benefits, it is recommended to remain open to loan-based (external) financing.
- In a case where financing is open, then the RES-STORAGE, RES-GAS and AT-NIMP scenarios would deliver the most positive socio-economic impacts. The latter has the lowest positive GDP impact of the three, but a significantly more positive price impact. AT-NIMP is the least beneficial for disposable income. The RES-STORAGE pathway could offer the most positive overall balance across the socio-impacts.
- In the case of closed (self-) financing, then the RES-STORAGE and RES-GAS scenarios have little impact, but of the two the RES-GAS a marginally more positive impact, as RES-STORAGE may have negative employment impacts. The most positive overall impacts are found in the AT-NIMP pathway which could deliver small benefits to GDP, employment and disposable income.
- The AT and AT-1000 scenarios have relatively minor social impacts under all assumptions.

- The NUCLEAR scenario has relatively negative socio-economic impacts, especially on prices. In a self-financing scenario it may have small positives for GDP and disposable income but underperforms compared to most other scenarios in this setting.
- The CCS scenario has negative impacts under all indicators and in all circumstances, its only positive is providing a small boost to disposable income up to 2040, but which is lost by 2050.
- Based on these conclusions either of the RES-STORAGE, RES-GAS or AT-NIMP pathways could be recommended from a socio-economic impact perspective. A final decision between them would need to be based on the broader considerations and also the likely financing means. In the case of significant self-financing being desirable then the AT-NIMP pathway would likely emerge as the recommendation from a socio-economic perspective.

Note: The scenario results are dependent on a series of parameters such as the techno-economic characteristics of alternative power generation options (e.g., capital costs of renewables, electricity production per MW of installed capacity etc.). Sensitivity analysis of the macroeconomic implications of alternative techno-economic characteristics will be conducted in Deliverable 6

6 Links to further analyses

The analyses developed for Deliverable 4 are tested and further analysed through sensitivity analyses run in Deliverable 6.

Specifically, modelling in Deliverable 6 considers several “sensitivity scenarios” related to the pathways, which were developed in response to stakeholder comments and questions received on the Deliverable 3 outputs. The sensitivity analysis will consider how the pathway modelling outputs would change given:

- Wind variability assumed to be much higher in all pathways;
- 90% minimum utilization is assumed for the nuclear capacity in the Nuclear + renewables + storage pathway; and
- The amount of biomass that can be consumed for electricity generation is more strictly limited (leading to increased prices) in the Renewables + storage pathway or All technologies no net imports (AT-NIMP) pathway.

Socioeconomic impacts are re-calculated under these sensitivities, and changes to quantified impacts on investments, electricity prices, GDP, employment, and disposable income are assessed.

The implications of these sensitivities are presented in the Deliverable 6 report. **Finally, the socioeconomic impact assessment in the sensitivity analysis (D6) report is leading in informing the policy action plans developed for each pathway in Deliverable 7**. The action plans include recommendations on the regulatory, financial, and social instruments that can be deployed to ensure successful implementation of the pathways. Along with findings from Deliverables 3 4, 5 and 6 results from all project phases will be provided to the Ministry of Economic Affairs and Communications, to inform their decision-making on what course(s) of action should be pursued.

7 References

1. Dietzenbacher, E., & Lahr, M. (Eds.). (2004). Wassily Leontief and Input-Output Economics. Cambridge: Cambridge University Press. doi:10.1017/CBO9780511493522
2. Panagiotis Fragkos, Leonidas Paroussos, Employment creation in EU related to renewables expansion, Applied Energy, Volume 230, 2018, Pages 935-945, ISSN 0306-2619, https://doi.org/10.1016/j.apenergy.2018.09.032.
3. Capros P, Van Regemorter D, Paroussos L, Karkatsoulis P, Fragkiadakis C, Tsani S, Charalampidis I, Revesz T, authors Perry M, Abrell J, Ciscar Martinez J, Pycroft J, Saveyn B, editors. GEM-E3 Model Documentation. EUR 26034. Luxembourg (Luxembourg): Publications Office of the European Union; 2013. JRC83177

8 Annex

Table 13: % changes (from the reference scenario) in total regional production - Loan based

	CCS	NUCLEAR	RES-STORAGE	RES-GAS	AT	AT-NIMP	AT-1000
Põhja-Eesti	0.19%	0.32%	0.45%	0.89%	-0.03%	0.52%	0.18%
Lääne-Eesti	-0.23%	-1.64%	2.05%	0.86%	0.21%	0.51%	0.15%
Kesk-Eesti	-0.64%	-1.19%	1.28%	0.92%	0.03%	0.62%	0.17%
Kirde-Eesti	-0.27%	-0.64%	0.58%	0.85%	0.25%	0.99%	0.41%
Lõuna-Eesti	-0.78%	-0.13%	0.43%	1.00%	-0.16%	0.75%	0.18%

Source: GEM-E3

Table 14: % changes (from the reference scenario) in total regional employment - Loan based

	CCS	NUCLEAR	RES-STORAGE	RES-GAS	AT	AT-NIMP	AT-1000
Põhja-Eesti	0.13%	0.33%	0.01%	0.19%	-0.01%	0.17%	0.03%
Lääne-Eesti	-0.26%	-0.62%	0.55%	0.18%	0.01%	0.13%	-0.02%
Kesk-Eesti	-0.45%	-0.61%	0.35%	0.22%	-0.05%	0.16%	-0.02%
Kirde-Eesti	-0.10%	-0.12%	0.14%	0.29%	0.03%	0.41%	0.07%
Lõuna-Eesti	-0.38%	-0.17%	0.08%	0.21%	-0.09%	0.19%	-0.01%

Source: GEM-E3

Table 15: % changes (from the reference scenario) in total regional production – Self-financing

	CCS	NUCLEAR	RES-STORAGE	RES-GAS	AT	AT-NIMP	AT-1000
Põhja-Eesti	-0.26%	0.01%	-0.36%	0.09%	-0.11%	0.11%	0.03%
Lääne-Eesti	-0.69%	-1.99%	1.11%	0.00%	0.11%	0.07%	0.01%
Kesk-Eesti	-1.12%	-1.55%	0.35%	0.05%	-0.07%	0.17%	0.02%
Kirde-Eesti	-0.70%	-1.02%	-0.37%	0.01%	0.16%	0.56%	0.27%
Lõuna-Eesti	-1.23%	-0.49%	-0.50%	0.12%	-0.25%	0.30%	0.02%

Source: GEM-E3

Table 16: % changes (w.r.t the reference scenario) in total regional employment - Self-financing

	CCS	NUCLEAR	RES-STORAGE	RES-GAS	AT	AT-NIMP	AT-1000
Põhja-Eesti	0.04%	0.22%	-0.23%	0.01%	-0.03%	0.08%	0.00%
Lääne-Eesti	-0.37%	-0.73%	0.31%	-0.03%	-0.02%	0.02%	-0.06%
Kesk-Eesti	-0.58%	-0.72%	0.09%	-0.02%	-0.08%	0.05%	-0.06%
Kirde-Eesti	-0.27%	-0.28%	-0.26%	-0.04%	-0.01%	0.25%	0.02%
Lõuna-Eesti	-0.49%	-0.27%	-0.18%	0.00%	-0.12%	0.10%	-0.05%

Source: GEM-E3

Table 17: Total employment in the reference scenario

	2025	2030	2035	2040	2045	2050
Loan	597.17	593.89	587.84	577.47	566.73	554.32
Self-financing	596.42	592.67	586.77	576.48	565.41	552.83

Source: GEM-E3

Trinomics B.V.

Westersingel 34

3014 GS Rotterdam

the Netherlands