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SELECTION OF RENEWABLE ENERGY POLICY SCENARIOS. RESULTS OF THE SCENARIO ANALYSIS AND DISCUSSION

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INTRODUCTION

The European Union's Energy Roadmap concludes that decarbonisation of the energy sector is technically and economically feasible. It is important to increase the share of renewable energy and make more efficient use of all forms of primary energy resources and types of energy. In the current situation, in which energy demand and imports of fossil fuels are rising, dependence on imported energy resources is increasing. This poses a risk to the security of the energy system and the uninterrupted supply of energy if it is not possible to reach a political or economic consensus with the energy supplier. All these factors underline the importance of increasing the use of local and renewable energy sources to meet energy demand in a sustainable, economically viable and secure way.

Policy instruments for the use of renewable and local energy resources are one of the key conditions for the transition to low-carbon energy sectors, but those must be sustainable and justified. For example, support for renewable energy is currently being reviewed in many countries, given that the economic burden of the support is above the allowable limit. In turn, reduced or suspended support creates instability in renewable energy production.

The project simulates existing, planned, and potential policies to assess the best way to integrate renewable and local energy resources into the energy system by 2030 and in the long term. Policy analysis is carried out for a number of possible combinations of support measures to assess if it is possible to achieve the set targets in the National and Climate plan by 2030 and to reach Climate neutrality by 2050. Such an approach make it possible to assess the impact of existing policies that create synergies or undesirable side effects and whether they maximize the return on investment from a socio-economic and environmental point of view. The economic potential of renewable and local energy resources is presented from a resource, technology and also territorial perspective, using a geographic information system platform. In addition, a risk analysis and impact assessment of the proposed policy scenarios is carried out.

The first chapter of the report analyses the various types of barriers to the implementation of renewable energy sources, the removal of which requires the use of policy instruments. The second chapter presents three alternatives for modelling development scenarios. The third chapter presents the methodology of the integration of policy instruments into the system dynamics (SD) model, while the results of SD modelling have been presented in Section 4. The last section describes the results for assessing the environmental impact of policy scenarios and the risk assessment.

1. CHOICE OF POLICY INSTRUMENTS TO REDUCE RES BARRIERS

1.1. Definition of RES barriers

Despite the fact that the development of renewable energy technologies has been one of the most discussed and research-rich fields of science, and scientists have come up with many practical and convincing technologies in the field of renewable energy, the path taken by society to shift from the use of non-renewable energy sources to the use of renewable energy sources (RES) has often been slow and unclear. Non-renewable energy sources remain the main global energy source, as well as a major factor that contributes to high levels of carbon dioxide emissions into the atmosphere, thus serving as one of the causes of global warming. Given that the world is still dominated by non-renewable energy sources (coal, gas, oil and nuclear energy) and the associated environmental impact, greater efforts are needed to reduce dependence on these resources by increasing the use of RES.

If RES technologies have undergone so many improvements and there are a number of successful and very promising examples where the installation of RES technologies has paid off both financially and improved the environment and quality of life, the question arises as to why non-renewable energy sources still dominate or make up a very large proportion of energy production? The question arises, what is it that hinders the implementation of RES technologies (Kariuki, 2018)?

There are various obstacles to the full implementation of RES technologies, both in terms of technology and social aspects. In order to identify the main aspects that hinder the implementation of RES technologies, the following barriers are considered:

- technical barriers;
- economic and financial barriers;
- political barriers;
- social barriers;
- psychological and cultural barriers;
- geographical and ecological barriers.

1.1.1. Technical barriers

Technical barriers to the implementation of RES technologies are the insufficient current level of development of technologies and technical skills, as well as the lack of infrastructure required to support RES technologies. Technical barriers are one of the main obstacles to investing in, for example, wind power technologies. The lack of competent staff to train, maintain and operate RES technology structures, especially in regions and countries with a low level of education, is an obstacle to the development of RES.

The lack of equipment and infrastructure in electricity transmission and distribution networks, as well as the lack of necessary equipment and services within local electricity companies in most developing countries, is a major problem for RES implementation. The equipment needed in these countries is usually not readily available and needs to be imported from developed countries, so imported equipment is usually expensive, and RES generation becomes expensive or even unavailable.

Insufficient connectivity or inability to connect RES technology to the national grid is a particular barrier to the wind energy sector. In the case of wind technology, large transmission losses are often observed when energy (whether electric or mechanical) is transported from production sites to consumption sites. Wind farms are often far from populated areas, in some cases offshore. This is a deterrent to a number of investors who do not want to invest in the construction of wind farms (Kariuki, 2018; Seetharaman et al., 2019).

1.1.2. Economic and financial barriers

Probably the most obvious and widespread barrier to the implementation of RES technologies is cost. In particular, capital costs or initial investments are required, for example, for the construction and installation of solar and wind farms. As with most RES, the operating costs of solar and wind energy technologies are low – this resource is "free", and maintenance is usually minimal, so most of the costs are incurred for construction and installation.

According to data from 2017, the average annual cost of installing solar technology ranged from around 1,460 EUR per kilowatt for large-scale systems to around 1,580 EUR for private systems (International Renewable Energy Agency (IRENA), 2020). In comparison, the cost of a new natural gas plant is estimated at around 700 EUR per kilowatt. The cost of wind energy technologies, in turn, ranges from 1,070 EUR to 2,460 EUR per kilowatt. As technology advances, the price per kilowatt continues to fall and looking at the statistics for recent years. It is a clear trend that is not changing.

These dynamics of price changes can be observed in Fig. 1.1, which shows the changes in the price of one kilowatt-hour for solar and wind energy in the period from 2010 to 2023. The price per kilowatt-hour of electricity generated by onshore and offshore wind turbines has remained relatively stable over this period and has not fallen sharply, but energy prices for both solar technologies have fallen sharply. In 2010, 1 kWh of electricity produced by solar energy cost around 0.35–0.40 EUR, but according to the latest data of 2021, it costs only around 0.05–0.10 EUR. For all RES technologies, the price curve of 1 kWh is on a downward trend and is expected to remain so in the future. The forecast in the graph for the price of 1 kWh produced by offshore wind generators in 2023 should be between 0.05 and 0.10 EUR/kWh (Broom, 2020).

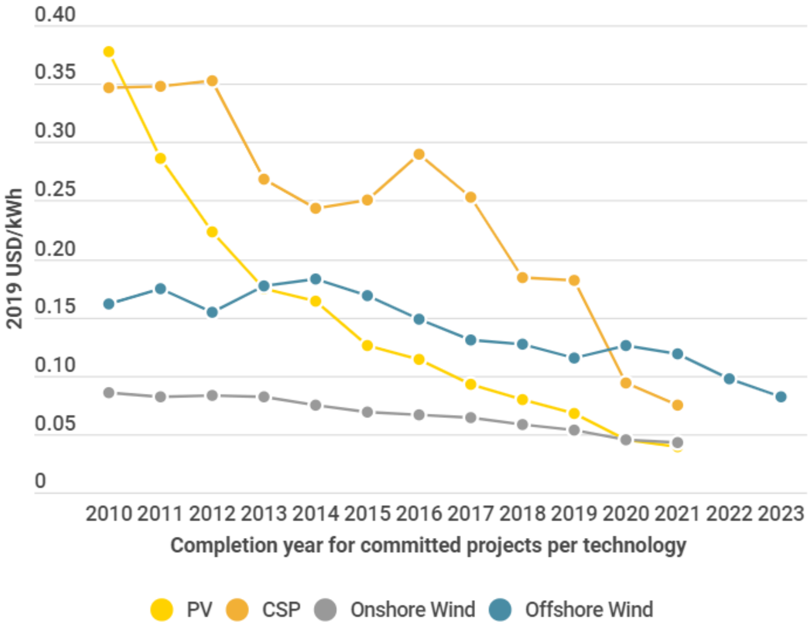

Fig. 1.1. Changes in the price of one kilowatt-hour for solar and wind energy, 2010 –2023 (Broom, 2020)

Higher construction costs may lead financial institutions to perceive loans taken for the development of RES technologies as risky, thus issuing loans at higher rates. In natural gas and other fossil fuel power plants, the costs of raw materials can be passed on to the consumer, reducing the risk associated with the initial investment. However, if the costs are taken into account during the life cycle of the project, wind and solar power plants may be the cheapest sources of energy production.

Initial capital, transaction costs, the economic situation, as well as the availability of financial incentives and subsidies are important factors that can determine the speed of the implementation of RES technologies. The initial capital costs of RES technologies are relatively high compared to fossil energy sources. As many energy producers choose to keep their initial investment costs lower while maximizing profits, high investment costs are still a major barrier to the implementation of sustainable RES technologies.

1.1.3. Political and administrative barriers

Experts in the field say that the transition to the use of RES is a political struggle and that efforts to move away from fossil fuels and decarbonise society will not be effective without destabilizing the current energy system. Despite the growing sense of urgency in the fight against climate change, the implementation of RES technologies seems to be hampered by democratic procedures. Often, local conflicts over the installation of RES technologies, especially for wind turbines, but also for solar energy installations, can delay or even stop the use of RES. Similarly, many similar conflicts have been observed historically over technologies such as hydropower and nuclear power. Therefore, this moment may seem ill-considered to call for greater public involvement in the transition to renewable energy.

However, over the past decade, RES supporters as well as social justice and environmental activists have organized a call to address the issue of energy democracy. The concept of energy democracy originated in the 1970s and 1980s. The movement sought to reconcile anti-nuclear activists and concerns about the geopolitical instability of fossil fuels with calls for action within the country and ideas for “technological democracy.” The origins of the current discourse on energy democracy can be traced back to a number of activist communities in Europe and the United States, and a clear programme for the democratic redistribution of energy has been in place for about a decade.

Compared to fossil energy resources, RES offer a number of other benefits in addition to resource switching, including the relatively free availability of RES, access to basic technologies and the modularity of these technologies. Seeing the potential of RES technologies, especially solar and wind technologies, energy democracy is focused on change in various aspects of this energy sector, including generation, transmission, financing, technology and knowledge with a view to achieving high levels of RES use (Burke & Stephens, 2018).

Another aspect that hinders the rapid increase in the capacity of RES technologies is the time-consuming process of project coordination. For example, the installation of wind turbines can take several years from the idea to the construction of the plant, as it is necessary to carry out an environmental impact assessment (EIA) and coordinate the technological solutions of the project with various stakeholders (Laflora, 2020).

1.1.4. Social, psychological and cultural barriers

The common denominator in the conversation about the social barriers to the implementation of RES technologies is people's concern about the changes in the environmental landscape when installing RES technologies. Fear of change can worsen people's quality of life. A more appropriate and useful approach would be to consider the development problems of RES technology projects as mainly social problems with technical aspects, and not the other way around. Adopting this view means focusing on social barriers as a possible main obstacle to the development of RES technologies.

For example, despite the many benefits of wind energy technologies and their rapid popularity increase in other countries in recent years, the implementation of wind energy technologies still faces social barriers. They can be divided into two main categories. The first category is general obstacles, for example, the striking and unavoidable presence of wind turbines when installed on land close to populated areas. Second, there are location-specific barriers. Although these barriers vary from place to place, depending on local natural and cultural characteristics, the most significant of these are the changes that wind turbines bring to the landscape they transform. Other objections include allegations that the turbines are noisy, that they reflect light as their blades rotate, that oil escapes from them and that the presence of a wind farm reduces the value of the land. Both of these barrier categories affect what we can expect from wind energy as one of the drivers of RES.

Developers have been forced to refine their project planning strategies, introduce new regulatory requirements, conduct more in-depth environmental impact assessments, extend project consultation periods, expand education and information programmes, as well as have been forced to suspend projects in rare cases to reduce these barriers.

These efforts on both sides can be seen as necessary steps in what will be needed for RES technologies to capture a larger share of the energy market. The emergence of additional social barriers is also likely to be inevitable, with RES technologies attracting more attention and a share of global energy (Pasqualetti, 2011).

The success of climate-friendly technologies and measures depends on their social acceptance. It is important to clearly understand the elements that influence public attitudes. The report of the POLIMP scientific project (Hofman, n.d.) identifies these elements as follows:

- Understanding of climate change and knowledge of RES technologies;
- Fairness of the decision-making process related to the RES technology project;
- A comprehensive assessment of the risks, costs and benefits of the technology;
- Local context;
- Trust in decision-makers and other stakeholders.

Table 1.1 shows an example that could help to assess the social acceptance elements of a RES project. This is just one of the ways to assess the social aspects of a project, the possibilities are very different, and the elements may vary depending on the specifics and purpose of the project. The symbol "+" in the result column of the table indicates a positive evaluation of the aspect (element), but "-" and "- -" indicate negative and strongly negative (Hofman, n.d.).

TABLE 1.1 EVALUATION OF THE SOCIAL ACCEPTANCE ELEMENTS OF THE RES PROJECT (HOFMAN, N.D.)

Element	Result	Description
Comprehension	+	In-depth understanding and organization of interest groups
Honesty	- -	Lack of honesty and transparency in the process, initially only landowners are involved in the process
Evaluation	-	There is no resistance to wind energy, but a lack of honesty in the context of transmission
Local context	--	The needs and demands of the local population and the local economy are being ignored
Confidence	-	Low confidence in the work of decision-makers

Cultural (also socio-cultural barriers) are, for example, the reluctance of households to use RES technologies for fear of their instability and inability to fully trust them as a full and stable way of obtaining energy. This barrier is one of the main problems why it is not possible to implement RES technologies in some countries. For example, general public disinterest and reluctance to engage in the development of wind power generators were identified as major social barriers to the development of renewable energy technologies in a study in the province of Saskatchewan, Canada (Richards et al., 2012).

It should also be taken into account that the lack of knowledge and awareness of RES technologies and systems among rural communities is another challenge in the development of RES. Although the situation is improving, there are still many people who do not understand the concept of renewable energy. These uneducated people in the regions are also poorly focused on the technical and environmental impacts associated with the excessive use of combustible RES. Together, these factors have slowed down the pace of RES technology infrastructure, technological knowledge development, circulation and use. For this reason, there is a need to raise awareness of renewable energy in communities and to focus on the necessary good socio-cultural practices (Kariuki, 2018).

1.1.5. Geographical and ecological barriers

The geographical location of the region and, of course, the location of the site and natural conditions can be an obstacle to the development of RES technologies. For example, the intensity of solar energy varies greatly from place to place on Earth and is one of the most important factors in the installation of solar energy technologies and the construction of solar parks. This is the reason that deters people from installing solar energy technologies, realizing that the amount of energy they produce will be very volatile (Kariuki, 2018).

Impacts on the environment, including the physical environment (for example, landscapes, protected areas, increased traffic), biodiversity, wildlife and greenhouse gas (GHG) emissions, are important factors for the technology to be socially acceptable. RES technologies are no exception.

Wind energy is one of the most controversial RES technologies, and the impact of the development of wind energy technologies on animal species and ecosystems has been the subject of several studies, in particular the potential impact of wind turbines on birds and bats. Concerns about the impact on wildlife and nature conservation are important if there is a desire to increase public acceptance of wind energy technologies.

Research on how people perceive and assess the impact of wind energy technologies on the climate and the environment needs to be complemented by how scientists and economists measure and assess the same impact. In addition, it must be borne in mind that both proponents and opponents of wind energy can hide their true motives behind a range of climate and environmental causes (Leiren et al., 2020).

One of the arguments against the installation of wind turbines is also the belief that they make a lot of noise. They make a relatively weak but characteristic noise. This is mainly caused by the turbine blades breaking the air. Noise is also generated by the turbine engine. The noise of the equipment can be tonal, which is especially annoying.

Wind turbines must comply with noise level limits n accordance with the values specified by law. Noise level limits apply to the total noise generated by all wind turbines and can be set for both slow winds when turbine noise is considered to be the most annoying and stronger winds. If the noise level does not exceed the specified limits, this does not mean that the noise is not audible. The limits have been selected so as not to cause significant interference.

It should be borne in mind that the development of wind turbines has come a long way and that noise problems have long been less relevant than in the past, although the stigma in society has remained. Modern wind turbines make significantly less noise. The noise generated by gears and the generator is reduced. Today's wind turbine engine block is soundproofed, and the generator with gears is installed to keep noise to a minimum. The blade design is also developed to reduce noise (The Danish Environmental Protection Agency, n.d.).

Another ecological aspect is related to the use of wood, which in the future will be one of the main drivers for the promotion of RES use in Latvia. On the one hand, it is positive because local bioresources are used. On the other hand, another particularly important goal of economic development is the development of the bioeconomy. The bioeconomy approach is to use bioresources in a sustainable way and to produce products and energy from bioresources through biotechnology, which have high added value and are able to replace products and energy produced from fossil resources. In this case, a dilemma arises between the demand for bioresources in energy and the bioeconomy, because, with a view to the sustainable use of bioresources, on the one hand, the use of bioresources in the energy sector must be increased and, on the other hand, bioresources must be used sustainably (Muizniece & Blumberga, 2017).

1.2. Identifying policy instruments to reduce barriers

Various support mechanisms can be implemented to reduce the above barriers. Table 1.2 lists potential policy instruments for reducing specific barriers.

TABLE 1.2 OVERVIEW OF POLICY INSTRUMENTS FOR REDUCING BARRIERS

Barriers	Policy instrument
Technical barriers	Support for science and additional research on the construction of offshore wind farms, use of hydrogen Promoting the integration of storage systems Support for the implementation of power-to-heat and power-to-gas technologies Sectoral alignment and consumer management Development of electrical networks Development of electric car charging infrastructure Biomethane infrastructure development
Economic barriers	Mandatory procurement component Subsidies for RES technologies Support for connection costs Reduced credit rates Tax rebates Raising fossil taxes
Political and economic barriers	Setting long-term RES goals at the national and local government level Support for local governments in developing energy plans Additional income for local governments where RES capacities are installed The simplified administrative process for project coordination
Social barriers	Educational campaigns EIA process facilitated Building energy communities
Geographical and ecological barriers	Identification of suitable sites for solar and wind technology deployment Evaluation of spatial plans Support for innovations to reduce environmental impact and increase technology efficiency Support for increasing the efficiency of the use of RES Assessing the risks of RES implementation and adopting appropriate measures Restrictions on the use of high-value biomass in the energy sector Restrictions on the export of bioresources

The main policy instruments for reducing technical barriers are related to support for the development of innovative RES technologies. The alignment of consumption and energy production loads has a key role to play, and the integration of storage systems, the use of surplus RES electricity in other sectors, the alignment of sectors and the promotion of consumer management should be encouraged. Support can be provided both financially to reduce the cost of these technologies and through research to raise awareness among energy producers of innovative technological solutions. An important technological barrier may be formed due to insufficient infrastructure. Therefore the development of infrastructure related to the use of RES should be promoted (promotion of the compliance of electricity network capacities, installation of electric car charging points, installation of biogas treatment plants).

In order to reduce economic barriers, the main policy instrument is financial support to cover the capital costs and connections of RES technologies or a mandatory procurement component for RES electricity. In addition, financial support can be provided for the connection of RES equipment to the electricity grid, or credit interest rates can be reduced when purchasing RES technologies. Economic barriers can also be reduced through various tax rebates, for example, a reduction in value-added tax on RES technologies or a real estate tax rebate on locations where RES technologies are installed. In turn, in order to increase the economic profitability of RES resources in relation to fossil resources, tax rates for fossil resources can be increased.

The main measure to reduce political barriers is to set long-term RES goals at the national and local government level and to follow the fulfilment of these goals, regardless of political interests. Given the important role of local governments in the development of RES, local governments should be supported in the development of energy plans in order to promote stakeholder understanding of the role of RES in the national and regional context. The experience of other countries shows that in order to motivate local governments to allow the installation of wind turbines in their territory, payments to local government budgets are increased if a wind farm is installed. Facilitating the administrative coordination process to reduce the time to install RES technologies is also important.

Public education campaigns have been identified as the main policy instrument for reducing social barriers, which would promote the understanding of all sectors about the implementation, costs and benefits of RES technologies. In order to shorten the installation time of wind farms and reduce barriers, the EIA coordination process could be facilitated or standardized. On the one hand, there would be a need for greater public involvement and information on the construction of wind farms, but on the other hand, it would be necessary to reduce the impact of unfounded public objections on the project coordination process. Another policy measure that would reduce both social and technical barriers would be both financial and administrative support for the development of energy communities.

In order to reduce geographical and ecological barriers, it is necessary to promote the efficient use of RES, for example, by promoting the increase of combustion efficiency in biomass boilers or the installation of high-efficiency solar panels. It is possible to reduce the risks associated with the installation of low-quality RES equipment by establishing an official list of specialists who have confirmed the quality of the work or by performing inspections of RES equipment. An important role in the reduction of barriers is the identification of appropriate areas that would be suitable for the location of wind farms and solar parks, as well as the marking of these places in the territorial plans of local governments. In order to promote the reduction of the environmental impact of RES technologies, it is possible to provide support for the development of innovative solutions. It is also important to define the sustainable use of biomass at the national level and to develop guidelines for the use of bioresources in local governments and companies in order to reduce the export of biomass and the use of quality wood in energy.

2. CHOICE OF SCENARIOS TO INCREASE THE SHARE OF RES

The use of a system dynamics model allows the analysis of different development scenarios using different combinations of policy instruments. In order to model the development of RES technologies, it is possible to combine various policy instruments and include different assumptions in the modelling of policy instruments in each of the scenarios.

In the modelling workshops organized within the framework of the project, the opinion was repeatedly expressed by stakeholders that it is necessary to set long-term goals until 2050 in the policy planning documents. Therefore, it is proposed to analyse two different scenarios for the period up to 2050, also identifying the values achieved in 2030.

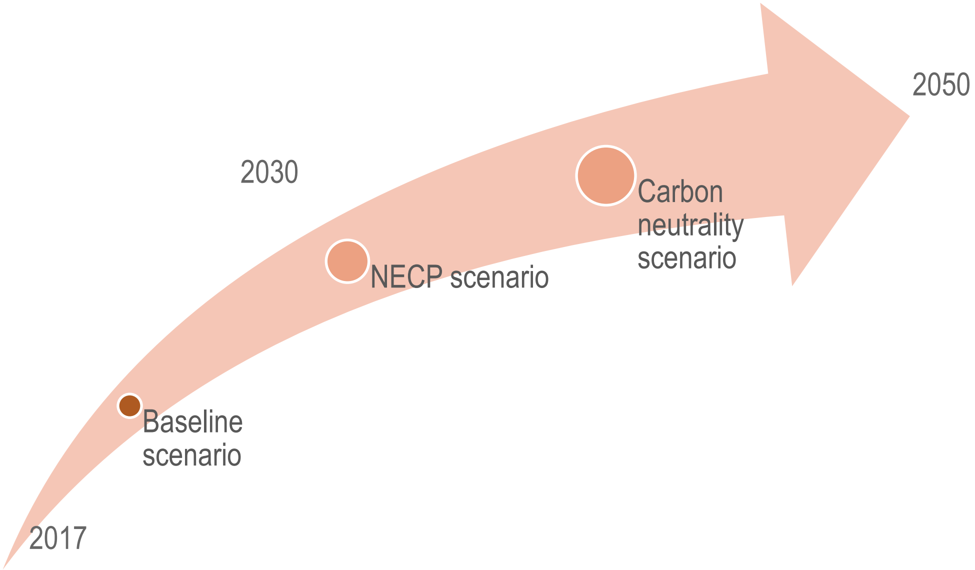

Fig. 2.1. Overview of long-term development scenarios

Within the framework of the project, three different scenarios have been modelled and compared - the Baseline Scenario, the NECP Policy Instruments Scenario for 2030 and the Climate Neutrality Scenario for 2050.

2.1. Baseline scenario

In the system dynamics model, the Baseline scenario describes the current situation without additional policy tools. The base year is 2017, so that the modelled scenarios can be compared to the current situation. The Baseline scenario includes current fossil tax rates, natural resources and CO2 emissions tax rates. The natural resources tax does not apply to the household sector. The Baseline scenario incorporates the existing regulation on the Mandatory procurement component and includes the approved subsidy amounts until 2022. The main assumptions are summarized in Table 2.1.

Table 2.1 Overview of policy measures included in the Baseline scenario

Tax rates	
Excise tax	
On natural gas in heat supply	1.65 EUR/MWh
On natural gas as fuel	9.64 EUR/MWh, but from 2021 – 1.91 EUR/MWh
On natural gas for the use in industrial production and other production-related processes, for the operation of technological equipment for the primary processing of agricultural raw materials and for the provision of the technologically necessary climate in the premises for industrial production and primary processing of agricultural raw materials	0.55 EUR/MWh
On petrol	411.21 EUR (per 1,000 litres) with a rate increase to 509 EUR (per 1,000 litres) in 2021
On diesel	332.95 EUR (per 1,000 litres) with a rate increase to 414 EUR (per 1,000 litres) in 2021
On diesel for farmers	50 EUR (per 1,000 litres) with a rate increase to 62.1 EUR (per 1,000 litres) in 2021
On liquefied petroleum gas (LPG)	161 EUR (per 1,000 kg) with rate increase to 285 EUR (per 1,000 kg) in 2021
Natural resources tax	
On CO_2 emissions	4.5 EUR per t_{CO2} with a rate increase to 15 EUR per t_{CO2} in 2022
Price of CO_2 emission allowance in the ETS sector	Adopted on the basis of the European Commission's recommendations, which forecast an increase in the price of allowances to around 50 EUR per allowance in 2040.
Vehicle operation tax	0–300 EUR/year
Subsidised electricity tax	5–15% of taxable income until the end of 2017.
Subsidies from 2017 to 2022	
For the development of district heating	49.5 MEUR
For increase in the energy efficiency of buildings	156 MEUR
For increase in the energy efficiency of the industrial sector	11.67 MEUR
For the renovation of local government buildings and transition to RES	33.8 MEUR

2.2. NECP development scenario

The first scenario envisages the inclusion of NECP (National Energy and Climate Plan) policy instruments to analyse the long-term impact of these policies until 2050. In this scenario, specific values would be assumed for the defined measures with the indicated amount of financing, and the achieved share of RES would be modelled, as well as other main indicators for comparison of scenarios. The policy measures included would be:

- Support for biogas and biomethane production, use of biomethane;
- Accelerated procedure for implementation of RES technologies (including permits);
- Support for research into innovative RES technologies and research into RES potential;
- Support for the use of RES and improvement of energy efficiency in district heating;
- Residual heat integration and temperature reduction of heating networks;
- Support for the integration of RES technologies in the industrial sector;
- Support for the use of RES and improvement of energy efficiency in local heating and individual heating;
- Support for the construction of high-capacity offshore wind farms;

- Reduced territorial restrictions for the construction of wind farms;
- Facilitated credit requirements for the use of solar energy for electricity generation;
- Extended net systems, extending it to remotely installed equipment owned by one household;
- Complete cancellation of the Mandatory procurement component for electricity stored and returned from the grid;
- Involvement of RE communities in RES support measures;
- Support for RES integration in the agricultural sector;
- Gradual increase of the natural resources tax (NRT) on both emissions of air pollutants and CO_2 emissions into the air;
- Increased CO_2 NRT rate for full capacity combustion plants where only fossil energy resources plants are re-installed;
- Gradually increased NRT rate for coal, coke and lignite;
- Differentiated rate of excise duty on fuel, taking into account CO_2 emissions capacity and created emissions of air pollutants;
- The electricity tax on electricity used in transport has been abolished – for electricity charged at public charging stations;
- Exemption of CO_2 NRT on peat fuel has been abolished;
- Information campaigns on ways to reduce the use of resources used daily, on the importance and necessity of RES and its contribution and benefits to the economy, society, nature and climate, on the principles of socially responsible use of RES;
- Information and education campaigns for local governments and planning regions, informing the population about the transition to zero-emission and low-emission vehicles.

Table 2.1 summarises the amount of funding allocated for investments in different RES technologies and additional funding for research assumed on the basis of the indicative funding specified in NECP. The supported intensity rates are assumed on the basis of the average values of similar support programmes in previous planning periods.

TABLE 2.2 MODELLED AMOUNT OF SUBSIDIES FOR DIFFERENT TECHNOLOGIES FROM 2022 TO 2030

Type of support	Support intensity	Modelled amount of subsidies, million EUR
Support for establishing offshore wind parks	50%	750
For the integration of RES into the district heating sector	40%	275
For the integration of RES into individual heating	40%	135
Support for solar electricity	40%	15
Support for research, technology development		292
Support for the purchase of zero-emission and low-emission vehicles	40%	40
Support for alternative fuel infrastructure		233
Support for development of bus fleets		50
Support for biomethane equipment		50
Support for biomethane transportation infrastructure		50
Support for new biogas plants		30

Table 2.3 summarises the information on modelled changes in fiscal policy based on the information specified in NECP. The share of tax increase is based on historical tax increases, forecasting a higher increase in excise duties on natural gas and natural resources tax and a more moderate increase in tax rates in the transport sector. In this scenario, tax rates increase until 2030.

Table 2.3 OVERVIEW OF TAX POLICY CHANGES IN THE NECP SCENARIO UNTIL 2030

Tax rates	Starting value in 2021	Growth rate, % per year
Excise tax		
On natural gas in heating, EUR/MWh	1.65	10%
On natural gas as fuel, EUR/MWh	1.91	10[1]
On natural gas for use in industrial manufacturing and other manufacturing-related processes, EUR/MWh	0.55	10%
On petrol, EUR/1000 litres	509	3%
On diesel, EUR/1000 litres	414	3%
On diesel for farmers, EUR/1000 litres	62.1	3%
On liquefied petroleum gas, EUR/1000 kg	285	3%
Natural resources tax		
On CO_2emissions, EUR/tCO2	15	10%
Price per CO_2 emission allowance in the ETS sector	22	3%

Table 2.4 summarises information and explanation of other policy instruments introduced in the NECP scenario. These policy instruments are used to reduce inconvenience costs resulting from the use of RES, to promote public awareness and to increase the economic benefits of using RES. For example, there are intentions to extend the net payment system to include legal persons and to increase the share of self-consumption electricity from installed RES power plants in individual power supply. A detailed description of the modelling of policy instruments is provided in Chapter 3 of the deliverable.

TABLE 2.4 OVERVIEW OF THE INTRODUCTION OF OTHER TYPES OF POLICIES IN THE NECP SCENARIO UNTIL 2030

Policy instrument	Description of activity
Information campaign on the use of RES in electricity and heat production	Implementing an information campaign, which reaches 70% of the target audience and reduces the inconvenience cost of RES technologies
Information campaign to increase the number of alternative fuel vehicles	Implementing an information campaign, which reaches 70% of the target audience and reduces the inconvenience cost of alternative fuels
Net payment system for RES electricity	Introduction of a net payment system for legal persons and households, increasing the share of self-produced electricity
Virtual netting	Introduction of a net payment system for households, increasing the share of self-produced electricity
Incentives for coordination of wind and solar plants	Implementing a policy for coordination of wind and solar parks, reducing the implementation time
Conversion of electricity into heat	The possibility has been included to use RES electricity surpluses in district heating using heat pumps
EV infrastructure policy	30 new EV charging stations created per year
Railway electrification	Increasing pace of freight transport using electric trains

To model the share of RES achieved in different sectors and in the country as a whole more accurately, in addition to the above-mentioned support mechanisms, policy instruments to contribute to the reduction of final consumption are modelled. The measures included are summarised in Table 2.5.

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[1] Fixed rate of 10 EUR/MWh from 2026

TABLE 2.5 OVERVIEW OF POLICY INSTRUMENTS REDUCING FINAL CONSUMPTION

Measure	Amount/type of support
Increase of energy efficiency	
in public sector	400 million EUR
in households	1,200 million EUR
in industry sector	225 million EUR
Change of mode of transport by increasing the transfer factor	From private to public transport 1.5% From buses to rail transport 1.5% From road transport to rail freight transport 1.5%

In order to reduce final consumption, financial support for improving energy efficiency in the household, public and industry sectors is included, according to the number of financial resources specified in NECP. In addition, a change in the mode of transport is being implemented through measures indicated in NECP such as improving public transport use possibility in large cities, developing the construction of car parks (Park&Ride) infrastructure, promoting railway as the backbone of a modern and environmentally friendly public transport system, etc.

2.3. Climate neutrality scenario

The second development scenario includes additional measures for the policy instruments identified in Chapter 2.2 to move towards climate neutrality in 2050. This development scenario makes it possible to identify the possibilities of completely excluding fossil energy sources by switching to RES and points to obstacles and barriers that require additional support for the measures included in NECP.

Table 2.6 summarises the total amount of funding allocated in the climate neutrality scenario until 2050. In this scenario, unlike the NECP scenario, support for integrating RES into centralised electricity production, including the construction of onshore wind parks, is provided without providing additional support for the construction of offshore wind parks. The supported intensity is maintained to the same extent as in the NECP scenario. In the Climate neutrality scenario, tax policy is maintained with the same increase as in the NECP scenario, but the rate of tax increases continues until 2050.

TABLE 2.6 MODELLED AMOUNT OF SUBSIDIES FOR DIFFERENT TECHNOLOGIES FROM 2022 TO 2050

Type of support	Support intensity	Modelled amount of subsidies, million EUR
For the integration of RES into the centralised electricity production	30%	750
For the integration of RES into the district heating sector	40%	550
For the integration of RES into individual heating	40%	405
Support for solar electricity	40%	30
Support for research, technology development		584

Funding additional to that specified in the NECP scenario is provided for increasing energy efficiency – an extra 200 million EUR in the public sector, 225 million EUR in the industrial sector and 600 million EUR in the household sector.

In addition to the measures listed in Table 2.4, the following support instruments are implemented in this simulation:

- the virtual netting system is also applied to legal persons;
- more effective information campaigns have been implemented, reaching a higher share of the target audience;
- the use of renewable electricity surpluses for the production of hydrogen for the transport sector is promoted;
- restrictions on the purchase of new cars powered by fossil fuels;
- the number of customers with an aggregator service increases, which provides a reduction in energy consumption;
- increasing rates of passenger transport using electric trains.

3. INCLUSION OF POLICY INSTRUMENTS IN THE SYSTEM DYNAMICS MODEL

In SD models, problems are managed and solved by changing inventories, and this is done by regulating flows. In SD, a policy is a set of decisions that regulate flows, reducing the difference between the desired and actual value of inventories. Decision-making requires information provided by the current values of inventories. The policy is included in the information feedback loops between flows and inventories.

Policy-making is a change in the decision-making rules governing flows, most often by creating a new feedback loop structure or modifying an existing one, strengthening the “good” loops and weakening the “bad” loops. When making a policy, the points of force are sought – parameters, a change in which changes the flow that affects inventories – a slight change in one parameter changes the whole system very significantly.

Policy implementation verification tests analyse whether the response of the real system to the policy change will coincide with the model's predicted change in system behaviour as a result of policy change. Policy implementation verification tests identify policy behaviour that has led to improved real system behaviour and analyse whether a policy found to be successful in the model also improves real system behaviour when implemented in it. When analysing possible changes in the behaviour of the system as a result of different policy actions, the plausibility of the resulting changes in behaviour should be assessed. Another type of testing is to test the response of the model to an existing policy that is used in the real system to see if the model responds to that policy in the same way as the real system has responded.

This chapter provides examples of the integration of different policy instruments into the established SD model. The modelling of policy instruments will continue in the next implementation period of the project. Therefore this chapter provides only examples of some sub-models of the SD model.

3.1. Subsidies for capital costs of RES technologies

The provision of co-financing for RES technologies reduces the total capital costs of RES technologies and is integrated into the capital cost calculation sub-model as one of the components of capital costs.

In the SD model, in order to model subsidy support, it is necessary to define two main parameters – the total available financing and the co-financing rate. Different amounts of co-financing can be modelled for the different scenarios analysed in Chapter 2.

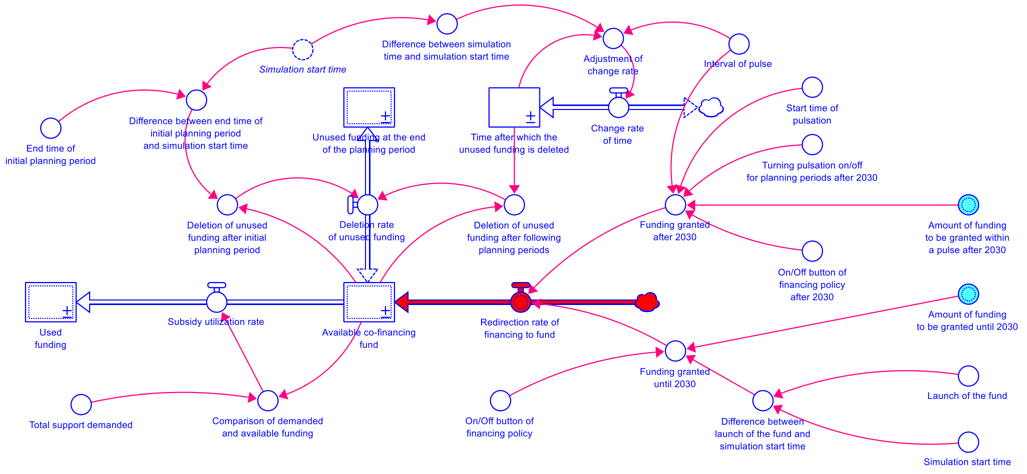


Fig. 3.1. Sub-model for defining available financing

The provision of co-financing for RES technologies depends on the amount of financing available, and Fig. 3.1 shows the structure that can be used to define the amount of financing available and to use it further in providing support.

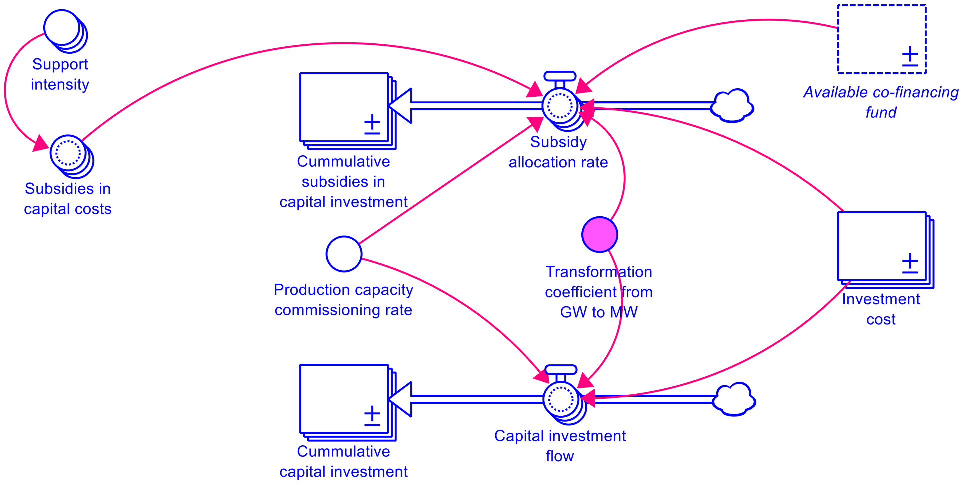


Fig. 3.2. Sub-model for determining aid intensities and calculating costs

The aid intensity indicates how much of the capital costs can be covered by the co-financing received. The structure of the model in Fig. 3.2 defines the aid intensity and, depending on the aid intensity, determines the amount of allocated aid out of the total capital costs.

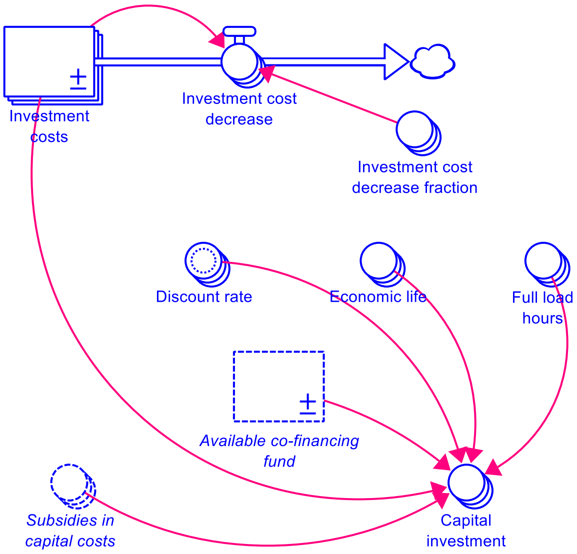


Fig. 3.3. Integration of co-financing into the SD model

When modelling the measures included in the National Energy and Climate Plan, the amount of financing is coordinated with the total financing indicated in the plan for the corresponding measures.

3.2. Changes in the tax system

In order to model changes in the tax system, changes are made to the tax rates specified in the SD model. Increasing fossil taxes increases the overall cost of fuel, making them less competitive with RES resources.

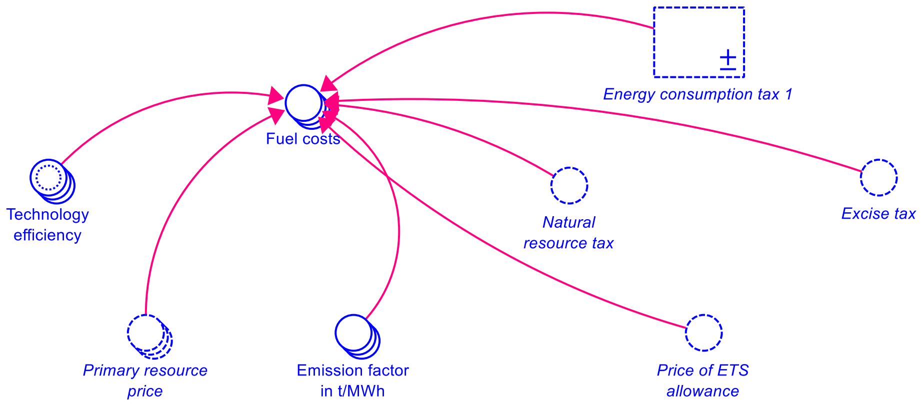


Fig. 3.4. Impact of taxes on fuel costs

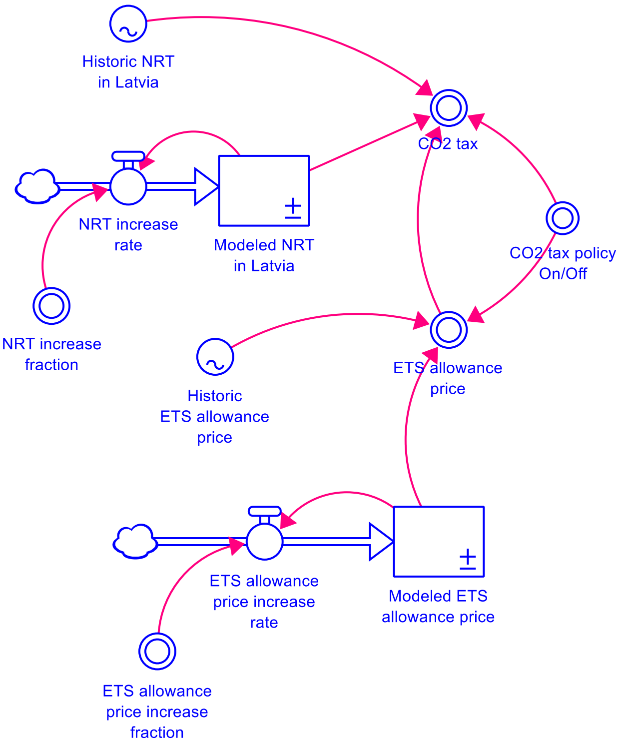


Fig. 3.5. Sub-model for calculating natural resources tax and ETS quota price

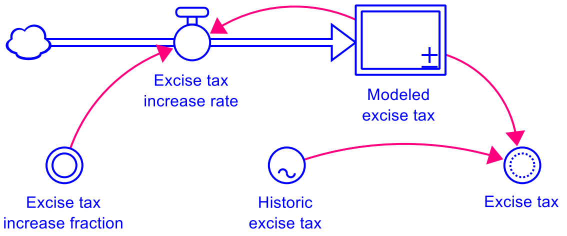


Fig. 3.6. Excise duty calculation sub-model

In the fossil fuel tax scenarios, it is possible to increase the excise tax on natural gas and the natural resources tax on CO_2 emissions. The model separately shows emissions generated under the Emissions Trading Scheme (ETS). For ETS installations, the cost of emissions is determined by the price of emission allowances. In the tax increase scenario, the natural resources tax on CO_2 emissions could be gradually increased to the level of the ETS allowance price after 2022.

3.3. Information campaign

In order to increase the pace of RES implementation, it is possible to model the deployment of an information campaign as a policy scenario. The development of an information campaign means that a wide range of high-quality information on the need for and benefits of RES is provided through various information channels, thus promoting public awareness and understanding of climate issues and the benefits of using RES.

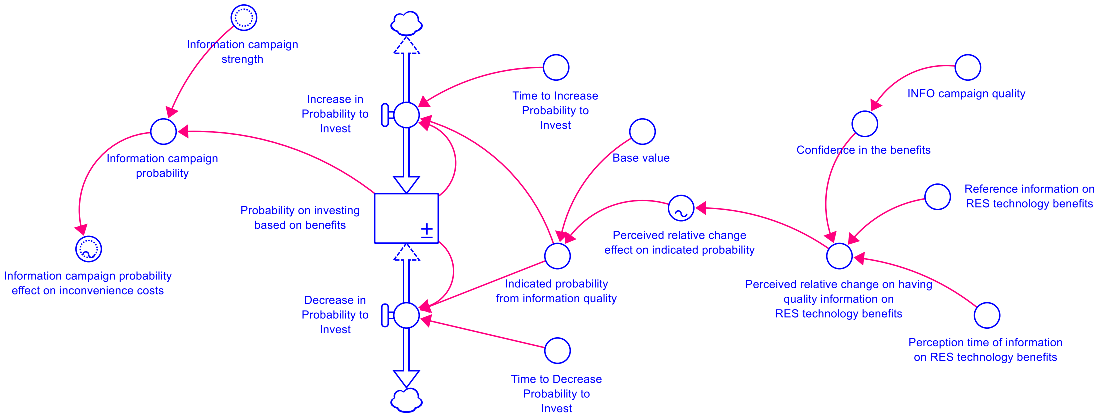


Fig. 3.7. Information campaign sub-model

The information campaign has two important parameters – the intensity of the information campaign and the quality of the information campaign – which determine how large part of the public can be reached and what the impact will be on the pace of installation of RES technologies. The intensity of the information campaign indicates how many different information channels are used (television, radio, newspapers, news portals, seminars, booklets, etc.). The quality of the information campaign indicates the quality of the information material. If the intensity of the information campaign is high and many different channels are used, but the quality of the material is low (information is general, difficult to understand, etc.), the benefits of the information campaign will also be low.

3.4. Support for RES research

In order to model the impact of research on RES development, a research sub-model is being developed. Research projects are intended for the implementation of technology development and demonstration projects to increase the share of RES in energy consumption.

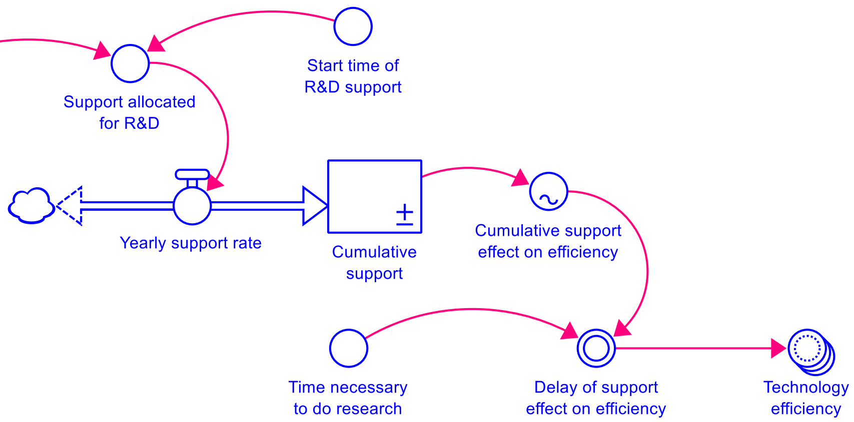


Fig. 3.8. Impact of research on technology efficiency

The implementation of research projects allows increasing the efficiency of RES technologies, as solutions for technology improvement and process optimization are sought and found. The benefits of research depend on the amount of financing available for research. The more financing is allocated, the more projects can be implemented, thus providing greater benefits. The financing allocation period is also important. The later funds are allocated to research, the later potential improvements in technology and processes will be made. It should be noted that the research process also takes time, and the results are not visible immediately after the financing is allocated.

3.5. Load shifting and aggregator modelling

When forecasting the growth of wind and solar power in electricity generation, it must be taken into account that high solar intensities and high wind speeds may result in surplus electricity generation over and above consumption demand for the period. There are several ways to use this surplus: storage in centralised storage facilities, storage in electric car batteries, export to neighbouring countries or reduction through load shifting.

A further developed SD sub-model assesses the dynamic impact of consumer management and its future role in the national energy sector. The modelling methodology is shown in Figure 3.9 by the hour. The first step consists of an analysis of the existing situation and the development of an hourly SD model. The hourly RES generation and demand sub-model is implicitly linked to the overall power system model by providing annual input data on RES generated and consumed electricity. Hourly solar and wind generation is compared to the average electricity demand profile of the residential, industrial and service sectors, identifying periods when surplus electricity is generated.

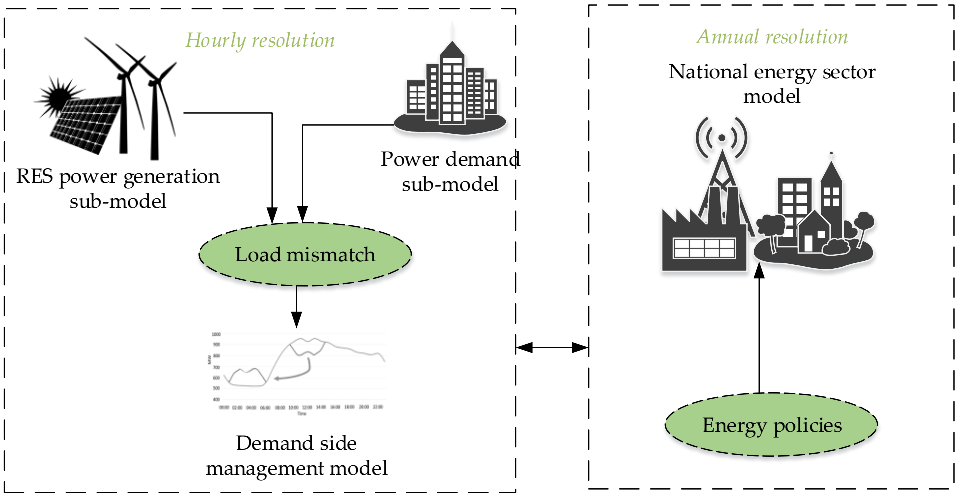


Fig.3.9. Methodology for linking the hourly and national energy model

Using an hourly SD model, load mismatch is analysed, and different scenarios are evaluated regarding energy management strategies and the role of aggregators in the energy sector. The aggregator is introduced to increase the overall flexibility of the system towards a higher share of integrated RES.

3.5.1. Modelling energy consumption and RES production

The key variable for the successful operation of the aggregator is energy consumption, so hourly electricity consumption data is used as the main input parameter to model possible load shift. The hourly consumption profile for different consumers is obtained from the Latvian electricity distribution operator AS "Sadales tīkli". The model uses average hourly electricity consumption from 70 households with total annual electricity consumption ranging from 1.8 MWh to 18 MWh per year and 50 industrial and service sector consumers in 2018. Industrial consumers are companies in the wood processing, food and other industries with annual electricity consumption ranging from 189 MWh to 8060 MWh. Consumers in the service sector include 25 different public and private companies, including banks, hospitals, shopping centres, educational buildings, etc. Annual electricity consumption in the service sector ranges from 54 MWh per year to 1972 MWh. The results obtained for electricity consumption are compared with the total electricity consumption in each sector at the national level, according to statistical data.

The RES energy production sub-model estimates the hourly energy production of wind and solar power plants based on the climatic conditions in Latvia. The solar generation figures are based on average solar irradiance data and assumptions on the average efficiency of photovoltaic panels. The model used data on average solar irradiance in 2018 from the national meteorological database. In July, the maximum hourly solar irradiance is 799 W/m^2, and the annual average solar irradiance is 1002 kWh/m^2.

The hourly wind energy production is based on the average hourly wind speed and general estimates of the technical characteristics of typical wind turbines. Hourly wind speed data from 2018 is used for the calculation. The average wind speed in Latvia at 2 m height is 3.4 m/s. As can be seen in Figure 3.10, higher wind speed fluctuations are observed in autumn and winter periods. In addition, restrictions have been added for hours above 6 m/s wind speed, as wind turbines have to be stopped to prevent unnecessary loading of the rotors.

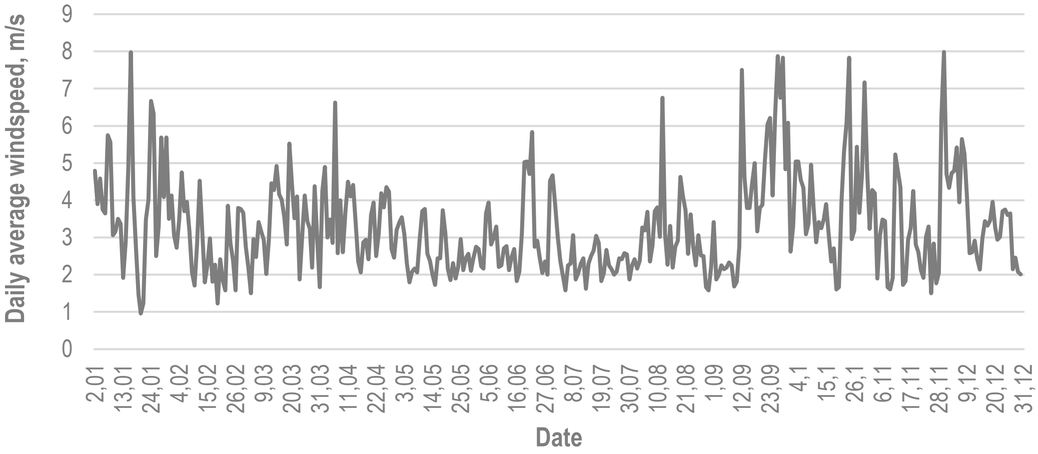


Fig.3.10. Wind speed measurements per hour

The main technical assumptions for the calculation of RES are summarised in Table 3.2, based on average values from technical catalogues of different technologies. Based on the specifications of ongoing development projects in Latvia, it was assumed that wind turbines with a height of 70 m and a rotor diameter of 60 m would be the most common solution.

TABLE 3.2 KEY TECHNICAL ASSUMPTIONS FOR RES TECHNOLOGIES

Parameters	Assumptions
PV efficiency, η_{PV}	0.18
Power factor, C_f	0.4
Productivity ratio, η	0.4
Rotor diameter, m	60
Wind turbine height,m	70
Height for wind speed measurements,m	2.5
Length of roughness, m	0.15

The total area of installed solar panels and wind turbines is calculated based on the projected RES capacity of the country.

3.5.2. Consumption management and aggregator modelling

Demand-side management has been introduced to align the RES power production and power consumption profiles. Within the research, two different types of aggregators and demand-side management mechanisms have been tested and compared:

- Load aggregator to balance the power load by shifting peak load to the night hours – Aggregator (Hours);
- A flexibility aggregator to decrease the RES surplus power is occurring by shifting the power load to the periods with higher RES production rates –Aggregator (RES).

For each type of aggregator, different approaches have been used for demand-side management.

The load aggregator submodel (Aggregator Hours) has been shown in Fig.3.11., in which the shifted load has been calculated by considering the hourly power consumption differences and potential for power increase or decrease.

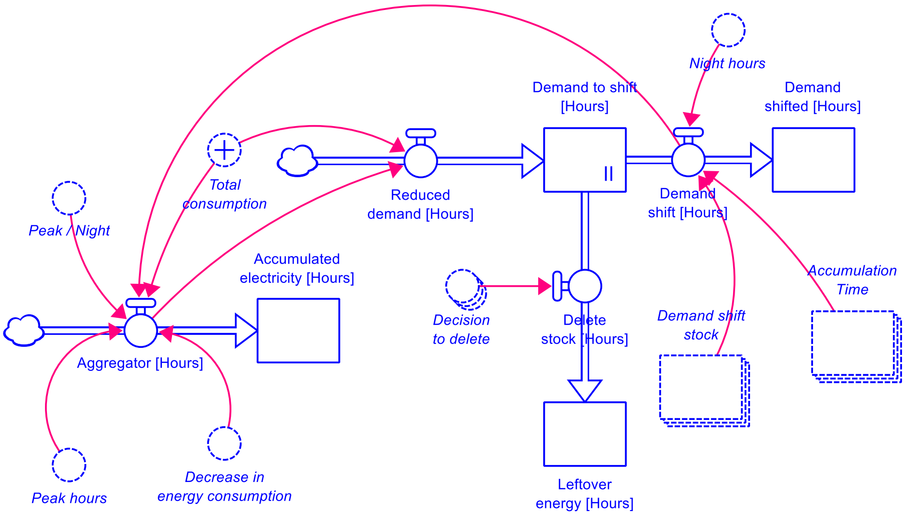


Fig.3.11. Load shifting sub-model for Aggregator (Hours)

The potential aggregated and shifted power consumption is determined by analysing power consumption in particular periods. In addition, the peak-to-night ratio is introduced to shift electricity from peak hours to night hours in the Aggregator (Hours) scenario. Finally, the shifted power flow "Aggregator (Hours)" is determined by calculating the potential aggregated amount of power.

The power consumption decrease rate depends on the share of power consumption that can be shifted, expresses what part of the total electricity consumption can be reduced, and the share of aggregator customers. The higher the share of aggregator customers, the more significant reduction of electricity consumption can be achieved. The study assumes that the 10% of total power consumption could be shifted to another period which is determined according to previous studies of several authors (Corradi et al., 2013; Ruiz et al., 2009).

The share of aggregators' customers in the variable and calculated, depending on how much electricity can be reduced and shifted. Two stocks, "Installed capacity without aggregator service" and "Installed capacity with aggregator service", are considered. Exceeding the 50% share of aggregator customers reduces the growth rate because acquiring new customers for the aggregator service is more complicated. In addition, there is a limiting parameter, "Boundary fraction", which determines how many customers of all can connect to the aggregator service.

In addition to the potential to shift the power demand, there is also an outgoing flow for deleting the shifted power consumption because of the assumption that electricity can only be shifted within 12 hour period. Therefore, before the start of the peak hour, the shifted stock is cleared and has a value of zero.

The flexibility aggregator sub-model (Aggregator (RES)) has a similar operating structure as the Aggregator (Hours) sub-model (see Fig.3.12.).

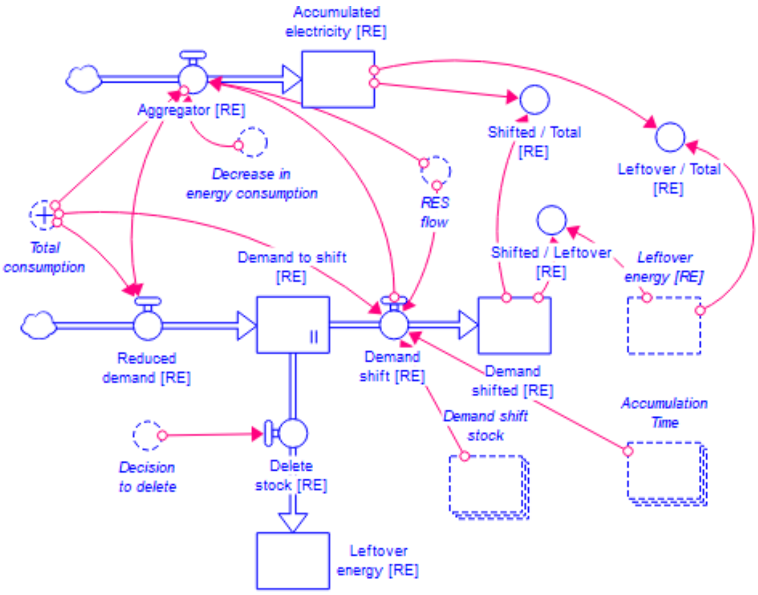


Fig. 3.12. Load shifting sub-model for flexibility aggregator

The main difference is that the power load is shifted based on the available RES energy flow or how much electricity was produced from RES each hour. Therefore, when the amount of RES produced is higher than the electricity consumption, the electricity consumption is increased by the same rate as the power reduction rate described previously.

In the last part of the modelling, the production and consumption sub-model is compared to assess the impact of different RES production and demand management options on the RES energy surplus.

3.6. Use of surplus electricity in the district heating

When forecasting an increase in wind and solar energy production, it should be taken into account that in the cases of high solar intensity and high wind speed, a surplus of electricity produced in excess of the consumption demand of the respective period may occur. There are several ways to use this surplus – to accumulate in centralized storage facilities, to accumulate in electric car batteries, to sell to neighbouring countries

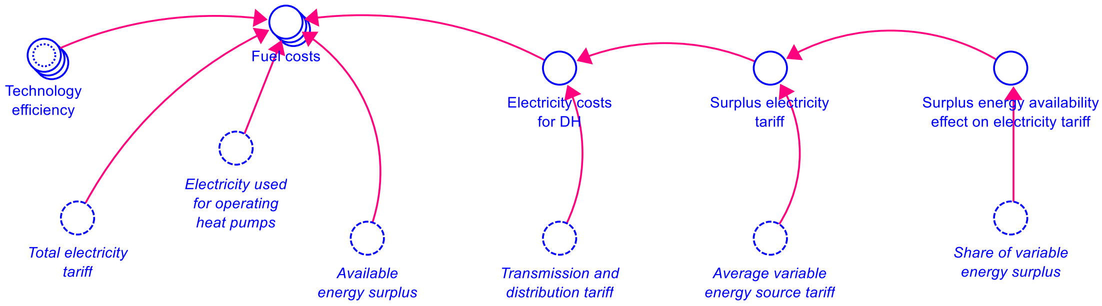


Fig. 3.13. Sub-model for the use of surplus electricity

Another possibility is to convert this surplus electricity into other forms of energy. One of the options is to convert surplus electricity into heat in district heating companies. The generation of surplus electricity means that there is nowhere to use the relevant amount of energy in a given period of time, which contributes to lower electricity prices, and it is possible to convert this cheaper energy into heat in a cost-effective way. The reduced price of electricity reduces the energy costs required to operate electric boilers and heat pumps, making it an economically viable alternative to biomass and natural gas heat production facilities in periods with significant renewable electricity surpluses.

3.7. Implementation of the NET system and virtual netting

NET system and virtual netting, as well as micro-generation sub-models, are created to model micro-generation development. Implementation of the NET system changes how the grid-connected prosumers are paying for the electricity. Without a NET system, full electricity tariff is applied to the electricity that is sent to the grid and later received back, while with a NET system, full electricity tariff must be paid only for the difference between electricity sent to the grid and received back if electricity amount taken from the grid exceeds the amount of electricity sent to the grid. Only connection fee and fixed MP component according to the connection capacity must be paid in case of additional electricity from the grid is not necessary. NECP and climate neutrality scenarios intend to cancel the MPC payment in full for accumulated electricity which is sent and later taken back frog the grid.

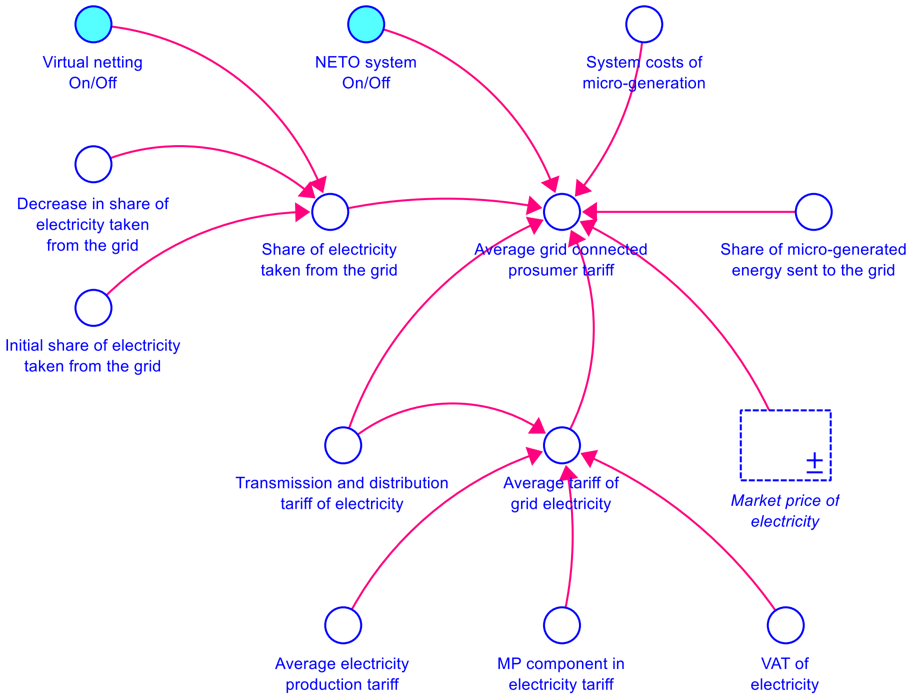


Fig. 3.14. Sub-model of the NET system and virtual netting

Virtual netting provides that electricity generated in one property can be used to cover the electricity demand of different properties. For example, electricity generated by a micro-generation system installed on a remote location (e.g. country house) can also be used to cover the electricity demand of city apartments by the same owner. Virtual netting would allow decreasing the share of electricity that is taken from the grid and not obtained by micro-generation units.

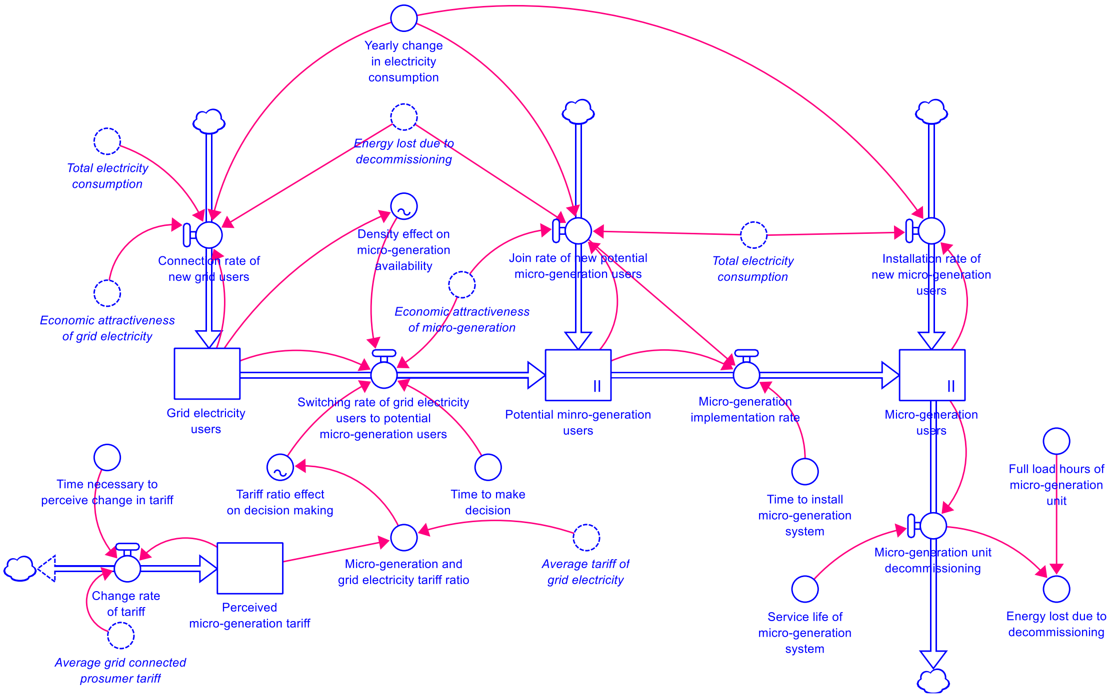


Fig. 3.15. Sub-model of micro-generation implementation

Implementation of the NET system and virtual netting would increase the attractiveness of micro-generation. It would allow more property owners to make a decision towards installing micro-generation systems. In the NECP scenario, implementation of the NET system will be extended to include also legal persons, but in the climate neutrality scenario also virtual netting will be extended to include legal persons.

3.8. Railway electrification

Electrification is one of the development routes for the railway. Both in NECP and in climate neutrality scenarios, the electrification of the railway is included as one of the policy measures to increase renewable energy share in the transport sector. Electrification of railway consists of two parts -electrification of railway infrastructure and electrification of trains. Electrification of railway lines is important because without electrified lines switching from diesel-fueled trains to electric trains is impossible. The share of electrified lines is one of the limiting factors for train electrification, setting the limit on how high the electric train share can be reached.

Railway line electrification consists of two stages – period until 2030, in which the total length of lines to be electrified is taken from NECP scenario, and the period after 2030, in which additional railway line electrification is considered in climate neutrality scenario.

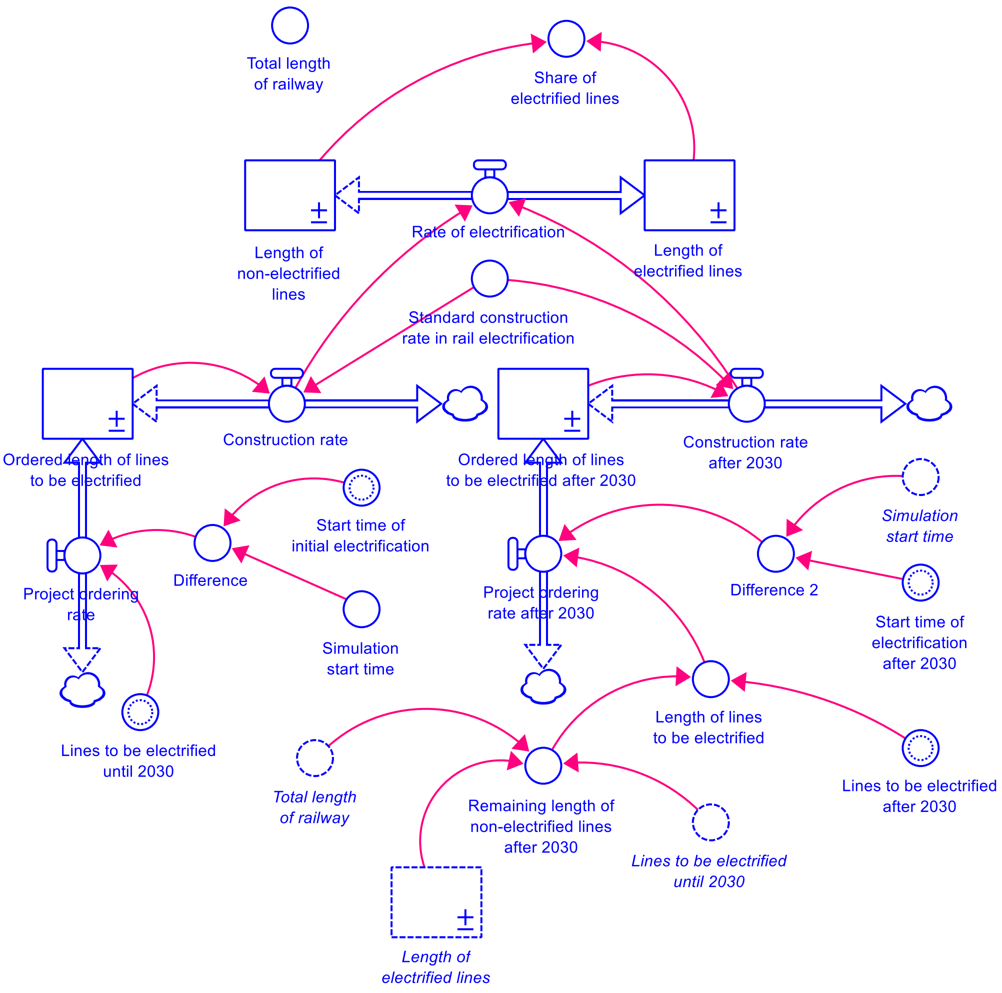


Fig. 3.16. Sub-model of railway line electrification

The model allows choosing the rate of train electrification; however, electrification of trains can happen only when sufficient length of railway lines are electrified. Freight and passenger train electrification is modelled separately.

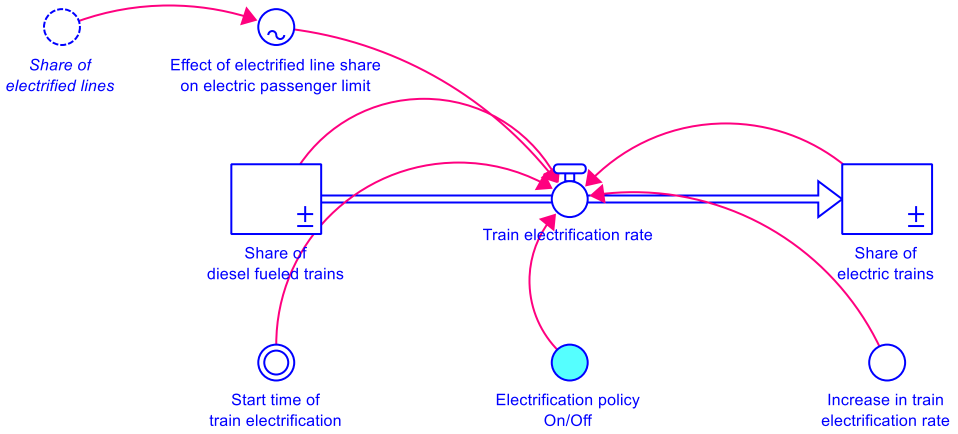


Fig. 3.17. Sub-model of train electrification

3.9. Simplification of solar and wind farm implementation procedure

The current coordination procedure of obtaining permits for the installation of renewable energy production technology is complicated and time-consuming. It may take from 5 to 10 years to get from the idea to the realization of the project. The duration is too long to attract potential investors to the project. This means that the procedure of obtaining permits must be simplified in order to allow the quicker realization of the projects. Procedure simplification policy is incorporated in the model in a manner, which decreases the project ordering time based on policy intensity. This allows arriving quicker from the idea to the project realization.

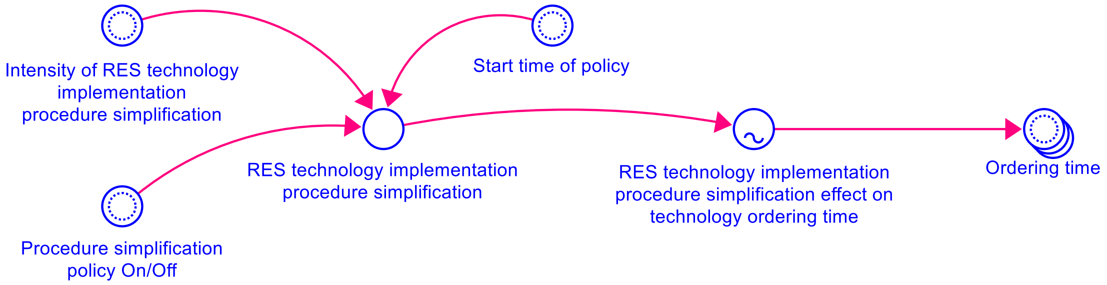


Fig. 3.18. Sub-model for simplification of solar and wind farm implementation procedures

3.10. Various transport policies

This section displays various transport policies incorporated in the model. One of the policies is purchase restrictions put on fossil-fueled vehicles. The way on how policy works is simple – a specific point in time is set after which the trading and purchasing of fossil-fueled vehicles is prohibited. This policy is included in the climate neutrality scenario, and the time after which the trading and purchasing of fossil-fueled vehicles are prohibited is set to 2030. No more diesel, gasoline and petroleum gas-fueled cars will be available when purchasing new vehicles. Restriction policy applies only to the new vehicle market, while exploitation of existing fossil-fueled vehicles will still be allowed. The restriction does not apply to the used vehicle market.

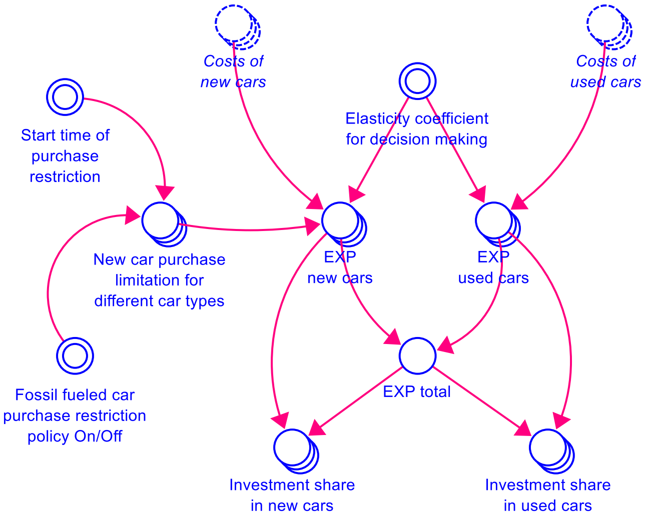


Fig. 3.19. Sub-model of the fossil-fueled vehicle restriction policy

Changing the way on how people move around and what means of transportation they are choosing is the path to a significant reduction in energy consumption. In the current situation, there is a very high share of private transport exploitation. Therefore private transport also contributes a lot to total transport energy consumption. It is common practice for only one or two people to share a car at the same time, which results in many vehicles on the street. This results in congestions, lost time, increased fuel consumption and lower air quality in the cities. All of these problems could be solved by relocating part of the private transport users to the public transport. One public transport can replace from 20 to 50 private vehicles. It would decrease the formation of congestions and also would allow decreasing the total energy consumption. The attractiveness of public transport must be increased, and the attractiveness of private transport decreased in order to stimulate the transition from private to public transport. Policy in the model allows regulating the rate at which the transition from private to public transport occurs.

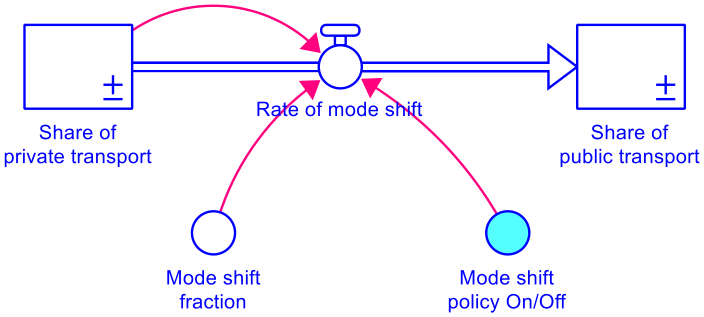


Fig. 3.20. Sub-model of mode shift

Promotion of other mode shifts also benefits compared to the current situation similar on how the switching from private to public transport benefits in decreasing the total energy consumption. Not only transition from private to public transport but also transition from one means of public transport to the other is incorporated in the model—for example, the transition from public road transport to the railway. A similar principle is used for freight transport. The transition from road freight transport to railway would allow increasing transportation efficiency in terms of energy consumption when transporting large volumes of cargo. Moderate mode shift values are chosen for the scenarios. Moderate values are chosen because, due to different circumstances, for some modes, the complete shift is not possible, and even a small faction is challenging.

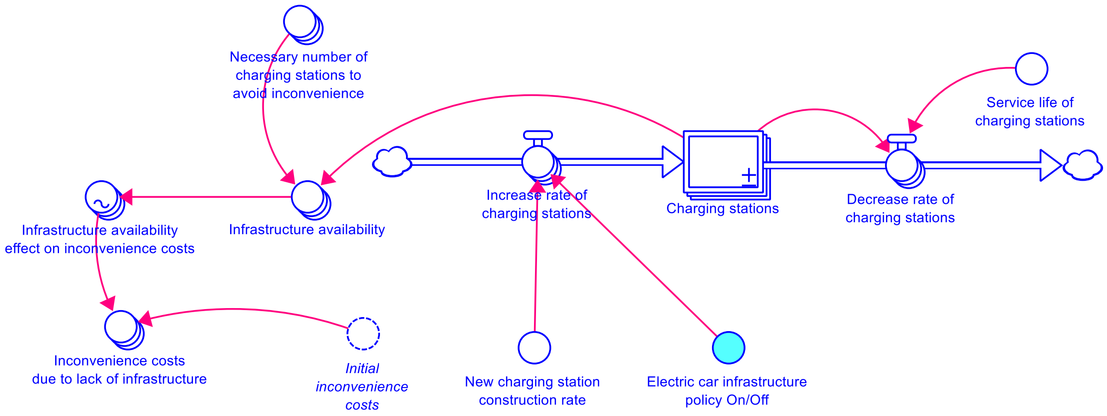


Fig. 3.21. Sub-model of electric vehicle infrastructure development

Infrastructure availability is a significant aspect of electric vehicles and other alternative fuel vehicle development. Lack of charging stations for electric vehicles or refuelling stations for hydrogen vehicles severely reduces the chance of a rapid increase in electric and hydrogen vehicle purchase numbers. Lack of infrastructure poses an inconvenience for potential users of alternative fuel vehicles. If the inconvenience is too high, potential users of alternative fuel vehicles will select the vehicles or transportation means which poses less inconvenience. The policy of infrastructure development allows increasing the development rate of the infrastructure in the model. This can be done by selecting the number of new charging stations or refuelling stations for alternative fuels installed annually.

4. RESULTS OF MODELLING POLICY INSTRUMENTS

This chapter summarises the results of the SD modelling on an hourly basis (Chapter 4.1) to assess electricity generation in the highly variable RES scenarios and on an annual basis (Chapter 4.2) to compare long-term projections in the NECP and Climate Neutrality scenarios.

4.1. Results of the modelling of hourly electricity consumption

As described in Section 3.5., four different power capacities of variable RES (VRES) combinations were analysed. Figure 4.1. presents the annual accumulated power production rate for different installed VRE capacities based on the national SD model to forecast the future trends of RES technologies installation. Scenario 1 shows the existing situation without solar electricity production and a small amount of wind power, which reaches only 160 MWh. In Scenario 2, when installed solar plant capacity reaches 100 MW, but the capacity of wind farms is 500 MW, the total solar power production is almost 100 MWh per year, but accumulated wind power reaches 1042 MWh per year. This amount is almost doubled in Scenario 3 with additional support policies for wind and solar plants, with total accumulated solar power of 148 MWh and 2008 MWh of wind power. Finally, the increase of solar power production rates is simulated in Scenario 4 when installed solar power capacity reaches 964 MW and produces 948 MWh per year, but the wind power plants provide only 310 MWh of electricity.

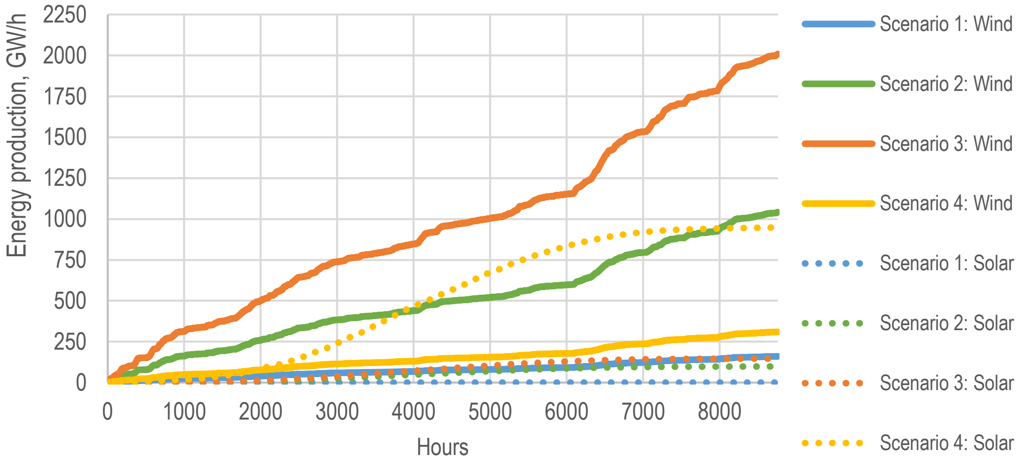


Fig. 4.1. Annual accumulated VRE electricity production for different scenario

The production includes the hydropower plants with a nominal capacity of 1000 MW and the base-load provided by biomass cogeneration plants (30 MW) to present the national energy balance accurately. Thus, hydro generation hourly and baseload profiles are constant in all scenarios, and only solar and wind profiles change based on installed capacities.

In addition, the surplus electricity generated is analysed. Scenario 1 has only a few hours when production exceeds consumption, while Scenarios 2 and 3 generate significantly more surplus electricity. Figure 4.2 shows the accumulated surplus to estimate the amount of energy that needs to be stored or otherwise disposed of during the year. Scenario 3 shows the largest surplus of electricity generated, over 600 000 MWh per year.

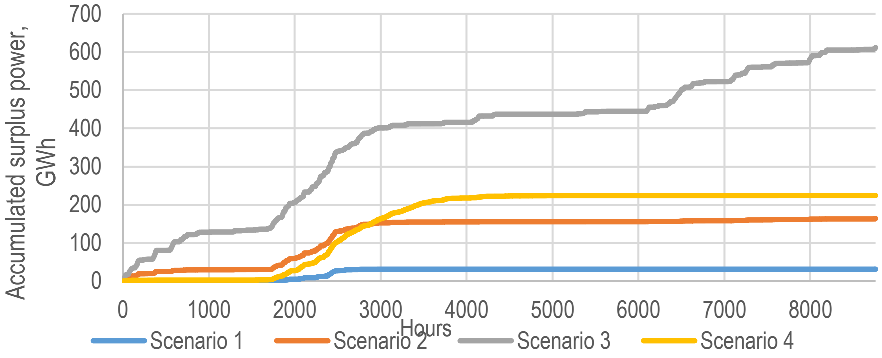


Fig. 4.2. Accumulated surplus power

In the case of low installed capacity, only a small amount of surplus power occurs. For example, in Scenario 1, only around 6 % of total electricity produced from RES (excluding hydro energy) cannot be consumed immediately. However, in Scenario 3, this number increases to 30 % from total energy produced from RES. These results are in line with similar previous research, where Andresen (Andresen et al., 2014) have analysed the impact on high shares of installed wind and solar power capacities. In the case of 100% of wind power scenario, 30% of surplus power occurs. However, the surplus power for low solar and wind capacities are insignificant.

One of the solutions to reduce the surplus electricity generated is the introduction of demand-side management and load shifting. As described in Section 3.5, the implementation of two types of load shifters and aggregators is analysed. An hourly shift aggregator smooths the electricity consumption load by shifting consumption during peak hours to hours during the night, while a RES aggregator shifts the energy consumption load to hours with higher RES electricity generation. An example of the change in electricity consumption because of the introduction of two different types of aggregators is shown in Figure 4.3. The graph shows the total amount of electricity produced by RES and the total electricity consumption for two weeks in the month of March. As can be seen in the case of RES aggregator deployment, electricity consumption is shifted to periods with higher solar and wind generation rates. On the contrary, when the hourly shifting aggregator is in operation, the maximum energy consumption is reduced, but this does not correspond to periods of RES production

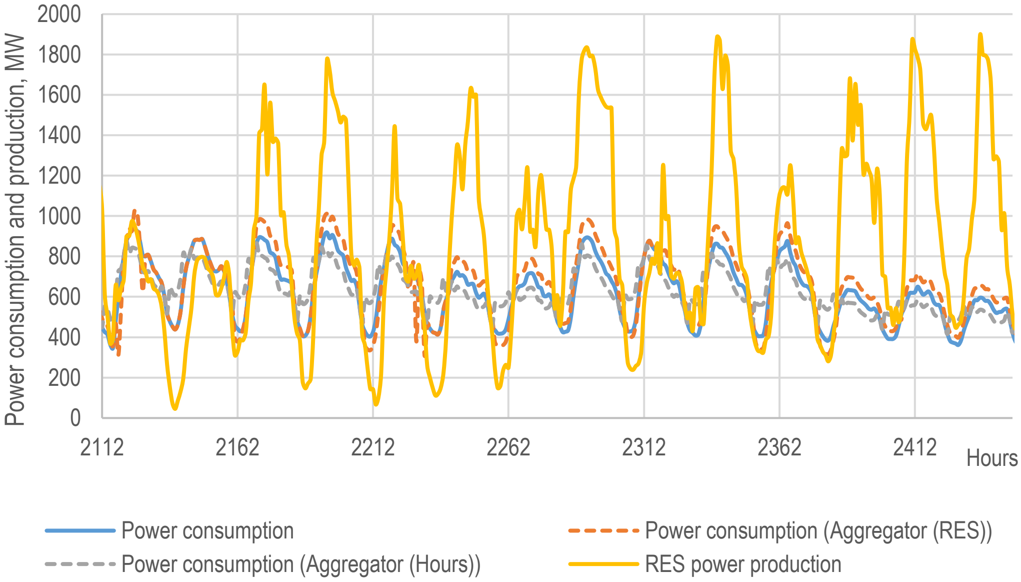


Fig. 4.3. Example of power consumption shift in different Aggregator types for Scenario 3 when all of the consumers use aggregator services

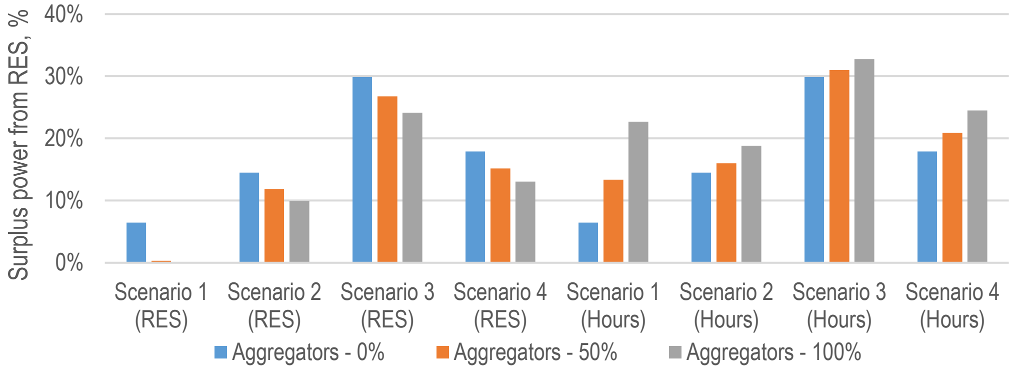


Fig. 4.4. RES surplus power and RES capacity ratio for different aggregator scenarios

The results also depend on the overall share of consumers using the aggregator's services. Therefore, in Figure 4.4, several shares of connected consumers are examined. The percentages reflect the level of aggregator diffusion in the system. For example, 0% means that no consumers use the load-shifting service, while 100% means that all eligible consumers use the aggregator services. From Figure 4.4, it can be seen that when load shifting is introduced according to the available RES electricity, in Scenario 3, the excess capacity decreases from 30% to 24% when all consumers change their consumption behaviour with the help of an aggregator. However, it should be noted that the power surplus increases when switching the load from peak hours to night hours without taking into account the availability of RES. The highest increase from 6% to 23% is in Scenario 1, while in Scenario 3, the electricity surplus could increase by 3% if the consumption load is smoothed. On the other hand, the smoothed electricity load can benefit from reduced installed capacity and primary energy savings when operating at nominal load conditions.

4.2. Scenario modelling results

This chapter shows the modelling results for the scenarios described in Chapter 2, taking into account the hourly modelling results described above. Scenario comparisons are provided for the Latvian scale, but individual parameters are also shown by regions to provide more detailed insight into the development of the energy industry in each of them.

4.2.1. Overall sector indicators

Figure 4.5 shows that compared to the baseline scenario, both the NECP and climate neutrality scenarios show a reduction in total energy consumption. NECP policy measures allow for a significant reduction in energy consumption, but the additional measures and funding included in the climate neutrality scenario are essential to reduce energy consumption even further. In the NECP scenario, total energy consumption reduces by 9.7% compared to the Baseline scenario, while in the Climate neutrality scenario – even by 16.6%.

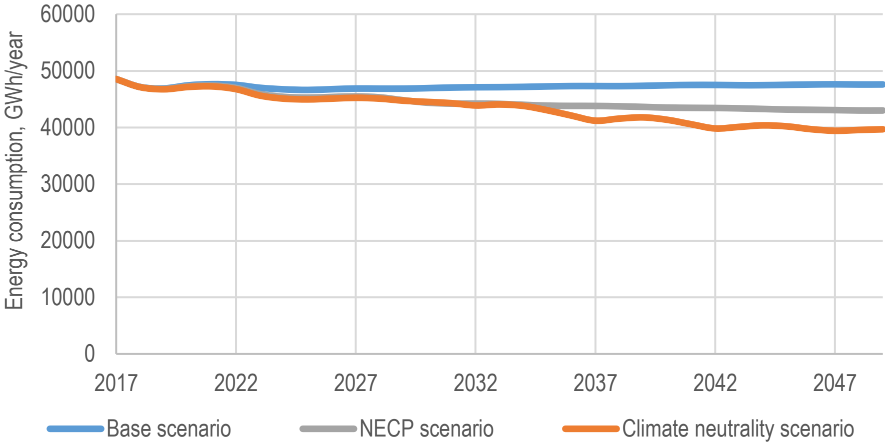
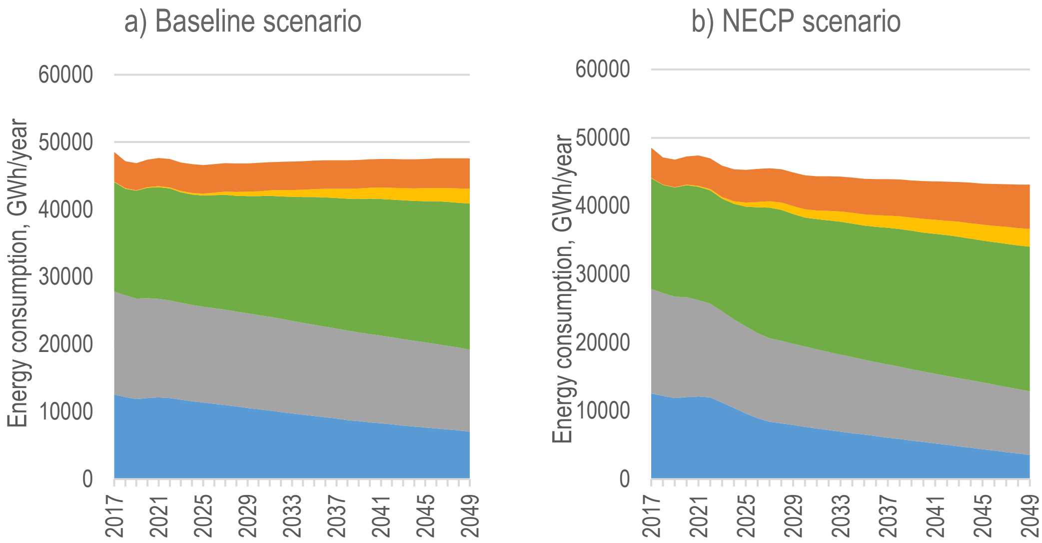


Fig.4.5. Total energy consumption in different scenarios

When looking at the overall energy consumption by resources, a significant reduction in the use of natural gas and other fossil resource is seen, while an increase is observed in the use of solar and other RES (see Figure 4.6). Compared to the baseline scenario, natural gas consumption decreased by 50.4% in the NECP scenario and by 92% in the climate neutrality scenario. The reduction in other fossil resources is significantly smaller – 23.3% and 44.3% in the NECP and climate neutrality scenario compared to the baseline scenario. This is mainly due to the use of fossil resources in the transport sector, where the reduction is more difficult to achieve. Policy scenarios show a negligible reduction in the use of biomass, while the use of solar and other renewable sources increases significantly. If the NECP scenario shows an increase of 14.1% in the use of solar energy against the baseline scenario, the increase in the climate neutrality scenario is already 128.2%. Solar energy includes solar energy from both the heating and electricity supply sectors. There is also a significant increase in the use of other RES. Compared to the baseline scenario, the NECP scenario shows that the growth of other RES reaches 44.1%, while in the climate neutrality scenario, it is already 100.1%.



a) Baseline scenario

b) NECP scenario

c) Climate neutrality scenario

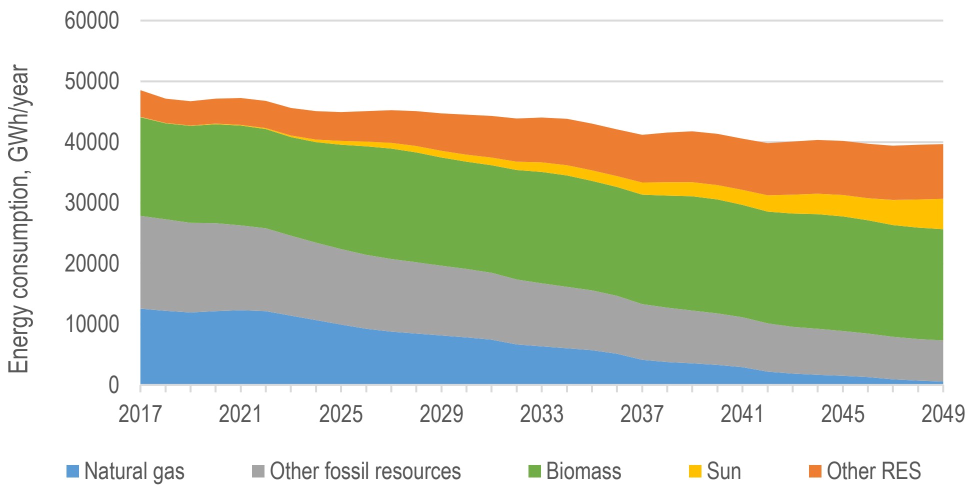


Fig. 4.6. Total energy consumption in modelled scenarios by resources

Figure 4.7 shows that there is a significant difference in the overall RES share indicators between the different scenarios. If, in the baseline scenario, the share of RES reaches 57.7% in 2050, it has increased to 69.7% in the NECP scenario and to 80.8% in the climate neutrality scenario. The transport sector is the main obstacle to achieving a higher share of RES. Although the results do not show a complete abandonment of fossil resources in the energy sector, in the climate neutrality scenario, the share of RES has increased by more than 100% compared to the value of 2017, and taking into account CO_2 removal planned in the LULUCF sector, it can be considered that the respective scenario reaches climate neutrality also without reaching 100% share of RES. The LULUCF sector was not modelled in this study, and the exact planned CO2 removals are not addressed, but the climate neutrality scenario takes into account the possible reduction in biomass availability taken from the results of the "*Meža eksperts*" model scenarios that were obtained in the "Energy and Climate Modelling Towards Carbon Neutrality" project, VPP-EM-2018/NEKP_0001".

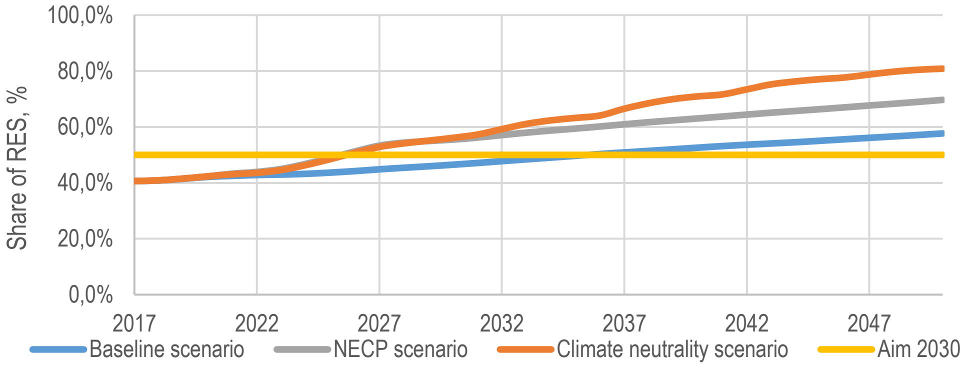


Fig. 4.7. The total share of RES in different scenarios

Figure 4.8 shows Latvia's total final energy consumption. As can be seen from the results, the dominant RES in final energy consumption is biomass, while solar energy and other RES form a relatively small part. This points to the fact that solar energy and other RES were mainly used for electricity production, as well as for the production of heat in district heating.

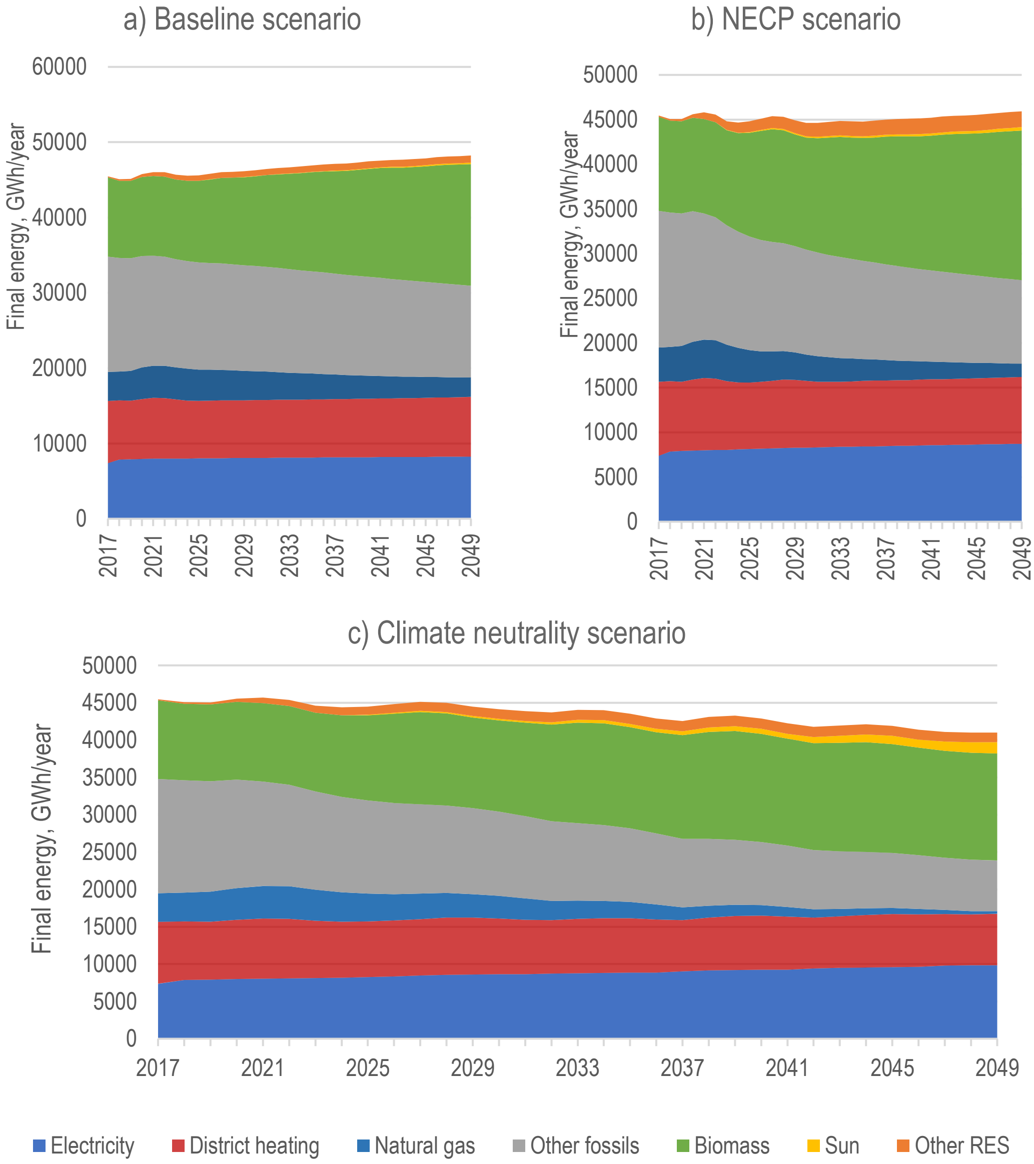


Fig.4.8. Final energy consumption in modelled scenarios by resources

The comparison of modelling scenarios shows that, like total consumption, the use of natural gas in final consumption in the NECP and climate neutrality scenarios decreases significantly, gradually approaching zero. If in 2017 natural gas accounted for 8.4% of total final energy consumption, then in 2050 natural gas consumption represented only 5.4% in the baseline scenario, 3.2% in the NECP scenario, and 0.9% of total energy final consumption in the climate neutrality scenario. All scenarios show an increase in biomass consumption. Compared to 2017, biomass consumption increased by 53.3% in the baseline scenario, by 58.7% in the NECP scenario and by 36% in the climate neutrality scenario. There are two explanations for the lower increase in biomass increase in the climate neutrality scenario. Figure 4.9 shows that in the climate neutrality scenario, the total final consumption is significantly lower than in the NECP and baseline scenario, which means that it is necessary to consume fewer resources, including biomass, in the climate neutrality scenario.

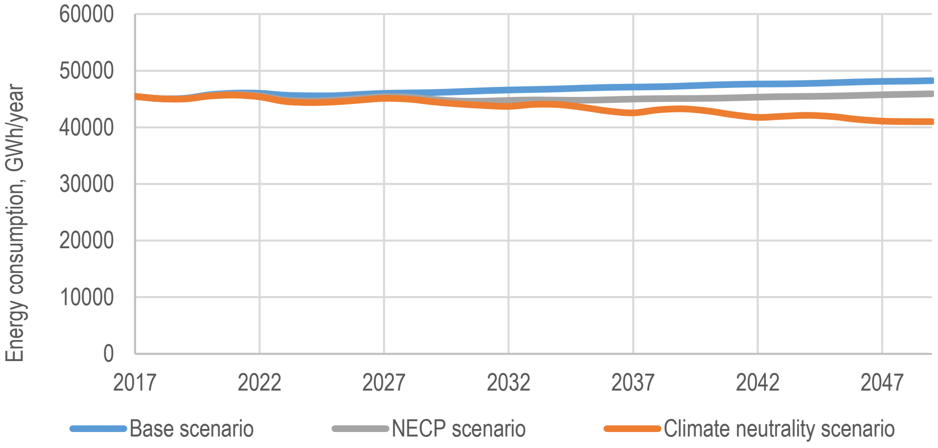


Fig. 4.9. Final energy consumption in modelled scenarios

The second explanation for lower biomass consumption in the climate neutrality scenario is given in Figure 4.10. In baseline and NECP scenarios, biomass availability has a growing trend, and it is seen that biomass consumption follows its availability while the available biomass amount reduces in the climate neutrality scenario. It can be seen in the climate neutrality scenario that there is an increase in biomass consumption, but it is slower than in baseline and NECP scenarios. Although the climate neutrality scenario shows that biomass consumption still has a significant margin for reaching the biomass limit, it is not still achieved. It is necessary to look at the consumption and availability of biomass by regions to understand the reasons why the limit is not reached (see Fig. 4.11).

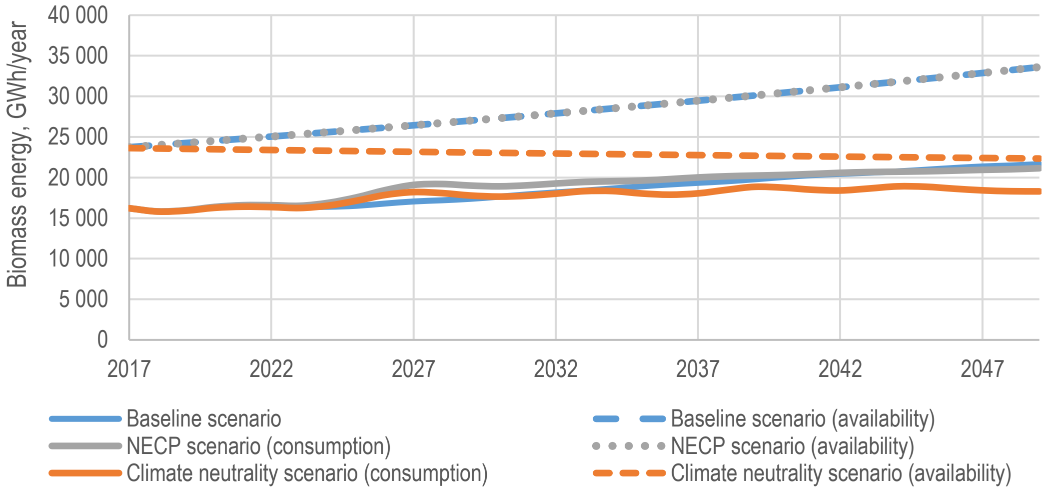
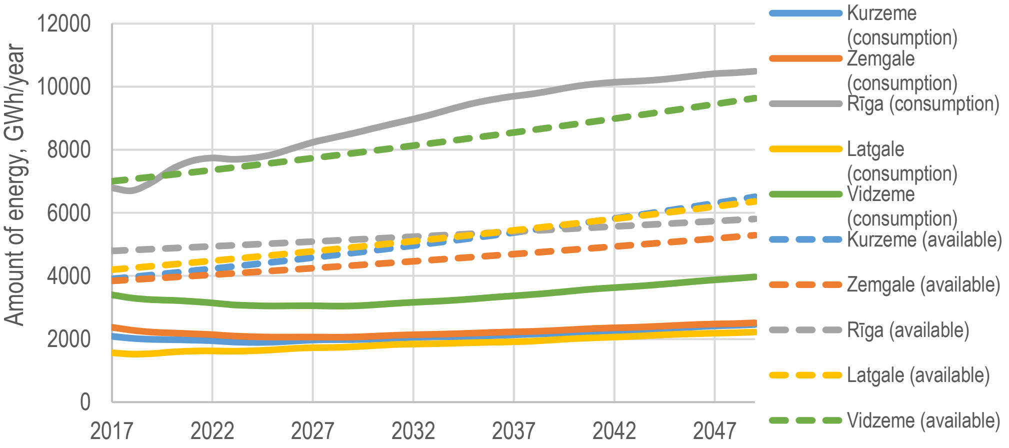
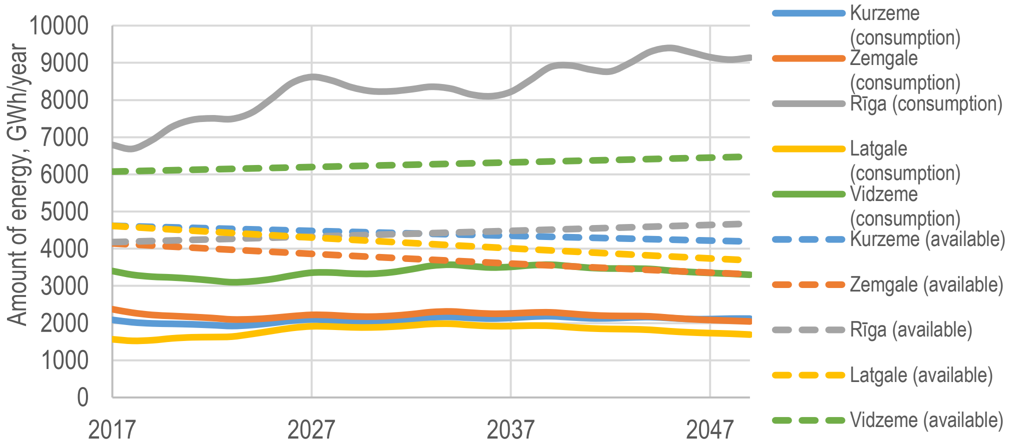


Fig. 4.10. Availability and consumption of biomass

Figure 4.11 shows that the availability of biomass is higher than consumption in all regions except the Riga region. This means that nothing significantly impedes the development of biomass in these regions, if necessary, and it is economically justified. The opposite situation is in the Riga region, where consumption initially exceeds the amount of resources available. This means that it is necessary to purchase the missing resources from other regions, which makes the use of biomass directly in the Riga region more expensive. Both baseline and climate neutrality scenarios show that biomass consumption in the Riga region increases, but a more rapid increase is observed in the baseline scenario because the corresponding scenario also shows a higher amount of biomass available. This means that more own resources are available before they need to be searched outside the region.



a) Baseline scenario



c) Climate neutrality scenario

Fig. 4.11. Availability and consumption of biomass by region in the baseline and climate neutrality scenario

Figure 4.12 shows the annual and all-period accumulated support amount granted for the integration of renewable energy sources into energy. This figure does not include support granted to the transport sector, which will be viewed separately. The figure shows the support granted for the integration of RES into electricity supply, district heating and individual heating. In the description of the scenarios, chapter 2 mentions that the largest amount of support is granted in the climate neutrality scenario, and, as shown in Figure 4.12, it is also in line with the results of the model. The largest amount of support available is spent in the climate neutrality scenario.

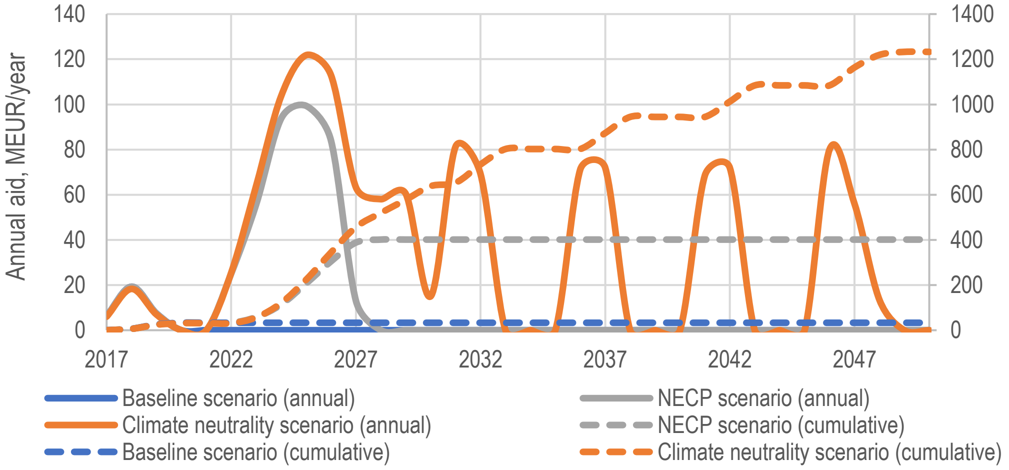
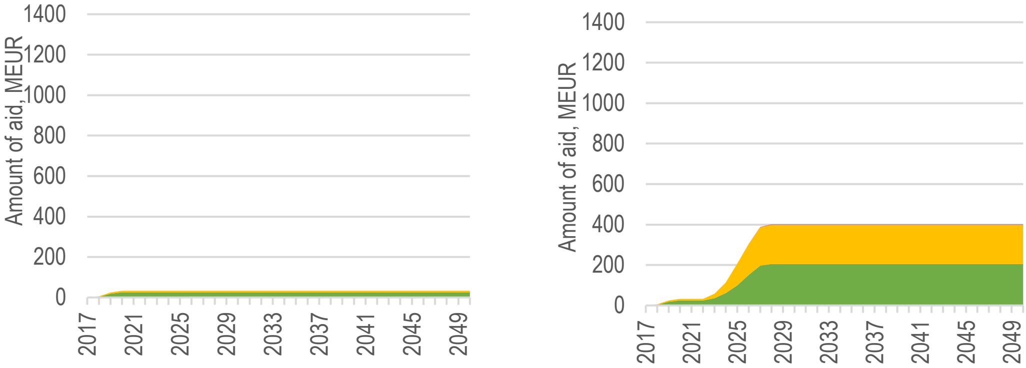


Fig.4.12. Amount of support granted for the implementation of RES

When considering the granting of support by type of resources (Fig. 4.13), in the baseline scenario, the support is very limited on the basis of the values given in the description of the scenarios, and the support is mainly provided for the installation of biomass technologies as well as in small amounts for solar technologies. The NECP scenario provides a significantly higher amount of support, and it can be seen that it is granted in similar portions for the installation of solar and biomass technologies, while other RES technologies do not receive support or receive minimal support. In the climate neutrality scenario, the largest amount of support is granted, and it can be seen that in this scenario, unlike in the NECP scenario, a substantial portion of the support is also granted for the installation of wind technologies as well as for the integration of heat pumps.



a) Baseline scenario

b) NECP scenario

c) Climate neutrality scenario

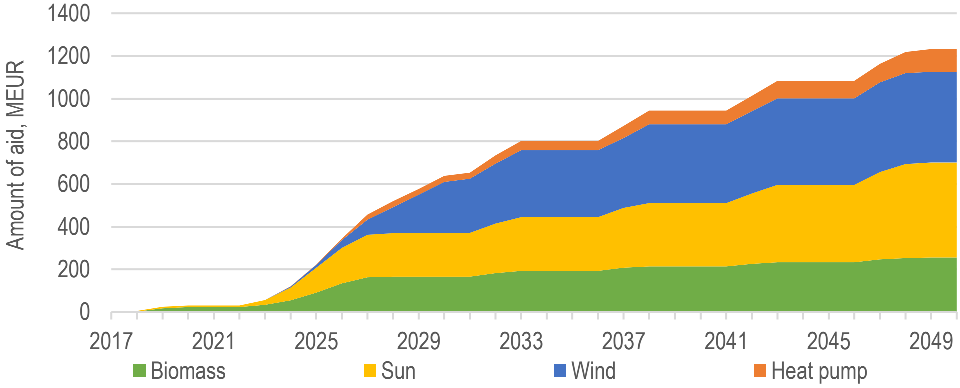


Fig. 4.13. The accumulated amount of support granted for the implementation of RES by type of resources

Figure 4.14 shows the share of total investment in energy for the installation of new technologies formed by support for the implementation of RES technologies. Total investments include the total capital costs of all technologies installed after 2017, including both investments in renewable energy technologies and fossil resource technologies. Figure 4.14 shows both the largest support amount and the largest total investment are seen in the climate neutrality scenario. This points to the fact that there is also a growing interest in the installation of new technologies, even if the support for investment is not sufficient for all the equipment. In the baseline scenario, the support amounted to only 0.6% of the total investment, while in NECP and climate neutrality scenarios, the support amounted to 6.2% and 12.3% of the total investment, respectively.

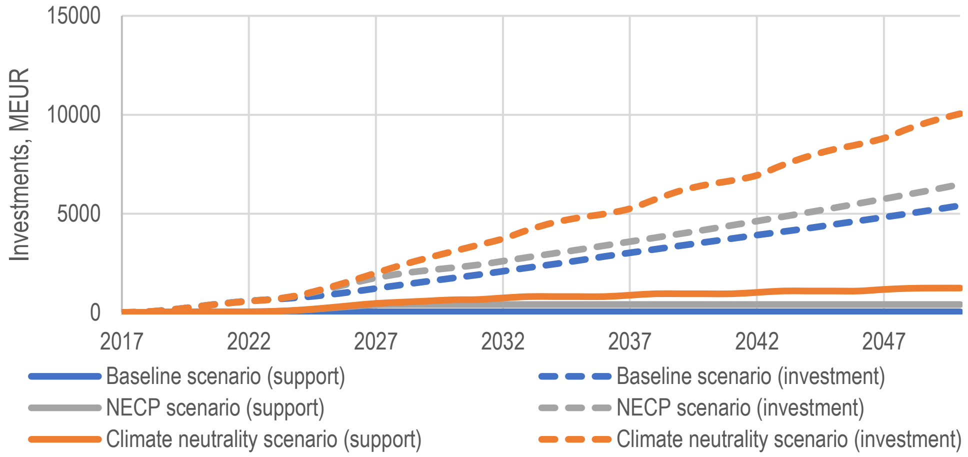


Fig. 4.14. Comparison of support and total investment in different scenarios

The policies used also have a significant impact on tax revenues from the use of fossil resources. The following figures show how tax revenues from excise goods, as well as from the natural resources tax on generation of CO_2 emissions, change in different scenarios. The excise duty is distinguished separately for natural gas and transport fuels.

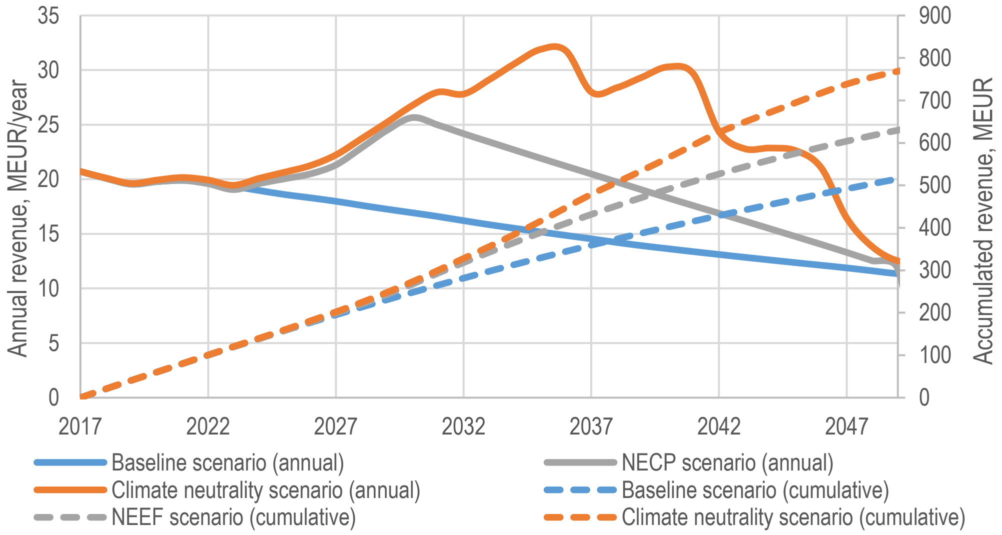


Fig. 4.15. Excise duty revenues from the sale of natural gas

Figure 4.15 shows that the highest annual and all-period accumulated income from the trading of natural gas is in the climate neutrality scenario. Although Figure 4.6 shows that, in the climate neutrality scenario, the amount of use of natural gas reduces significantly when compared to the baseline and NECP scenarios, however, taking into account higher excise duty rates, it is possible to generate higher tax revenues even at a lower level of natural gas use. An increased tax rate raises the price of natural gas, which is one of the factors contributing to a reduction in natural gas consumption.

The natural resources tax, which is charged for generating CO2 emissions, is another type of tax that was analysed in the study. As can be seen from Figure 4.16, similarly to the excise duty, the highest income from the natural resources tax can be seen in the climate neutrality scenario. It can be seen that the increase in the natural resources tax has an effect on both the reduction in the share of fossil resources and in the tax revenue category looking at Figures 4.6 and 4.16.

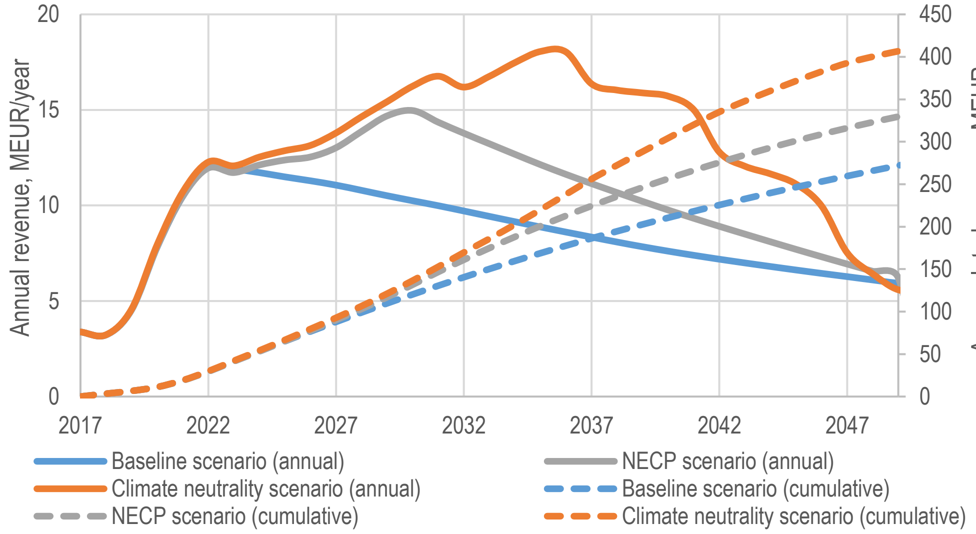


Fig. 4.16. Revenue from natural resources tax

It can be seen that in 2050 annual tax revenues at different tax rates are almost the same, indicating that after 2050, with natural gas consumption continuing to fall, the annual tax revenues in the NECP and climate neutrality scenarios will be lower than in the baseline scenario looking at the annual tax revenue indicators in Figures 4.15 and 4.16. In the long term, after 2050, cumulative income at lower rates in the baseline scenario could be higher than in NECP and climate neutrality scenarios, yet this would hinder the achievement of climate neutrality targets.

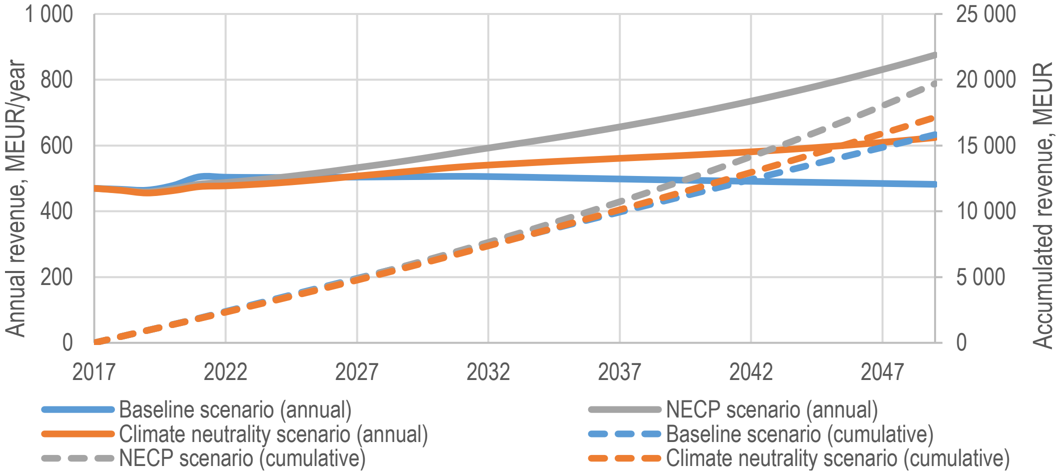


Fig. 4.17. Excise duty revenues from the transport sector

The largest income from excise duty comes from the transport sector. Unlike in the previous tax groups, the highest income from the excise duty on transport fuels is obtained in the NECP scenario rather than in the climate neutrality scenario (see Figure 4.17). This is due to the fact that NECP and climate neutrality scenarios use the same tax rates for transport fuels, so given the faster decline in fossil fuel use in the climate neutrality scenario, less revenue is generated from fossil fuels. However, revenues from excise duty in the climate neutrality scenario are higher than revenues in the baseline scenario.

4.2.2. Electricity supply sector

This chapter analyses how electricity production will develop, both in the centralised and individual way, in different scenarios.

Figure 4.18 shows that, depending on the scenario, the share of RES in electricity production in 2050 ranges from 70.4% in the baseline scenario to 99.1% in the climate neutrality scenario. However, it is important to note that the share of RES only partly shows changes in electricity production. Both the share of electricity imported and the amount of energy produced on-site and electricity consumption vary significantly among the scenarios, so it is also necessary to look at these parameters separately in order to better understand the development of electricity supply.

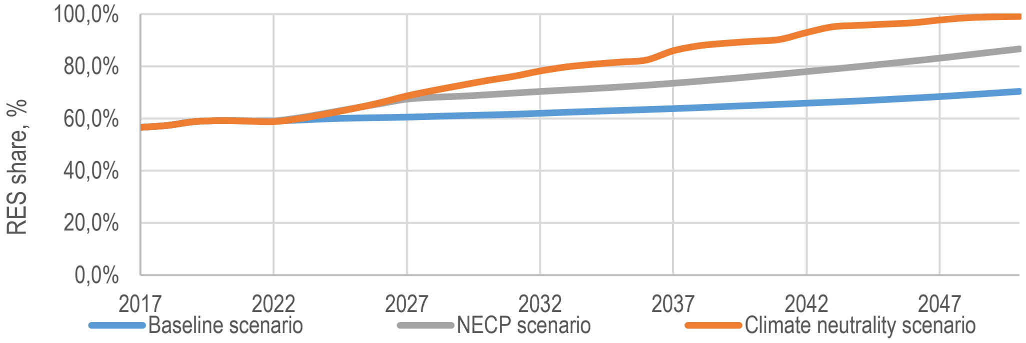


Fig. 4.18. Share of RES in electricity production in different scenarios

Figure 4.19 shows that in the NECP and climate neutrality scenarios, there is an increase in electricity consumption against the baseline scenario. A significant increase in consumption is observed exactly in the climate neutrality scenario. There are a number of causes for the increase in consumption observed in the NECP and climate neutrality scenarios. This is mainly related to an increase in electricity demand for hydrogen production needs, electrification of the heating sector and the replacement of fossil fuels used in transport.

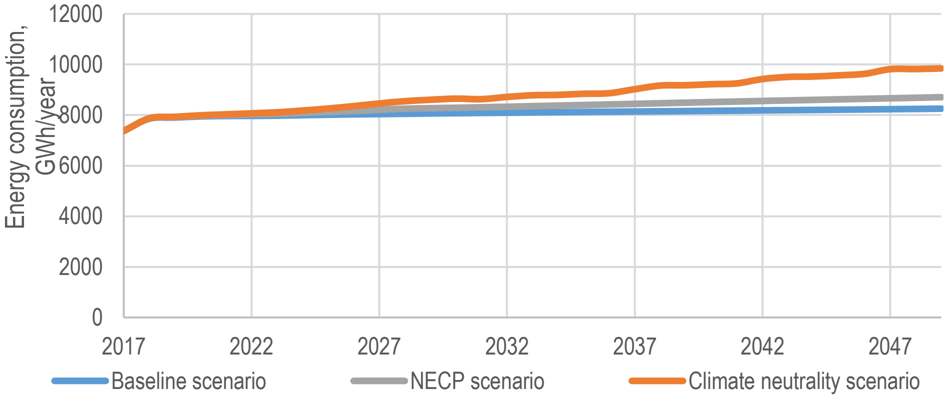


Fig. 4.19. Electricity consumption in different scenarios

Figure 4.20 shows how hydrogen production has developed in different scenarios. Since hydrogen is mainly used for two purposes – biomethanation and transport fuel, the production of hydrogen also depend directly on the demand of these two sectors. Since the model provides that biomethane is produced for transport needs, transport demand for biomethane and hydrogen represents the total demand for hydrogen. Figure 4.19 shows that more hydrogen is produced in the NECP scenario than in the climate neutrality scenario. This is explained by the development of the transport sector, which is described in detail in section 4.2.5.

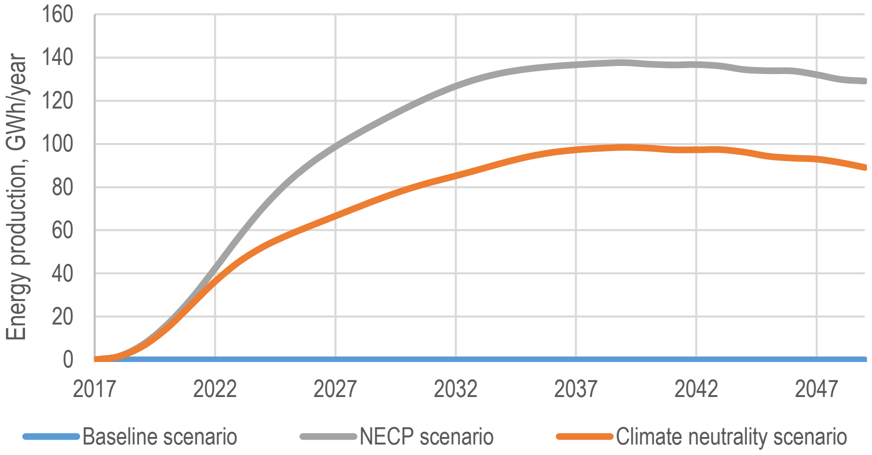


Fig.4.20. Hydrogen production amounts in different scenarios

If the production of hydrogen had relatively little impact on the increase in electricity consumption, the electrification of DH has the most significant impact on the increase in consumption. Figure 4.21 shows that the increase in electricity consumption in DH is significant in both NECP and climate neutrality scenarios. Compared to the baseline scenario, electricity consumption in 2050 increased by 175% in the NECP scenario and by even 186% in the climate neutrality scenario. It is important to note here that the consumption values for 2050 in the NECP and climate neutrality scenarios are similar, but electrification was more rapid in the climate neutrality scenario, so the total electricity consumption until 2050 is significantly higher in the climate neutrality scenario. 102.5% more electricity is consumed in the climate neutrality scenario than in the NECP scenario in the entire period. This is mainly due to the faster development of solar and wind electricity production in the climate neutrality scenario, thereby contributing to the development of cheap surplus energy, which increases the interest of heating companies in installing electricity conversion technologies in heating companies.

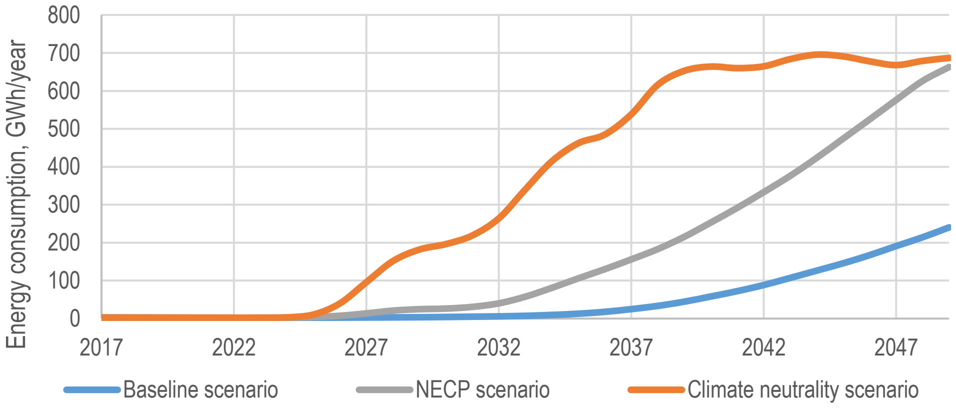


Fig. 4.21. Use of electricity in district heating

The main difference in the increase in electricity consumption makes the increase in electricity used in the transport sector. This is mainly due to the faster electrification of the railway network, switching both freight and passenger train flow from diesel trains to electric trains. If only partial railway electrification is envisaged in the NECP scenario, the climate neutrality scenario already provides for more comprehensive electrification, which is also reflected in Figure 4.22, where electricity consumption in the transport sector in the climate neutrality scenario is 155.9% higher than in the NECP scenario and by 760.1% higher than in the baseline scenario.

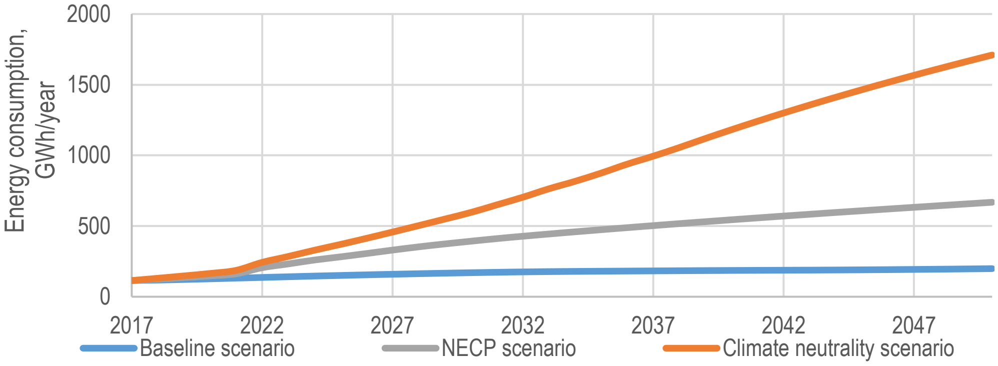


Fig. 4.22. Use of electricity in the transport sector

Figure 4.23 shows how the amount of electricity imported changes depending on the scenario. It can be seen that in the NECP scenario, there are the largest annual net electricity imports, and most electricity is imported over the whole period, as electricity consumption increases, while investment in the installation of RES technologies is low due to the lack of support, the installation of new capacities is slow. Therefore, the difference between demand and the amount produced on-site is higher than in the baseline scenario. This difference reduces only at the end of the period, as the volume of investments in renewable technologies installed without support increases. It is important that support for the development of an offshore wind park is provided in the NECP scenario, but the model based on the comparison of costs shows that even with available support, offshore wind parks are not economically justified until 2030, and their installation would require support intensity above 50% used in the NECP scenario.

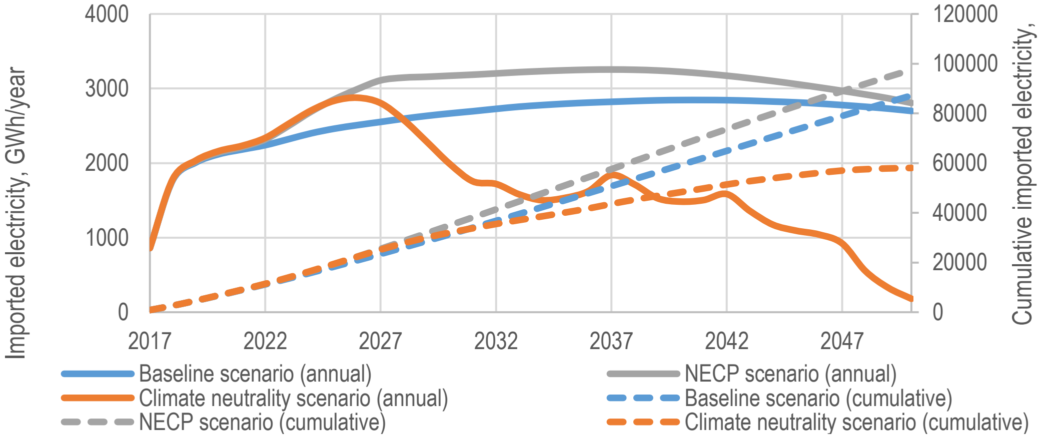
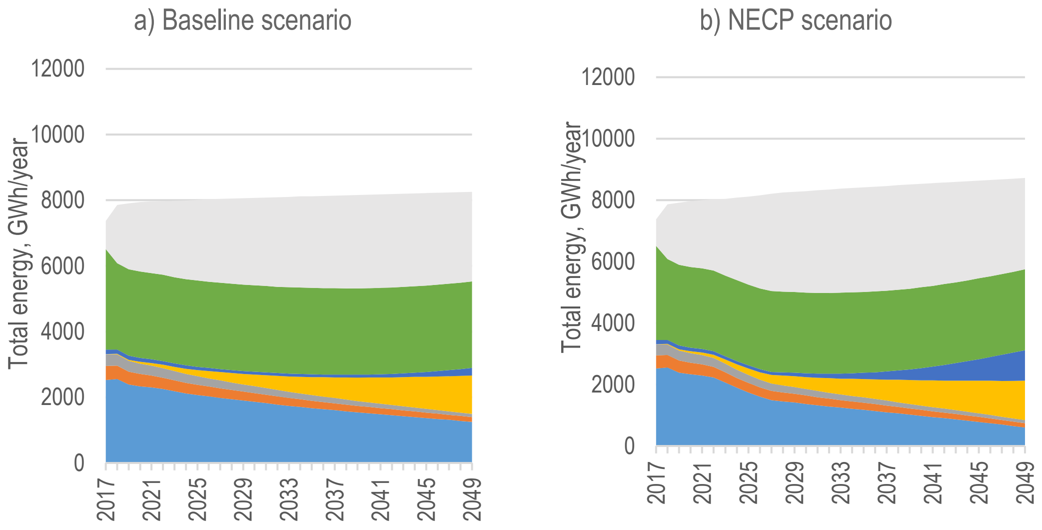


Fig.4.23. Electricity imports in different scenarios

A different situation is observed in the climate neutrality scenario. Figure 4.23 shows that, in the case of the climate neutrality scenario, annual net imports gradually decrease from 2026, and only 3.3% of local electricity consumption will be imported in 2050. These are 32.9% in the NECP scenario and 33.1% in the baseline scenario. This means that the climate neutrality scenario is the closest to energy independence in the electricity supply sector. The climate neutrality scenario accordingly has the lowest amount of electricity imported over the whole period up to 2050.

Figure 4.24 shows how electricity production by types of resources looks in different scenarios. In the baseline and NECP scenarios, the share of electricity imported increases significantly due to the lack of support for the implementation of RES technologies that could compete with the price of the electricity market (NORDPOOL). This prevents the replacement of natural gas in electricity production with renewable sources. It can be seen that there is an increase in solar energy use in both baseline and NECP scenarios. This is mainly the case in individual sectors, while centralised electricity production in large solar parks does not actually take place. Thanks to additional policies, including an increase in natural gas taxes, when comparing the NECP scenario with the baseline scenario, natural gas consumption appears to be declining in the NECP scenario, and wind energy acquisition increases as the year 2050 approaches.


a) Baseline scenario

b) NECP scenario

c) Climate neutrality scenario

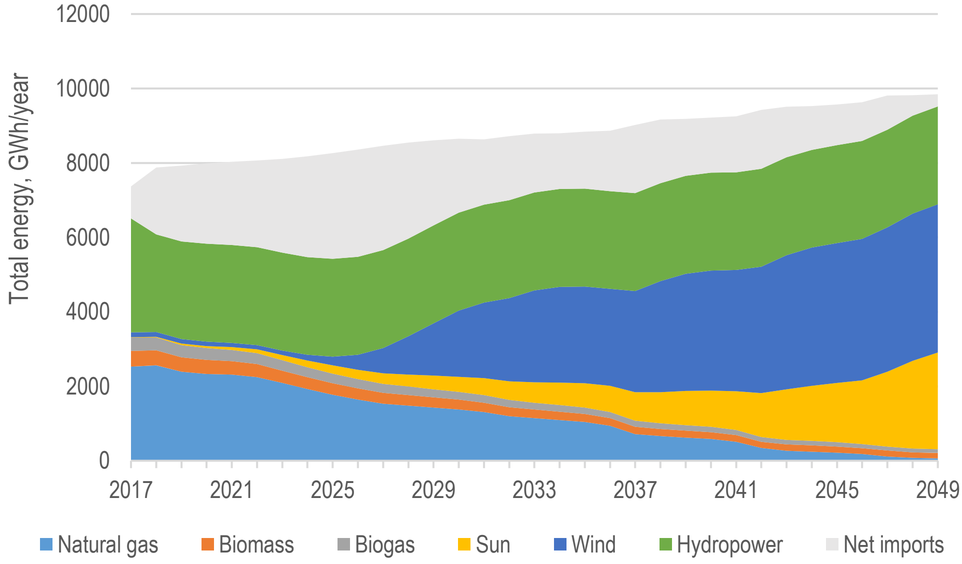


Fig. 4.24. Electricity production by types of resources

From the point of view of renewable sources, the most positive picture is seen in the climate neutrality scenario. Figure 4.24 shows that thanks to supporting combined with the increase in taxes on fossil resources, the use of natural gas in electricity production in 2050 does not actually take place, while wind energy is rapidly developing. Compared to the NECP scenario, an increase is also seen in solar energy generation, including in a centralised way. The exclusion of natural gas in the climate neutrality scenario makes it possible to achieve the above-mentioned share of RES of 99.1%.

Figure 4.25 shows how the available funding is distributed by years and technologies in different scenarios. As has already been mentioned above, the baseline scenario does not contain support or does not use it. The NECP scenario foresees 750 million euros to develop offshore wind parks by 2030, but this available support is not spent in the model due to high costs. Both the baseline scenario and the NECP scenario show support for the use of biomass, but these are indirect subsidies from the DH sector, where support is granted to biomass cogeneration plants. Part of the support, in this case, is shown in DH but remains in the electricity part.

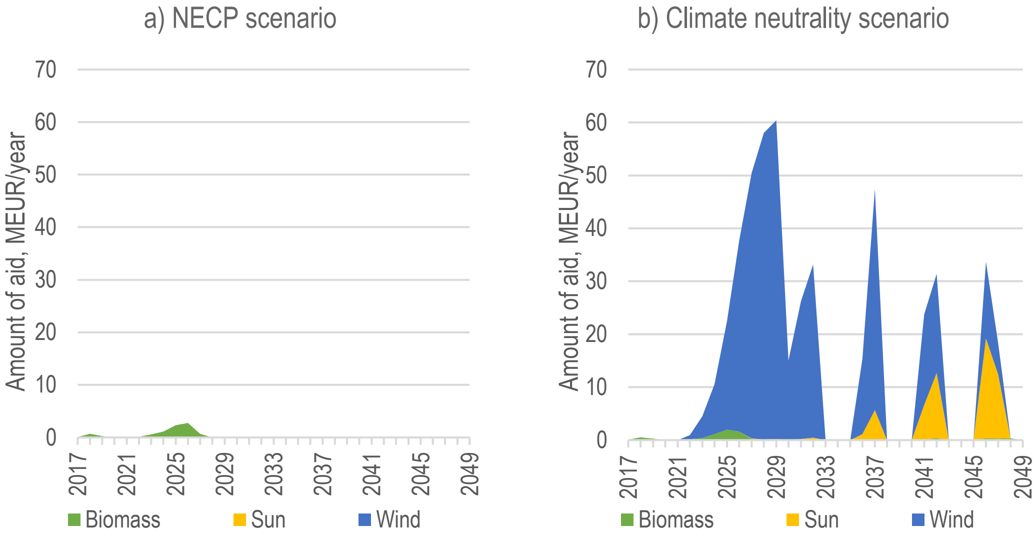


Fig. 4.25. Annual support amount for electricity production technologies by types of resources

The support available in the climate neutrality scenario is used for the construction of onshore wind parks until 2030, while after 2030, funding is spent on both onshore wind parks and centralised solar parks. Figure 4.26 shows that in the baseline and NECP scenarios, support for the installation of electricity technologies is not granted or used. Therefore total investments are relatively small. These matches Figure 4.24, where no rapid and significant changes are observed in the baseline and NECP scenarios. The most significant changes are observed in the climate neutrality scenario. Total investment increase as support for RES increases, and there is rapid development in the electricity production sector.

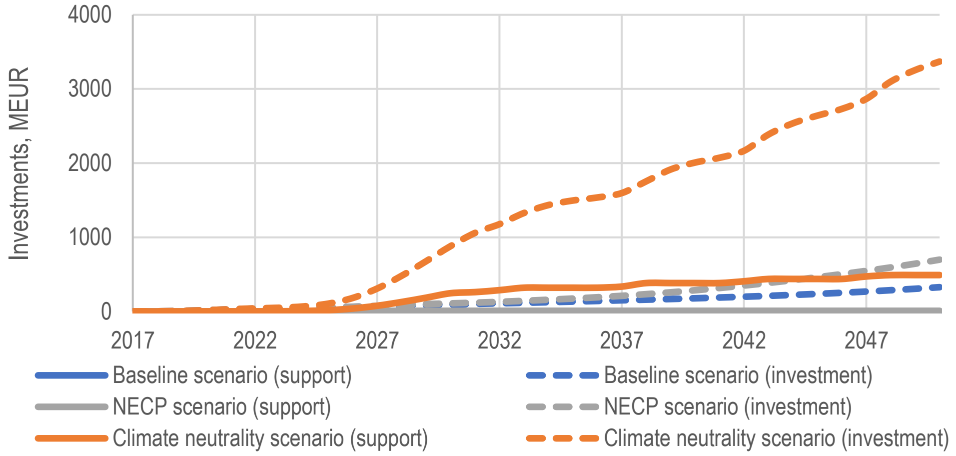


Fig.4.26. Accumulated investments and support in different scenarios

Support for the installation of electricity production technologies is granted not only for centralised production plants but also for the installation of PV systems at consumers, thus encouraging them to become self-producers. Figure 4.27 shows the accumulated support amount granted to individual producers for the installation of PV systems in different scenarios. In the baseline scenario, no support was granted, but in NECP and climate neutrality scenarios, the support was granted.

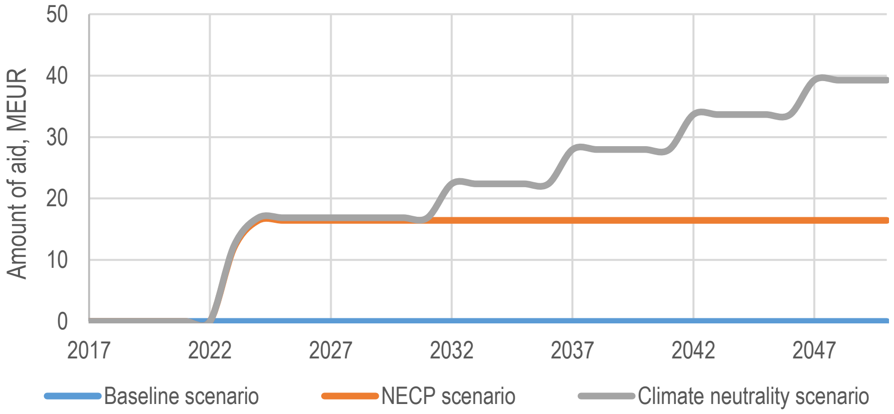


Fig. 4.27. Support granted for installation of PV panels at individual producers

Figures 4.28 and 4.29 show how electricity production in the model is developing in the region. Figure 4.28 shows the development of regions in the baseline scenario, while Figure 4.29 shows the climate neutrality scenario.

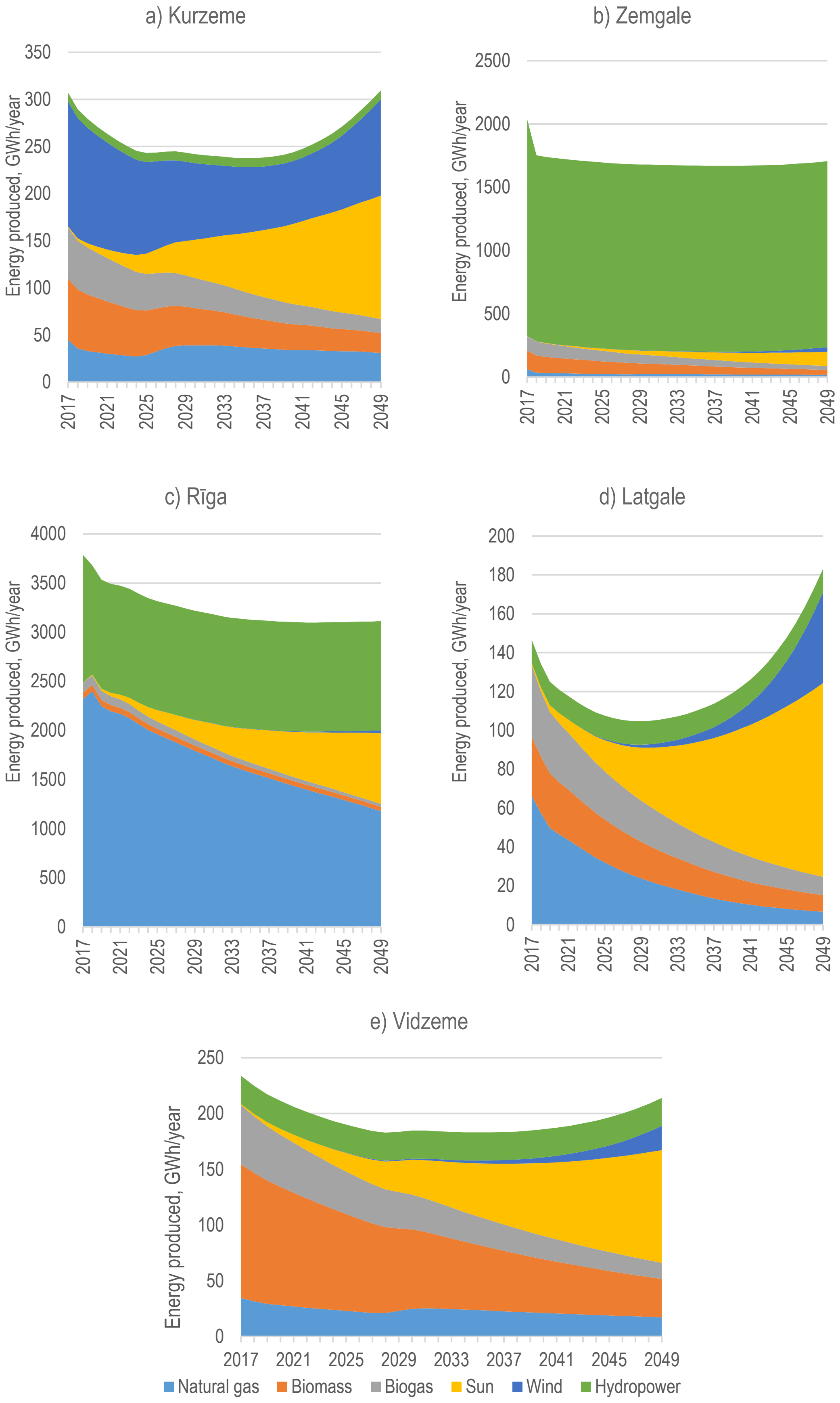
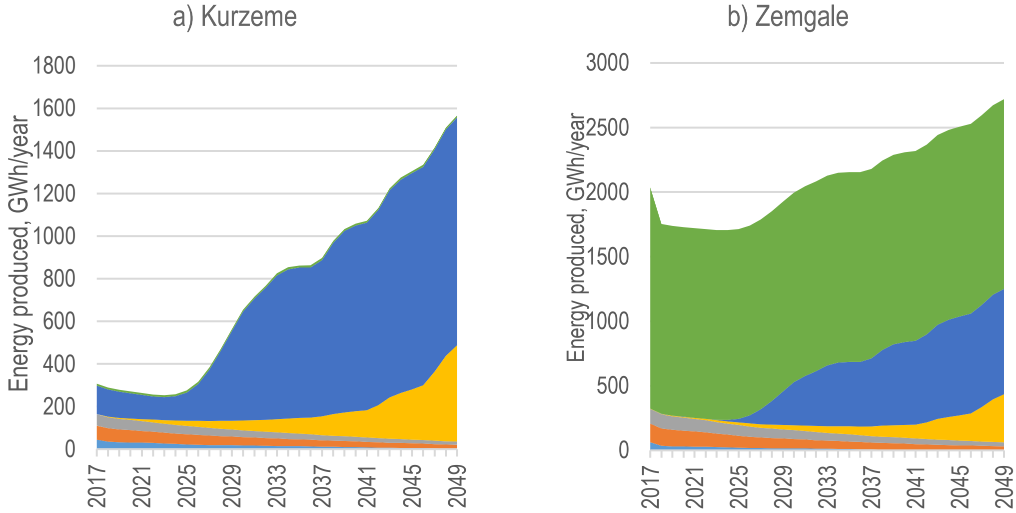
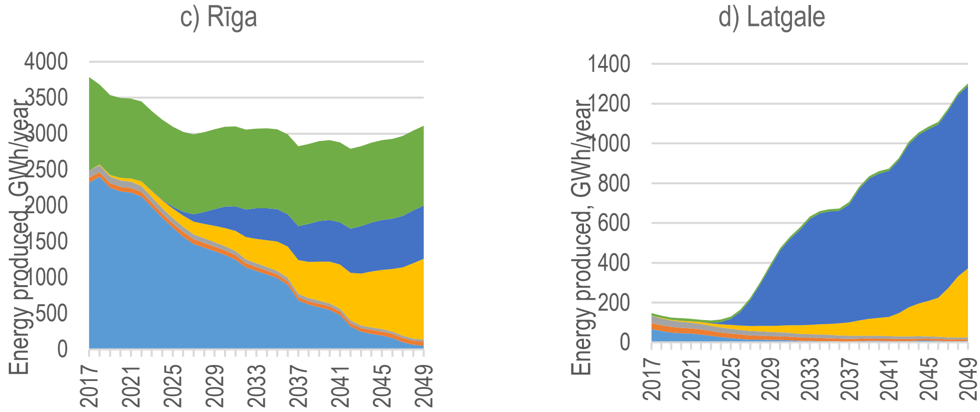


Fig. 4.28. Electricity produced by types of resources by regions in the baseline scenario

Figure 4.28 shows that the total volume of electricity produced by regions does not significantly change, but only the resources used to change. The development of solar power production is observed in all regions. This is mainly due to the installation of solar PV panel systems at final consumers. In Latgale and Vidzeme regions, there is also a small amount of wind energy acquisition at the end of the period. Most natural gas is used in the Riga region due to its use at CHPP-1 and CHPP-2, but natural gas consumption gradually decreases. There is also a decrease in natural gas consumption in Latgale, while in Vidzeme and Kurzeme regions, natural gas consumption does not change significantly or even increases slightly.


a) Kurzeme b) Zemgale


c) Rīga d) Latgale

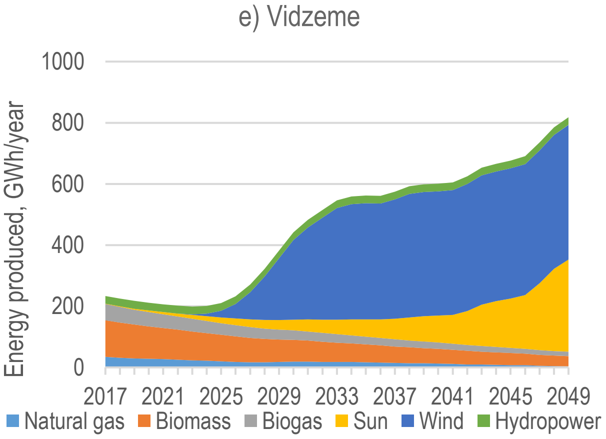

e) Vidzeme

Fig. 4.29. Electricity produced by types of resources by regions in the climate neutrality scenario

Figure 4.29 shows that the acquisition of wind energy in the climate neutrality scenario already takes place in all regions, indicating high potential in all regions. It can be seen that all regions, except the Riga region, experience an increase in electricity production, which is linked to the development of the use of wind and solar energy. In the Riga region, the decrease in electricity production is related mainly to the closure of CHPP-1 and CHPP-2, thereby abandoning the use of natural gas, which forms a large part of the electricity produced in the Riga region. The climate neutrality scenario shows that production becomes more dispersed for each region, with the exception of Riga, contributing a higher share of energy produced than before. If, until now, the largest electricity capacity was concentrated in the Riga region, and thanks to the Daugava HPP cascade, partly also in the Zemgale region, electricity production could be distributed across all regions in the future.

By region, the choice of production technologies is influenced by resource availability, territorial constraints, infrastructure availability, as well as costs.

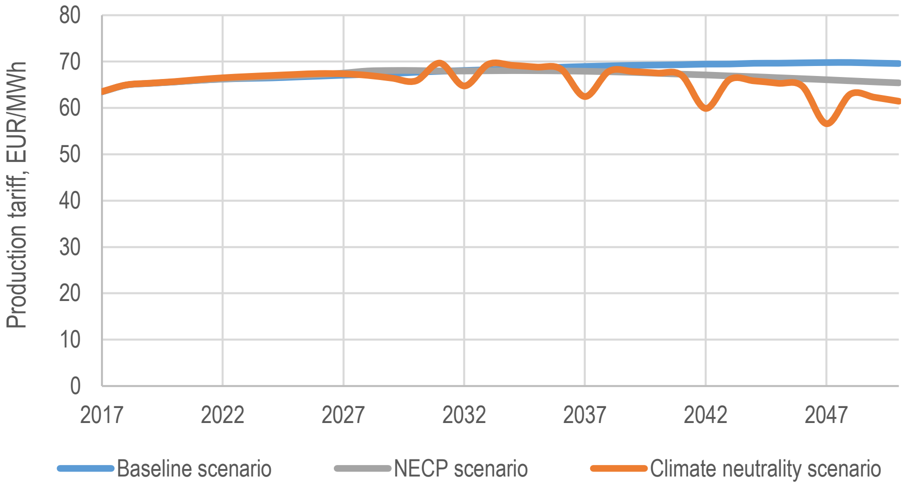


Fig.4.30. Electricity production tariff in different scenarios

Figure 4.30 shows how the rates of electricity production would develop in different scenarios. The graph shows that the integration of RES in the long term would lead to a reduction in the electricity production tariff. The production tariff applies only to the amount of electricity produced on-site and does not include the price of the electricity imported. Price fluctuations observed in the climate neutrality scenario are linked to the granting of support for the installation of RES technologies. Technologies installed with support are able to ensure a lower electricity production price.

4.2.3. District heating

This chapter analyses how DH will develop in different scenarios. Figure 4.31 shows the share of RES increasing in all scenarios, including in the baseline scenario, but the most rapid increase in the share of RES is in the climate neutrality scenario, where it reaches 98.4% in 2050. This is thanks to additional support and higher taxes on fossil fuels compared to the NECP scenario.

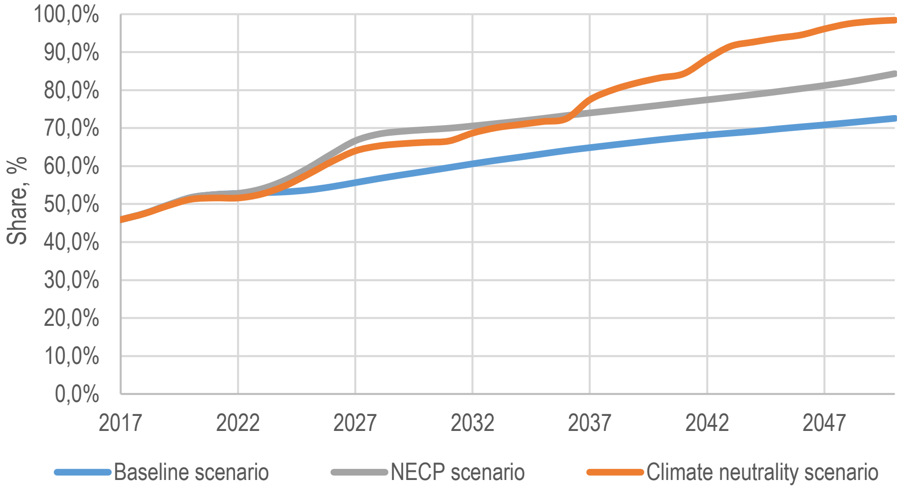


Fig. 4.31. Share of RES in district heating

Figure 4.32 shows the impact of the introduction of energy efficiency measures. The graph shows that the total amount of heat produced in the NECP and climate neutrality scenarios decreases. There is also a slight decrease in the baseline scenario, where the amount of heat produced in 2050 is 4.4% lower than in 2017. In the NECP and climate neutrality scenarios, declines are 9.6% and 16.9% compared to the values of 2017, respectively.

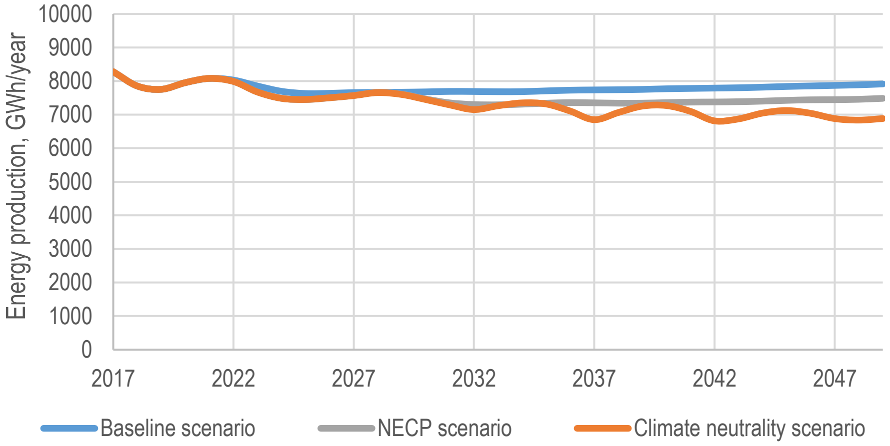


Fig. 4.32. Amount of heat produced in district heating

Figure 4.33 shows how the energy produced in DH varies by type of resource. In 2050, in the baseline scenario, natural gas consumption is still very high, while the abandonment of natural gas in the climate neutrality scenario is almost complete. In 2050, 28.4% of total thermal energy is produced from natural gas in the baseline scenario, while only 13.6% and 1.3% in the NECP and climate neutrality scenarios. Biomass plays a key role in all scenarios, but the highest share of biomass is exactly in the baseline scenario, where biomass accounts for 47.6% in 2050 and only 40.6% and 42.3% in total heat generation in the NECP and neutrality scenarios, respectively. This involves a much faster integration of solar collectors and heat pumps into district heating processes. The fastest installation of heat pumps takes place in the climate neutrality scenario. This is largely due to the rapid development of the electricity sector in the direction of RES resources, mainly in the direction of wind energy, thereby contributing to the decline in electricity prices.

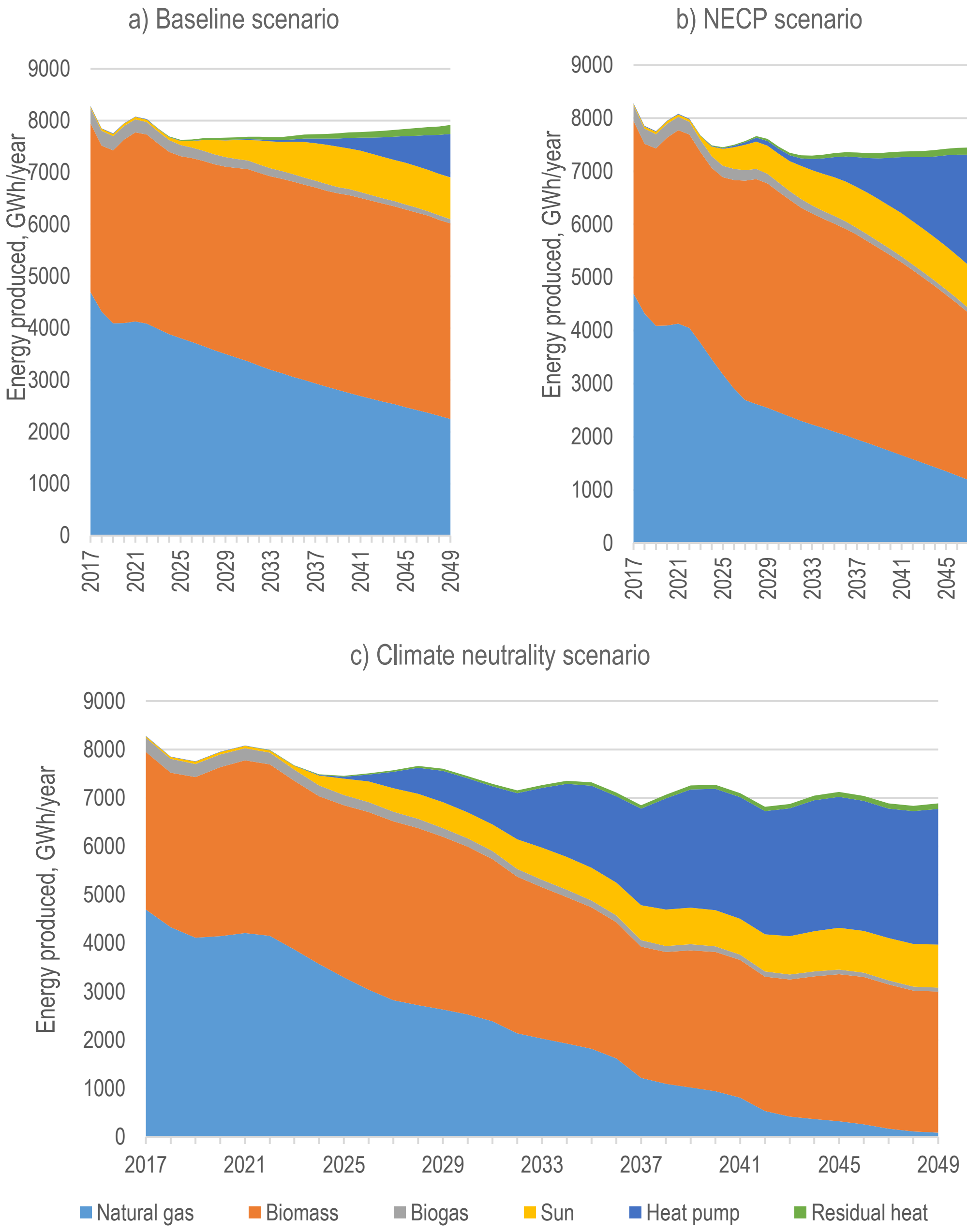


Fig. 4.33. Heat production in DH by types of resources

Figure 4.34 shows how much support for the installation of RES technologies is granted to DH in each of the scenarios. A small amount of funding is available in the baseline scenario, which is distributed mainly for the installation of biomass equipment, while a small amount of support is also received by solar technologies. In the NECP scenario, the funding available from 2021 to 2030 is used to install biomass and solar technologies. A small amount of funding is also channelled to the installation of heat pumps. The climate neutrality scenario shows that a more substantial part of the funding is being channelled to the installation of heat pump technologies, and the support granted to biomass plants reduces. Thanks to the support granted, a more rapid electrification of DH takes place in the climate neutrality scenario, which is already seen in Figure 4.33.

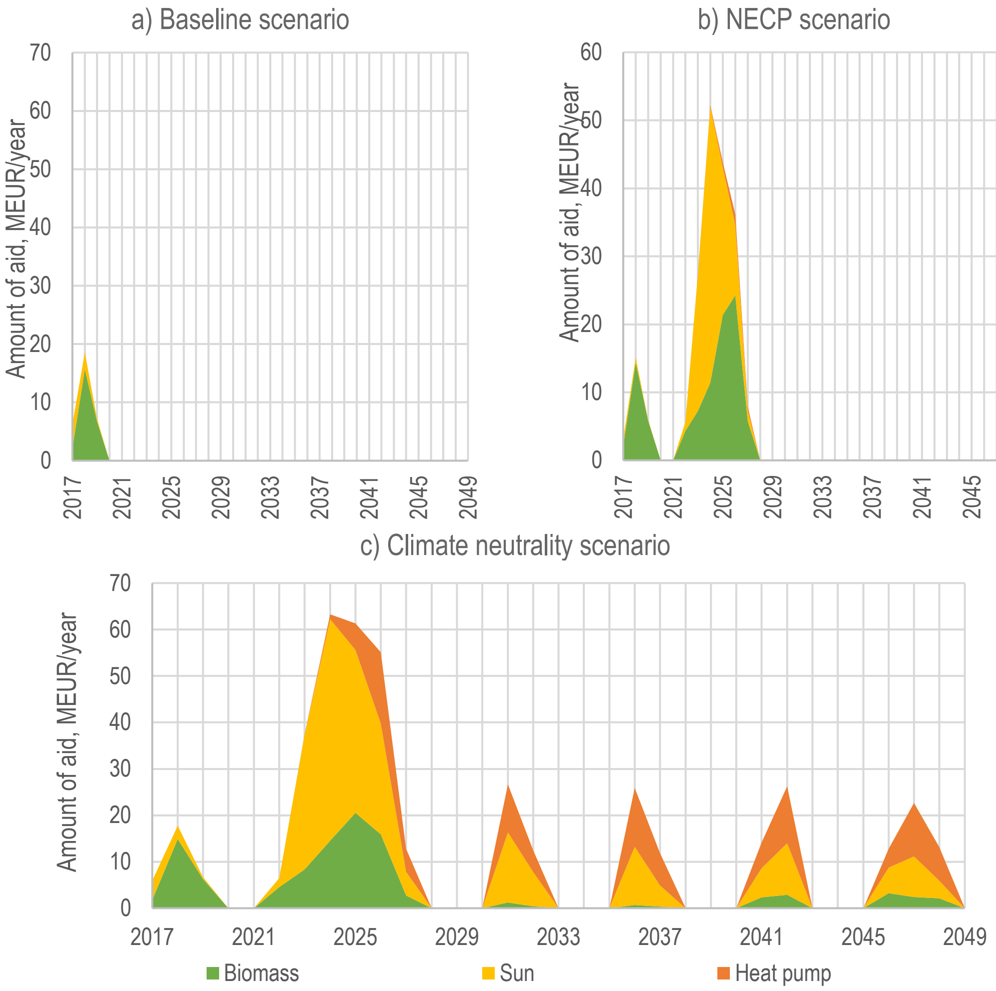


Fig. 4.34. Annual granted support indicators in different scenarios

Figure 4.35 shows how high the total investment in DH is by 2050 and how much of the investment is covered by the support granted. The graph shows that the amount of support is already higher, as the total investment is higher. In the baseline scenario, the support amounts to only 1.4% of the total investment, while in NECP and climate neutrality scenarios, the support increases to 10.4% and 16.4% of the total investment, respectively. In the climate neutrality scenario, the total investment is 19.5% higher than in the baseline scenario.

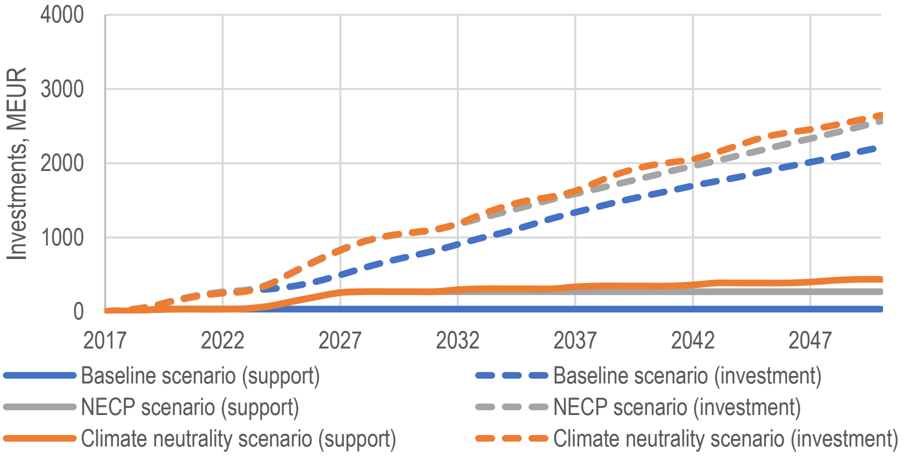


Fig. 4.35. Accumulated investments and support in different scenarios in DH

Figures 4.36 and 4.37 show how production in DH by region changes in baseline and climate neutrality scenarios.

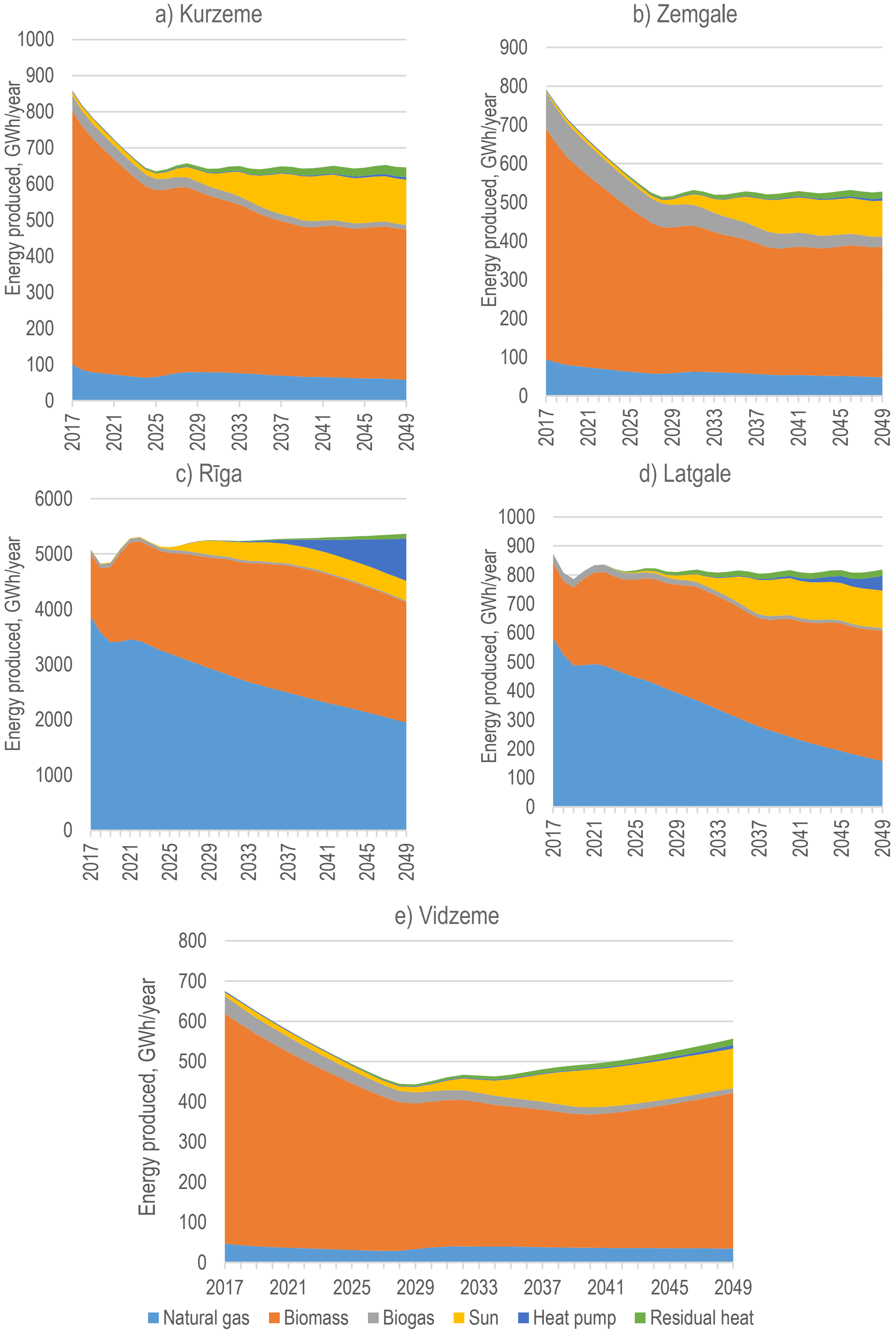
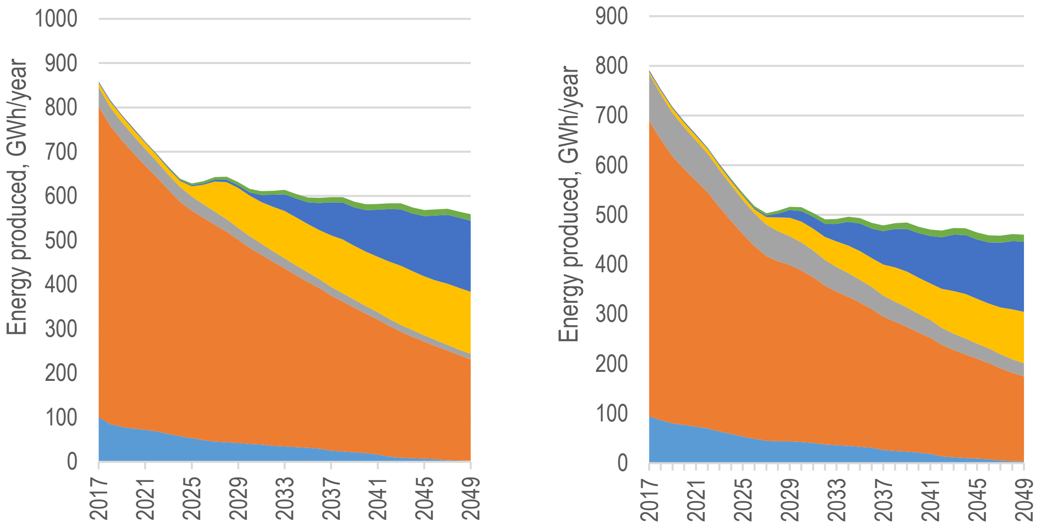


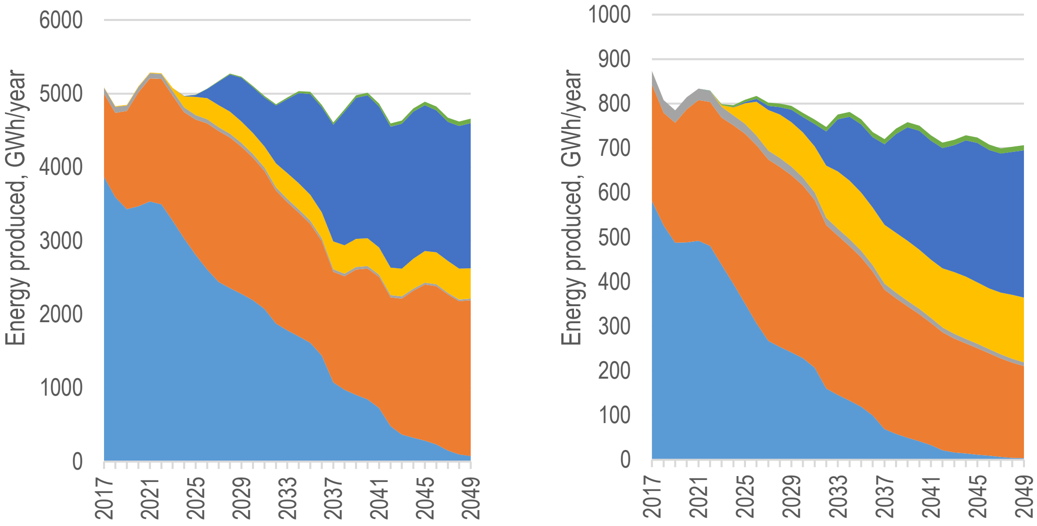
Fig. 4.36. Generated heat in DH by types of resources in regions in the baseline scenario

It can be seen that in the baseline scenario (Figure 4.36), in the regions where initial natural gas consumption is high, it is starting to decrease by gradually switching to biomass and other RES, but in the regions where the initial natural gas consumption is low, it is not replaced, and the production of heat using natural gas remains unchanged until 2050. The integration of solar technologies into district heating is taking place in all regions. The slowest development of solar technologies is in the Riga region, while the installation of heat pumps in the Riga region is the fastest, while, apart from the Latgale region, in the other regions, heat pump technologies are not actually used in the production of heat in DH in the baseline scenario.



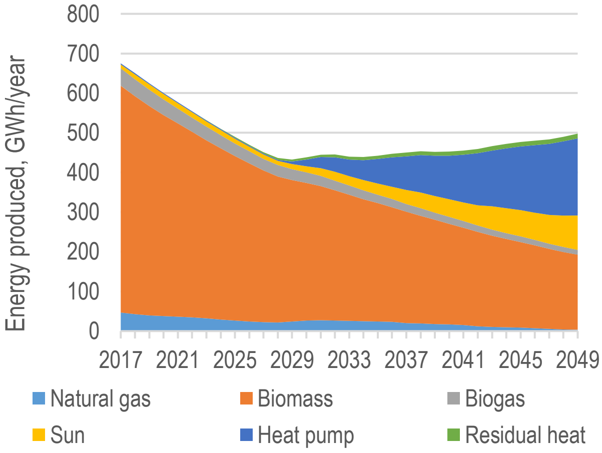
a) Kurzeme

b) Zemgale



c) Rīga

d) Latgale



e) Vidzeme

Fig. 4.37. Generated heat in DH by types of resources in regions in the climate neutrality scenario

Figure 4.37 shows that in the climate neutrality scenario, the rapid installation of heat pump technologies takes place in all regions, not only in the Riga and Latgale regions. At the same time, the use of solar energy in the Zemgale and Vidzeme regions slightly declines. Unlike in the baseline scenario, the abandonment of natural gas takes place in all regions, both in those regions where the initial use is small and in regions where the initial share of natural gas was high.

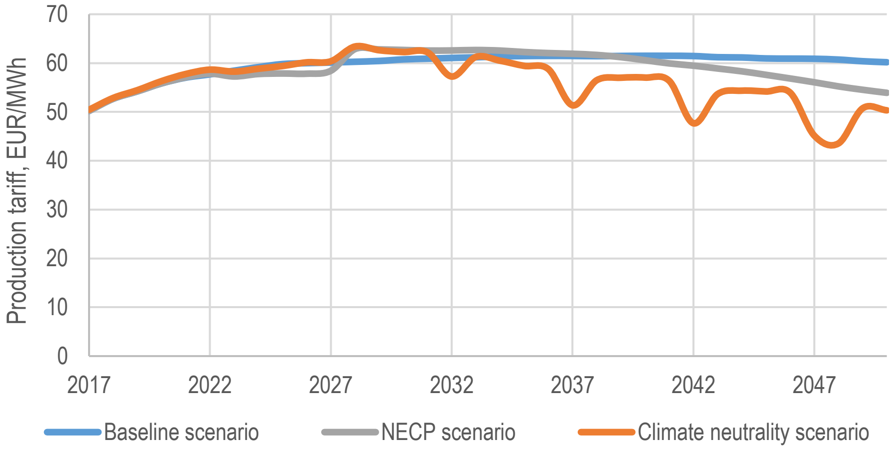


Fig. 4.38. Average DH production tariff in different scenarios

Figure 4.38 shows how the average heat tariff for DH changes in different scenarios. The graph shows that switching to renewable energy sources in district heating is likely to reduce the heat production tariff in the long term compared to the baseline scenario where natural gas consumption remains relatively high.

4.2.4. Individual sectors

This section covers the development of energy consumption in individual sectors – households, industry, services and the public sector. Figure 4.39 shows how the share of RES with change in different scenarios in households, industry, services and the public sector.

The graph in Figure 4.39 shows that the initial share of RES in the household sector is already relatively high. All scenarios show an increase in the share of RES, but it is relatively small in the baseline scenario. It has increased from 74.1% to 81.6% in the baseline scenario, while it reaches 89.0% and 97.1% in NECP and climate neutrality scenarios, respectively.

There is also an increase in the share of RES in the industry sector. Until 2027, in the baseline scenario, the increase in the share of RES against the value of 2017 is modest, but there is a gradual increase in the share of RES over the remaining period. The most rapid increase in the share of RES is in the climate neutrality scenario, but the difference between the NECP and the climate neutrality scenario is small. The share of RES of 88.7% is reached in the NECP scenario, and 93.6% – in the climate neutrality scenario.

In the services and public sectors, similarly to the household and industry sectors, there is an increase in the share of RES in all scenarios. Similarly to the household and industry sectors, the highest share of RES is in a climate neutrality scenario, which is related to the use of additional policy instruments. The share of RES amounts to 77.3% in the baseline scenario and 86.4% and 96.0% in the NECP and climate neutrality scenarios, respectively.

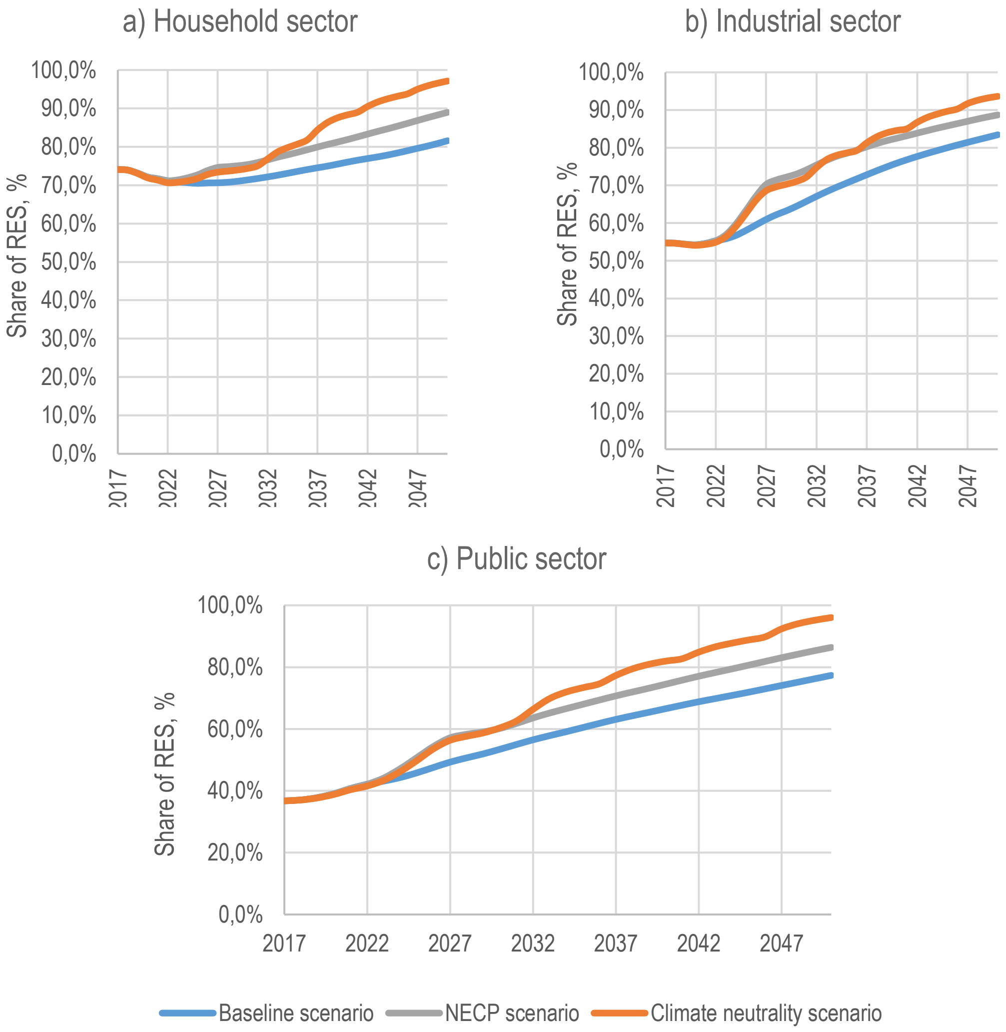


Fig. 4.39. Share of RES in individual sectors

Figure 4.40 shows how the consumption of resources in the household sector changes in different scenarios. A significant difference is seen exactly in total energy consumption. The graph shows that a significant reduction in energy consumption compared to the baseline scenario is seen in the climate neutrality scenario. The climate neutrality scenario is the only one in which consumption of the household sector in 2050 is lower than in 2017. It can be seen that biomass is the dominant resource in all scenarios. If there is no substantial change in the distribution of resources in the baseline scenario, then in the climate neutrality scenario, there is a rapid abandonment of natural gas and other fossil resources, as well as at the end of the period, the use of solar energy is starting to enter the system. In the household sector, the use of solar energy is much lower than in district heating.

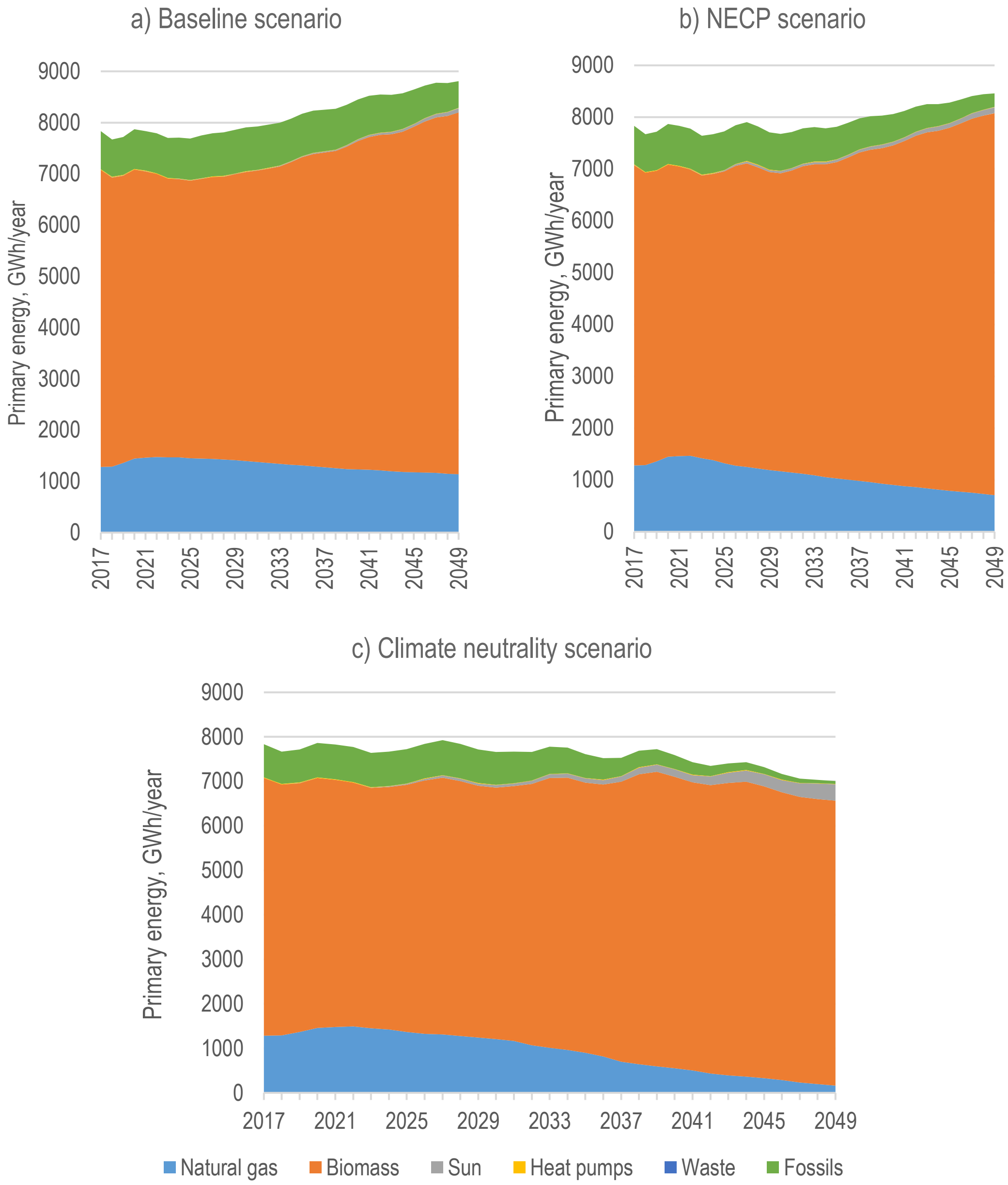
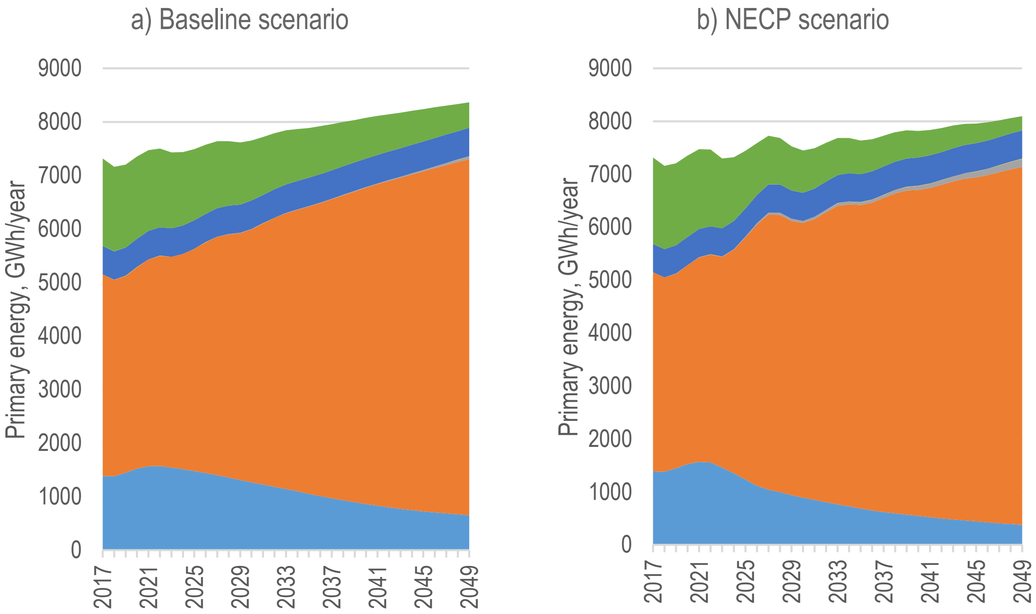


Fig. 4.40. Energy consumption of the household sector by types of resources in different scenarios

Figure 4.41 shows that biomass is also the dominant resource in the industry sector, but in 2017 the share of biomass was lower than in the household sector. The graphs show gradual switching from fossil resources to biomass in the baseline scenario, but the transition rate is slow. The growth in energy consumption observed in the industry sector is also covered by biomass. The climate neutrality scenario shows a reduction in energy consumption, which is related to improved energy efficiency, as well as a much more rapid abandonment of fossil resources in this scenario. In the climate neutrality scenario, a substantial part of the total energy is generated by solar energy, and the share of solar energy is significantly higher than in the household sector.



a) Baseline scenario

b) NECP scenario

c) Climate neutrality scenario

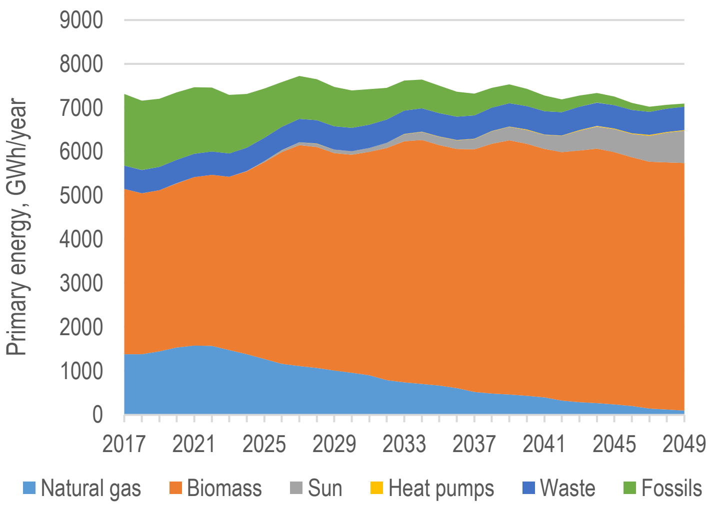


Fig.4.41. Energy consumption of the industry sector by types of resources

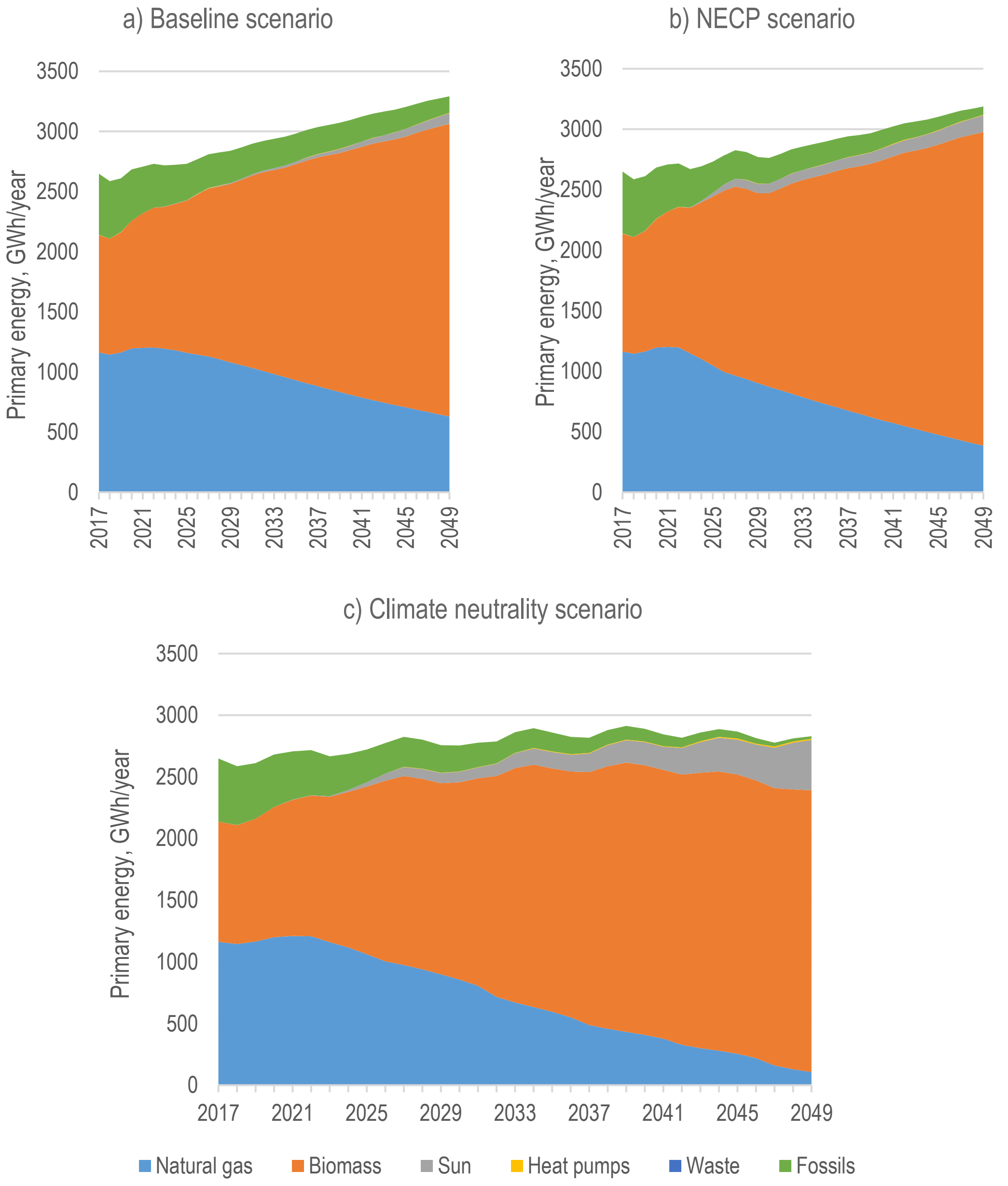


Fig. 4.42. Energy consumption of the services and public sector by types of resources

Figure 4.42 shows how the distribution of resources changes in different scenarios in the services and public sector. These sectors had significantly higher consumption of fossil resources in 2017. The baseline scenario shows an increase in energy consumption, while in other scenarios, it decreases as a result of energy efficiency measures. In the NECP scenario, energy consumption decreased by 3.2%, while in the climate neutrality scenario by 14% compared to the baseline scenario. In the services and public sector, we observe a trend for the replacement of resources, which is similar to the household and industry sectors. In the baseline scenario, the abandonment of fossil resources is relatively slow, while biomass consumption increases to cover the energy needs. In the climate neutrality scenario, there is an almost complete abandonment of fossil resources and a faster implementation of solar and biomass technologies.

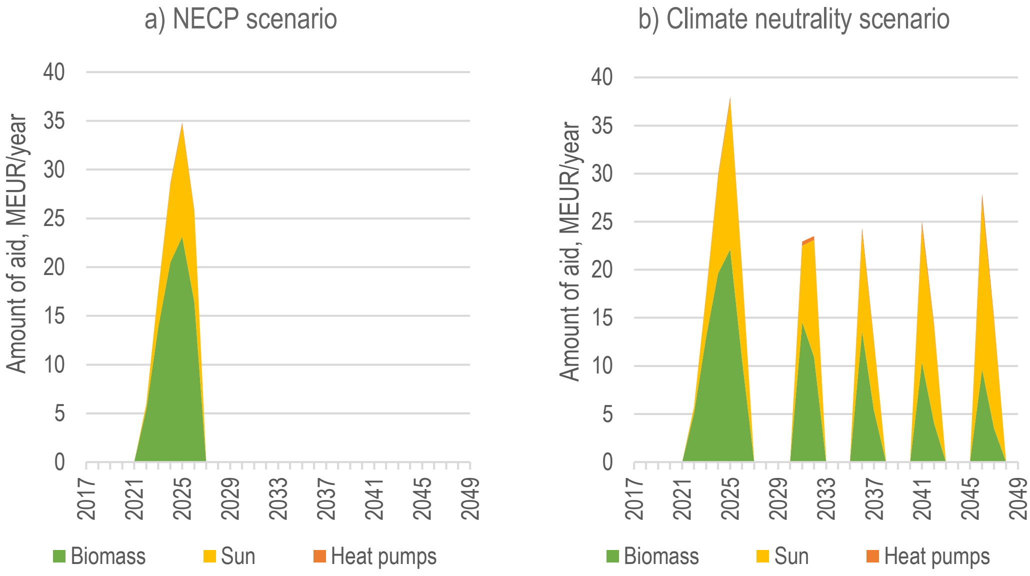


Fig. 4.43. Annual support in individual sectors by types of resources

In the baseline scenario, no support for the implementation of RES technologies in individual sectors is envisaged. Figure 4.43 shows that in the NECP scenario, support is provided for the period from 2021 to 2030, which is used to install solar and biomass technologies. In the climate neutrality scenario, additional support is also provided beyond 2030. It can be seen that in the climate neutrality scenario that support for the installation of solar and biomass technologies is also distributed after 2030, and only an insignificant part is granted for the installation of heat pump technologies. The amount of support shown in Figure 4.44 is summarised from all individual sectors.

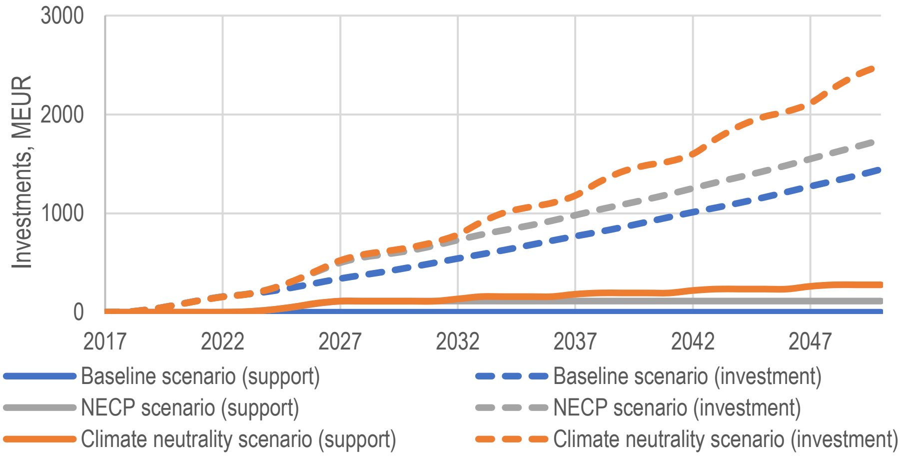


Fig. 4.44. Accumulated investments and support in different scenarios in individual sectors

Figure 4.44 shows the total investment and the amount of support granted for all sectors described in this section. There is a similar trend in DH. With the increase in support amount, total investment also increases. In the baseline scenario, no support is granted, while support amounts to 6.5% and 11.1% of total investment in the NECP and climate-neutral scenarios, respectively. In the NECP scenario, the total investment is 20.6% higher than in the baseline scenario, but in the climate neutrality scenario, it is even 72.8% higher than in the baseline scenario.

4.2.5. Transport sector

This section shows how the energy consumption of the transport sector will change in different scenarios. Figure 4.45 shows that the development of RES in the transport sector is not as rapid as in other sectors. In the baseline scenario, the share of RES without the introduction of strict policy instruments reaches only 11.4% in 2050. This means that the abandonment of fossil fuels is hardly happening at all. It is possible to raise the share of RES in transport by introducing support measures, raising tax rates and promoting rail electrification. In the NECP scenario, the share of RES is reaching 30.4% in 2050, while in the climate neutrality scenario, even 42.6%. This, of course, indicates that there is still a high share of fossil fuels, but switching to renewable fuels in the transport sector is much more difficult because of high investments. It is true that by reducing the total energy consumption of the transport sector, thus reducing the absolute values of emissions and developing carbon removal, climate neutrality can also be achieved with a conditionally low share of RES in transport.

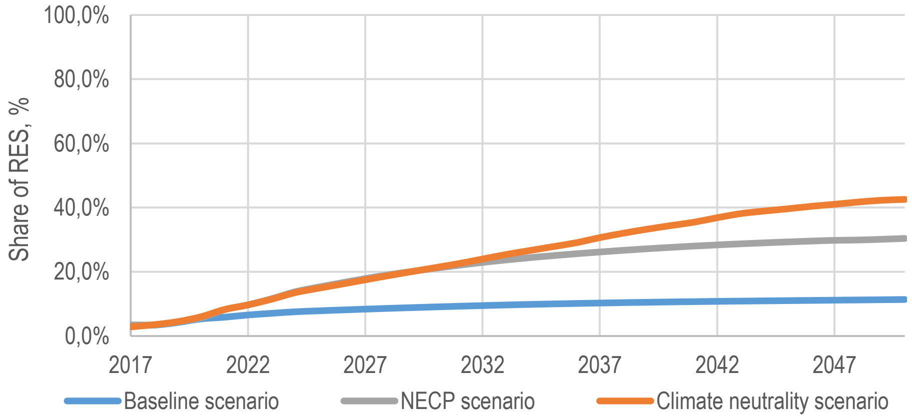


Fig.4.45. Share of RES in the transport sector

Figure 4.46 shows that the policy instruments selected in the scenarios can help to achieve a significant reduction in energy consumption in the transport sector. This is mainly due to a change in the mobility mode, resulting in switching from private transport to public transport. It is also one of the measures that could be most difficult to implement. The graph shows that the policy instruments used can reduce energy consumption by 9.8% in the NECP scenario and by 23.6% in the climate neutrality scenario.

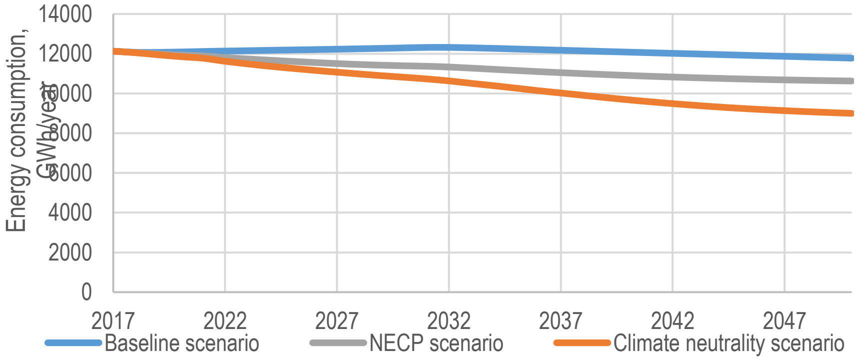


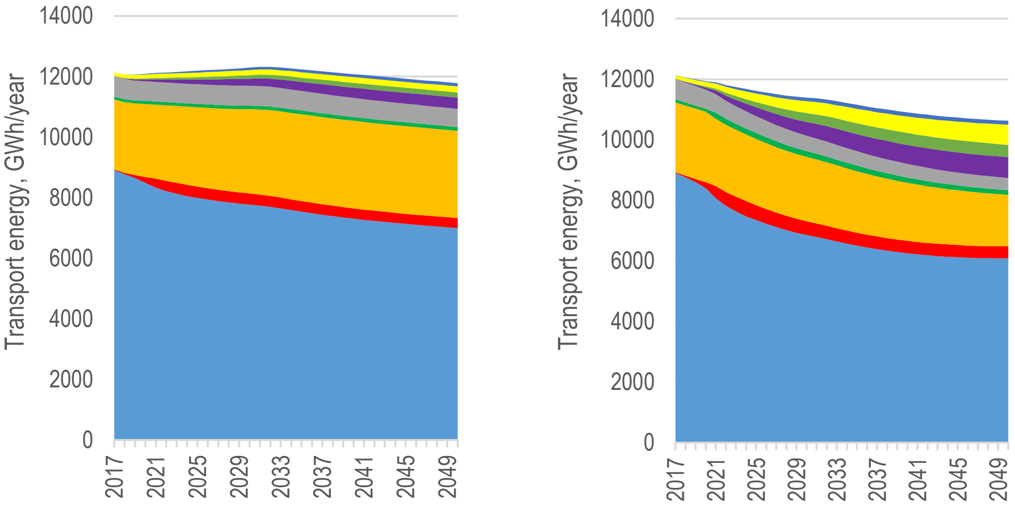
Fig. 4.46. Energy consumption in transport in different scenarios

Figure 4.47 shows how the fuel types used in the transport sector change in different scenarios. It can be seen that there are no significant changes in the baseline scenario. There is a slight decrease in diesel consumption, but there is a slight increase in petrol consumption. There is also a slight increase in the use of renewable fuels, but this does not allow the share of RES to exceed 11.4% in 2050.

A significantly different situation is observed in the climate neutrality scenario. Thanks to the set of policies employed, the consumption of diesel fuels declines significantly, and petrol consumption declines. A sharp increase in renewable fuels and electricity consumption is observed.

a) Baseline scenario

b) NECP scenario



c) Climate neutrality scenario

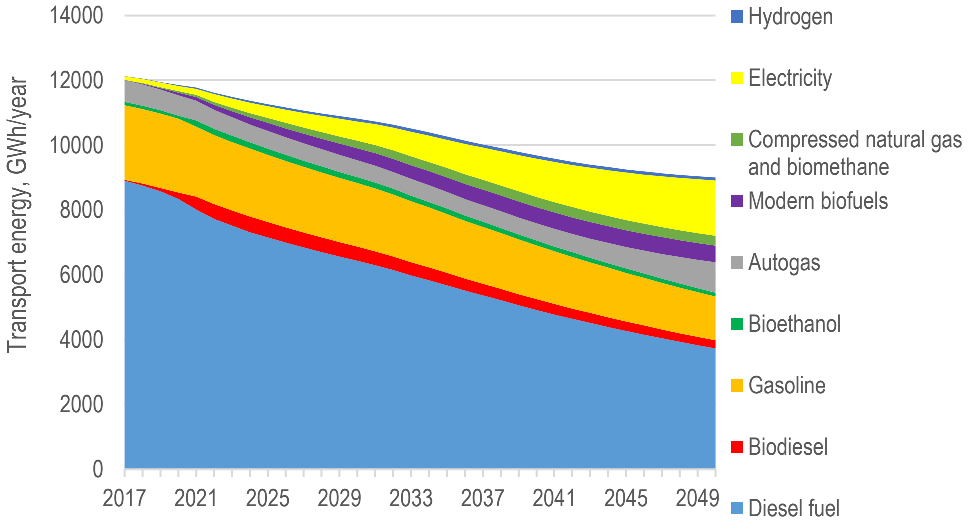
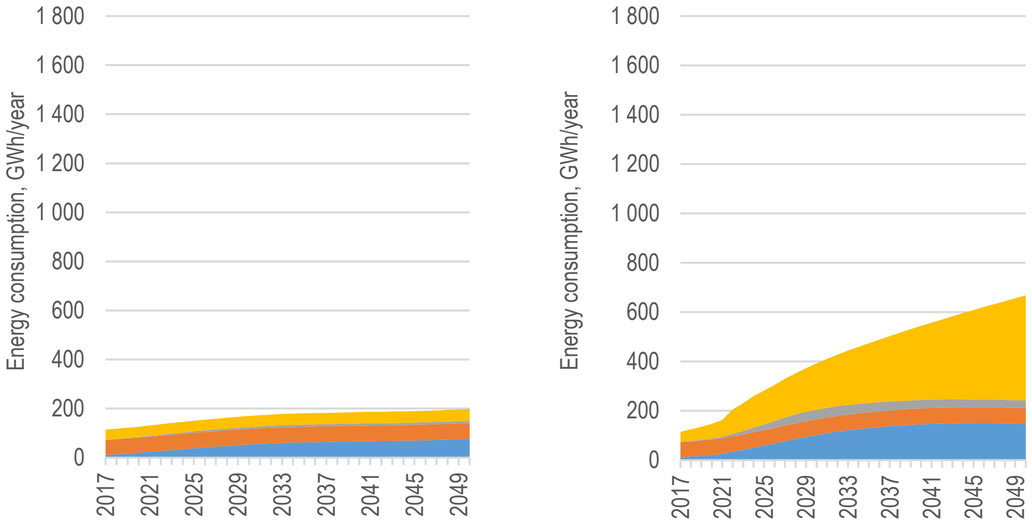


Fig. 4.47. Transport energy consumption by types of fuel

To better assess where exactly the fastest growth in electricity consumption is taking place, Figure 4.48 shows the distribution of electricity consumption by transport groups in different scenarios. It can be seen that in the baseline scenario, the total electricity consumption is relatively small and is distributed evenly between passenger vehicles, buses and railways. The bus category also includes electrified urban transport – trams and trolleybuses, which account for a significant share of electricity consumption in this category in the baseline scenario.



a) Baseline scenario

b) NECP scenario

c) Climate neutrality scenario

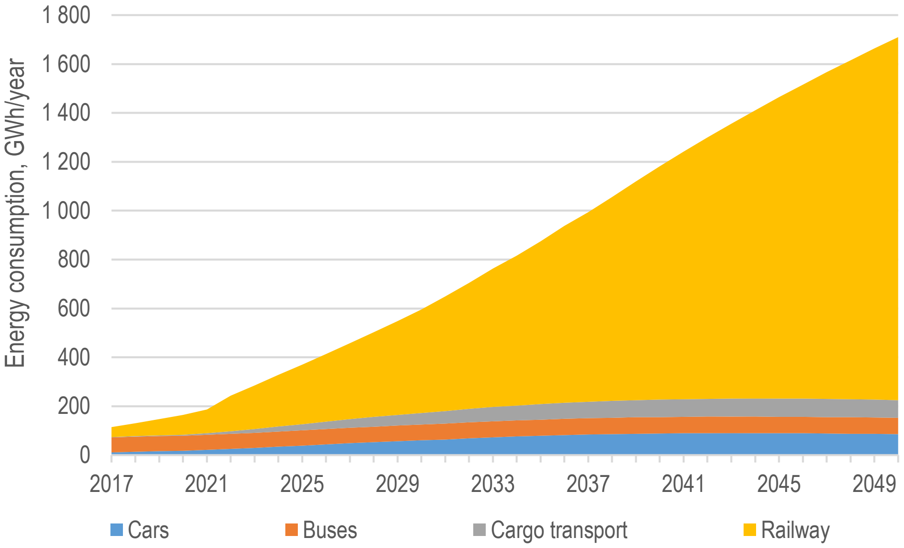


Fig. 4.48. Distribution of electricity by transport groups

In Figure 4.48, the NECP scenario shows an increase in electricity consumption in the railway category, due to the partial railway electrification process, as well as in the category of passenger cars, partly due to the availability of support. The climate neutrality scenario shows that the majority of electricity consumption takes place exactly in the railway category. This is due to the fact that, unlike in the NECP scenario, complete railway electrification is carried out in the climate neutrality scenario. Electricity consumption in the railway sector has increased by 775.3% in the NECP scenario and by 2947.5% in the climate neutrality scenario compared to the baseline scenario. A reduction in electricity consumption in the passenger vehicle group is observed in the climate neutrality scenario compared to the NECP scenario. This is mainly due to the fact that most of the population is switching to public transport. This reduces both the total energy consumption in the passenger car group and the consumption of electric cars.

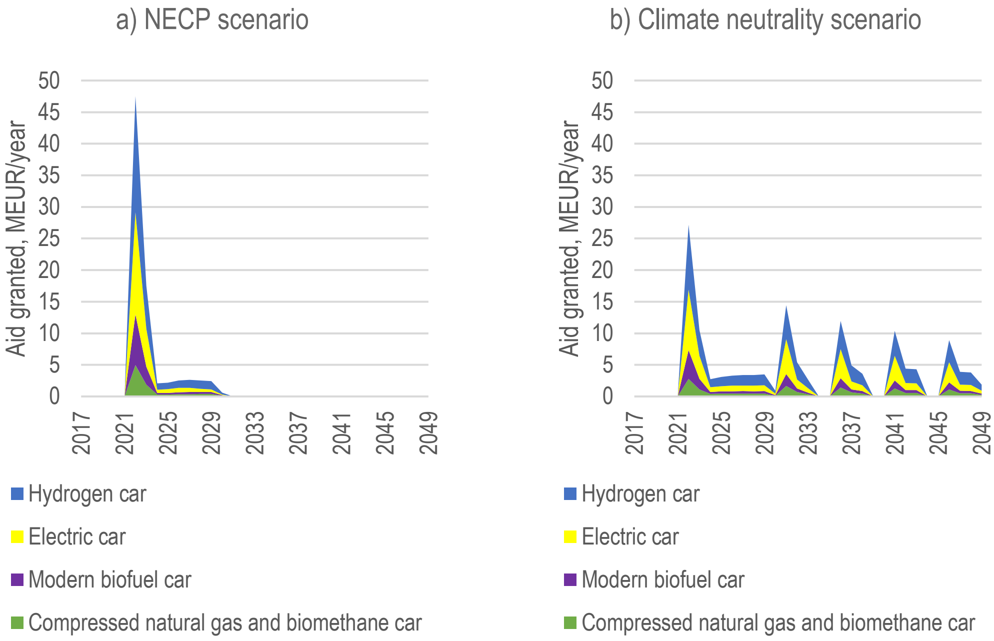


Fig. 4.49. Annual support amount for different fuel vehicles

Figure 4.49 shows what support is granted for different RES fuel vehicles in different scenarios. No support is granted in the baseline scenario. Support is granted from 2021 to 2030 in the NECP scenario and also after 2030 in the climate neutrality scenario. It can be seen that support in the NECP and climate neutrality scenarios are granted to different types of cars. The largest amount of support is channelled to the purchase of electric vehicles, but a sufficient part of the support is also used to promote the introduction of hydrogen cars, modern biofuels, CNG and biomethane-powered vehicles.

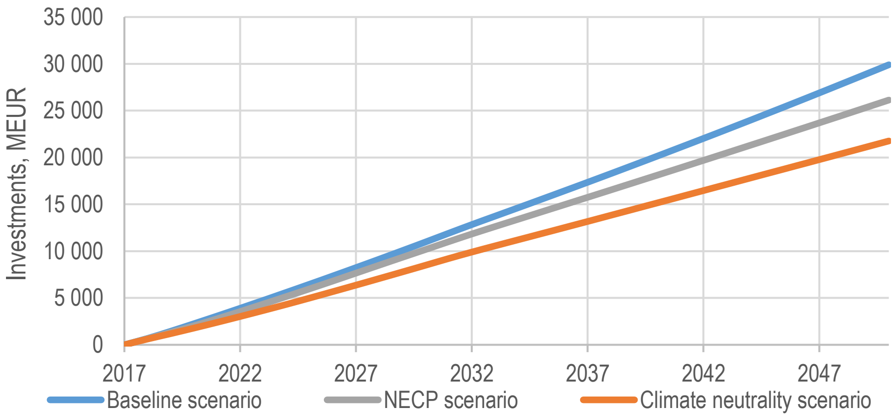


Fig. 4.50. Total investment in road transport in different scenarios

Figure 4.50 shows that very high investments are made in the transport sector in all scenarios. It can be seen that the largest amount of investment is in the baseline scenario and is related to the highest energy consumption and the highest number of vehicles in the baseline scenario. In NECP and climate neutrality scenarios, where a gradual switching to public transport, including railways, the need for the purchase of new vehicles will reduce, which also reduces the total amount of investment. The total amount of support does not appear in this graph because it is negligible compared to the total investment in the purchase of vehicles, even in the climate neutrality scenario. The support granted in the climate neutrality scenario represented only 0.6% of the total investment. Although the support contributes to the introduction of RES-powered vehicles, much more investment would be needed to have a more significant impact on the use of RES fuels in the transport sector.

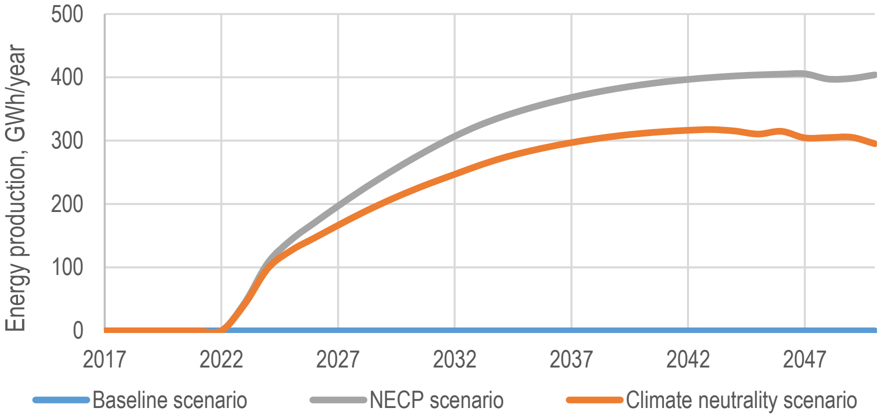


Fig. 4.51. Amount of production of biomethane for use in transport

Figure 4.51 shows how biomethane production developed in the transport sector in different scenarios. It can be seen that the highest production was in the NECP scenario rather than the climate neutrality scenario. The explanation here is the same as for the reduction in the number of electric vehicles in the category of passenger vehicles. As overall demand for energy in the climate neutrality scenario reduces, demand for biomethane also decreases accordingly, which means lower production volumes.

5. IMPACT ASSESSMENT AND RISK ANALYSIS OF POLICY SCENARIOS

5.1. Criteria for RES impact assessment. Review of literature

A review of literature has been carried out to comprehensively assess and compare scenarios of renewable energy policies. The methods used in the studies vary; several authors have used one of the decision-making methods to draw conclusions that are more precise from different aspects. This section summarises the criteria used in scientific studies to assess the integration of RES.

Most authors divide the criteria to be analysed into categories and subcategories, selecting technological, economic, social, environmental and institutional criteria to assess the sustainability of energy systems (Santoyo-Castelazo & Azapagic, 2014).

Various criteria and specific indicators were analysed for the development of sustainable local energy systems in Finland (Väisänen et al., 2016). From a technological point of view, compliance with consumption needs, compatibility, return on investment, reliability and renewability were used as indicators to be analysed. From an economic point of view, the availability of resources and job creation were examined. From a public point of view, the authors looked at health effects, the use of local resources and acceptance by society. Environmental factors are the most represented in the study and include indicators such as biodiversity, water use, greenhouse gas intensity, required land areas, ozone depletion, generated solid waste and water pollution. Finally, institutional criteria were further divided into regulatory and political indicators.

Another study analysed technical, economic, environmental and social aspects for comparing renewable energy systems (Şengül et al., 2015). Technical aspects include energy production efficiency, energy efficiency, primary energy ratio, security, reliability and development. The economic aspects analysed in this study are capital expenditure, operating and maintenance costs, fuel and electricity costs, net present value, payback time, lifetime costs. The environmental aspects selected were NO_x emissions, CO_2 emissions, CO emissions, SO_2 emissions, particulate emissions, volatile organic compounds and land use. Finally, social factors included social acceptability, job creation and social benefits.

In the analysis of electricity production technologies in Lithuania, five groups of criteria have been used to assess technologies: institutional political, economic, technological, socio-ethical and environmental protection (Štreimikienė et al., 2016). Institutional political factors include respect for international commitments, the legal framework for operations, autonomy of technology, support from government authorities and impact on sustainable energy development. The economic factors analysed are economic efficiency, the competitiveness of technology, production costs and the value of the technological complex. Socio-ethical criteria include the impact on social welfare, impact on sustainable social development and acceptance by society. Technological factors include the nominal capacity of the technology, technology reliability (casualty risk), technology innovation and resilience. Environmental criteria include an increase in the share of RES in the total energy balance, the impact on climate change and the reduction of pollution (SO_2, NO_x, NH_3, NMVOC), the generation of waste and respect for local natural conditions.

A study was published in 2013 (Stein, 2013), which developed a model for ranking electricity production technologies. Financial, technical, environmental and socio-economic criteria were used. Financial criteria included overnight costs, variable operating and maintenance costs, fixed operating and maintenance costs, as well as fuel costs. Technical criteria included the heat tariff, production efficiency and capacity utilisation factor. Environmental criteria were measured as externalities and reduction in a lifetime. Socio-economic and political criteria were defined as available reserves of fuel in years, job creation and net imports as a percentage of consumption.

The study on energy planning and the development of RES at the regional level in Greece uses economic, environmental, social and technical criteria (Mourmouris & Potolias, 2013). Economic criteria included investment costs, net present value, operating and maintenance costs, payback period, fuel costs and lifetime. GHG emissions reduction, land use and visual impacts were included in the environmental criteria. Social factors included social acceptability, job creation and social benefits. Finally, technical criteria analysed in the study were efficiency, security, accessibility and reliability.

Table 5.1 summarises the indicators contained in various studies, which can be used to compare different scenarios.

TABLE 5.1 REVIEW OF THE CRITERIA USED IN THE SCIENTIFIC LITERATURE

Criteria	Description	Unit
Energy availability	Share of time within which the power plant is capable of providing the necessary capacity	%
Employment	Number of jobs created during the lifecycle, including design, construction, operation and maintenance	Jobs per year/GWh
Land use	Required area	m^2/MWh
Noise pollution	Noise generated	dB
Energy production efficiency	Energy used efficiently	%
Power factor	Duration of use of installed capacity	%
Economic division	Share of RES contribution to GDP	% (of EUR)
Payback schedule	Technology payback	Years
Costs of energy production	Operating and maintenance costs	EUR/kWh
Capital expenditure	Equipment and technology costs	EUR/kWh
Fuel costs	Fee for fuel used	EUR/kWh
Emissions (lifecycle)	Emission generated throughout the lifecycle	gCO_2e/kWh
Delivery tariff	Costs of electricity for final consumer	EUR/kWh
Technological safety	Number of casualties from the use of technology	Injuries/hours worked
Ecosystem protection	Bird, animal accidents	Number of events/hours worked
Social acceptability	Public opinion	% of support / average assessment
Economic lifetime	Duration of use of technology	Years
Biogenic emissions	Emissions from biomass	gCO_2e
Pollutants	Carbon monoxide, solid particles, nitrogen oxide, sulphur dioxide	Tons/MWh
Use of water	Water consumption	l/MWh
Availability of resources to other industries	Consumption of resources	m^3, tons or MWh
Hazardous materials, waste	Volume with hazardous waste generated	tons
Recycling	Recycled amount after the use of technology	%
Continuity of manufacturing	Consistent production throughout the year	Manufacturing variations
Visual impact	Landscape change	Positive / negative
Externalities	Costs caused by different impacts	EUR/kWh
Loss of lifetime	The expected loss of lifetime is a degree	Days
Fuel reserves years	Number of years until complete depletion of the respective non-renewable source on earth	Years

5.2. Comparison of the impact of the modelled scenarios

Based on the literature analysis, the impact factors are divided into four main categories: social, environmental, technological and economic. Since not all the criteria listed in the scientific literature are applicable to impact assessment at the national level, only part of the factors considered is selected in the following assessment. Social factors include employment and changes in end tariffs. Environmental factors include the share of RES achieved, land use, lifecycle emissions, water use and externalities. Technological factors include energy availability, the efficiency of energy production and the power factor of the shares of RES achieved. The economic factors derived from the SD model are total investment, the financial support provided and increased tax burden.

In addition to the obtained results of the SD model, a number of impact factors have been defined in different categories. Different assumptions of the impact from different energy sources have been used for the calculation, as summarised in Table 5.2.

TABLE 5.2 ASSUMPTIONS REGARDING THE SPECIFIC IMPACT OF DIFFERENT ENERGY SOURCES

Factor	**Unit**	**Solar**	**Wind**	**Biomass**	**Hydro**	**Natural gas**
Employment	Job-years/Gwh	0.87	0.17	0.21	0.27	0.11
Lifecycle emissions	g_{CO2e}/kWh	48	11	230	24	490
Land occupation	m^2/MWh	8.7	0.7	450	3.5	0.1
Water use	l/MWh	330	43	85100	4961	500
External environmental costs	EUR/MWh	0.60	0.19	2.01	0.54	1.85
Energy availability	%	20	38	80	50	85
Power generation efficiency	%	20	35	25.3	90	38.8
Capacity factor	%	22	44	83	57	85

5.2.1. Social factors

Employment is measured as created jobs per GWh produced, which shows how many jobs are created throughout the lifecycle of the technology, including design, construction, operation and maintenance (Stein, 2013). The working year's indicator (Fig. 5.1) describes the jobs created during the lifecycle of power plants, including design, installation and management. The factor is assessed in two ways – both as a job creation indicator evidencing opportunities to boost employment and as a characterization of human resources capacity. If the importance of solar energy increases in case of any scenario, the greatest number of working years by 2050 will be created through this resource. In the case of wind energy and biomass, these changes are lower.

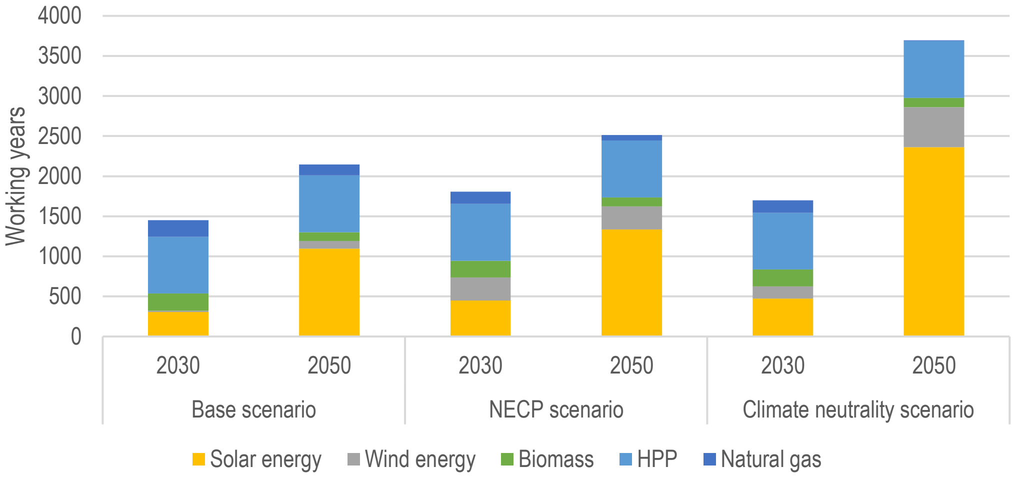


Fig. 5.1. Comparison of working years in different scenarios

The prices and tariffs of the necessary energy sources are additional social factors that may affect the solvency of the population. The results of the SD model summarised in Figure 5.2 allow for a comparison of average heat and electricity tariffs in different development scenarios. In the baseline scenario, the average heat tariff in 2030 and 2050 is around 60 EUR/MWh, while the average electricity tariff rises from 52 EUR/MWh in 2030 to 56 EUR/MWh in 2050. In the NECP policy scenario, the heat tariff rises slightly to 62 EUR/MWh in 2030 but reduces to 54 EUR/MWh in 2050. Until 2030 there is also a similar trend in the Climate neutrality scenario, while until 2050, the heat tariff in this scenario decreases to 50 EUR/MWh. In the NECP scenario, the average electricity tariff reduces to 51 EUR/MWh but slightly rises to 54 EUR/MWh in 2050. In the climate neutrality scenario, this increase is slightly higher – to 53 EUR/MWh in 2030 and 58 EUR/MWh in 2050, but the average tariff is lower than in the Baseline scenario. ‘

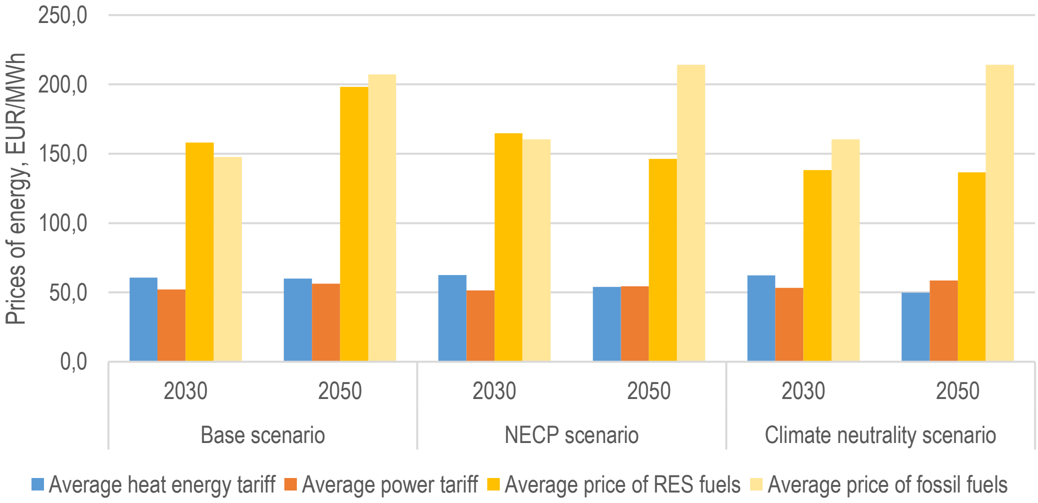


Fig. 5.2. Comparison of energy costs in different scenarios

In addition, changes in fuel prices have been analysed by doing a separate analysis of fossil fuels (diesel, petrol, compressed natural gas) and RES fuels (biofuels, biomethane and hydrogen). As shown in Figure 5.2, prices of fossil fuels are rising due to changes in tax policy. In the Baseline scenario, the price of fossil fuels is 147 EUR/MWh in 2030 and 207 EUR/MWh in 2050. In the NECP and Climate neutrality scenario, prices of fossil fuels rise to 160 EUR/MWh in 2030 and to 214 EUR/MWh in 2050. On the other hand, prices of RES fuels decrease compared to the Baseline scenario through the implementation of a number of support measures (support for science and research, support for building infrastructure). In the Baseline scenario, the average price of RES fuels is 158 EUR/MWh in 2030 and rises to 198 EUR/MWh in 2050. In the NECP scenario, prices of RES fuel rise slightly until 2030 but fall to 146 EUR/MWh in 2050. In the Climate neutrality scenario, prices of RES fuel range from 138 EUR/MWh to 136 EUR/MWh in 2050, reaching a significantly lower level of prices than fossil fuels.

5.2.2. Environmental factors

One of the key environmental factors characterising sustainable development of the energy sector is the share of RES achieved, which is compared for the different modelled scenarios in Figure 5.3. This factor also characterises the fulfilment of political commitments in meeting or failing to meet the targets set by the EU.

In the Baseline scenario, the total share of RES reaches 47% in 2030 and 58% in 2050. In the NECP scenario, the total share of RES achieved increases significantly to 56% in 2030 and 70% in 2050. In the Climate neutrality scenario, nearly 100% share of RES is achieved in power supply and district heating, and the total share of RES reaches 81%. The lowest share of RES in all scenarios is in the transport sector, which reaches 9% in the Baseline scenario and 21% in the NECP and Climate neutrality scenarios in 2030. In 2050, the share of RES in the transport sector will be 11% in the Baseline scenario, 30% in the NECP scenario and 43% in the Climate neutrality scenario.

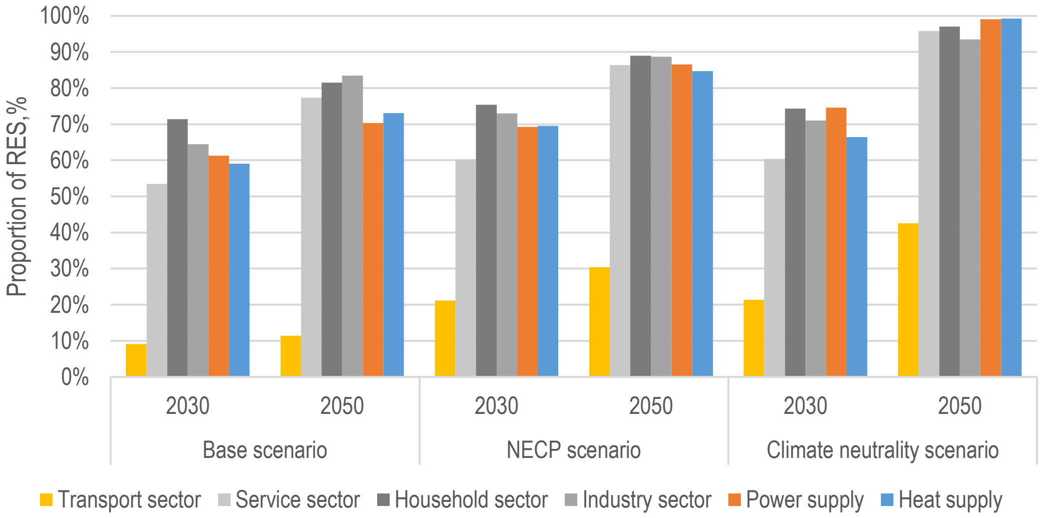


Fig. 5.3. Share of RES achieved in different scenarios

Another environmental factor related to the wider deployment of RES technologies is land use, which is defined as the land needed for technology, including land use for resource extraction and for other phases of the lifecycle, m^2 per MWh produced (UNCCD, 2017). The area required for energy production in the modelled scenarios for different RES sources is shown in Figure 5.4. In the case of the use of biomass energy, the required land area is significantly above the potential needs of all other resources. In the Climate neutrality scenario, the amount of land needed to produce solar energy also increases slightly.

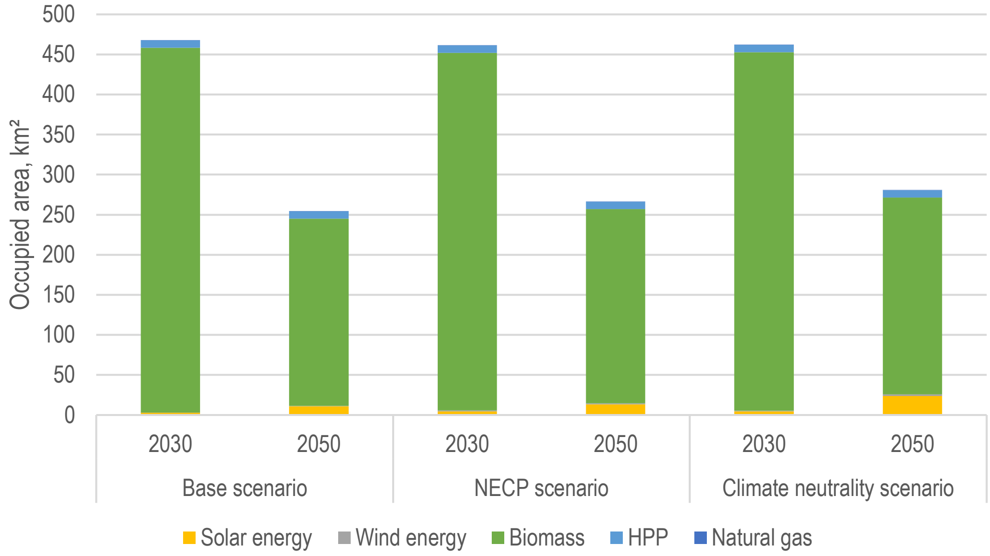
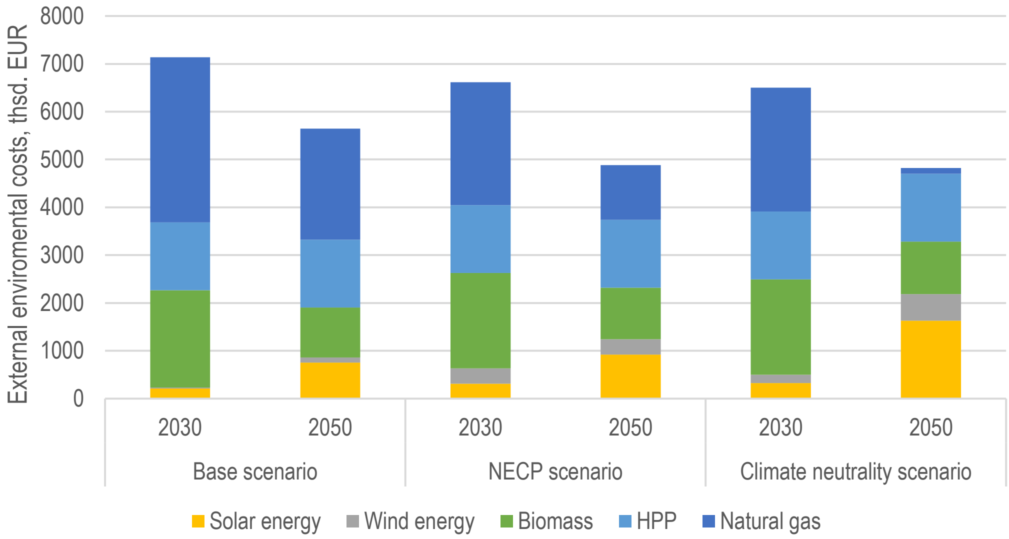


Fig. 5.4. Area occupied for energy production, km^2

The indirect environmental costs incurred in relation to the specific technology are assessed as externalities and measured in EUR per MWh produced. (Stein, 2013). The externalities (Fig. 5.5) are higher for the use of natural gas, so the rest of the RES has a significant positive impact on environmental parameters. However, the use of solar and wind energy also entails small external costs. Therefore the total externalities in the NECP and Climate neutrality scenarios in 2030 and 2050 are similar.



Fig, 5.5. Comparison of externalities in different scenarios

The largest lifecycle emissions (Fig. 5.6) are caused by the use of natural gas and biomass. In the Climate neutrality scenario, lifecycle emissions from the use of solar energy also increase slightly, as PV technologies need to be produced. However, a significant reduction in lifecycle emissions is seen in the Climate neutrality scenario.

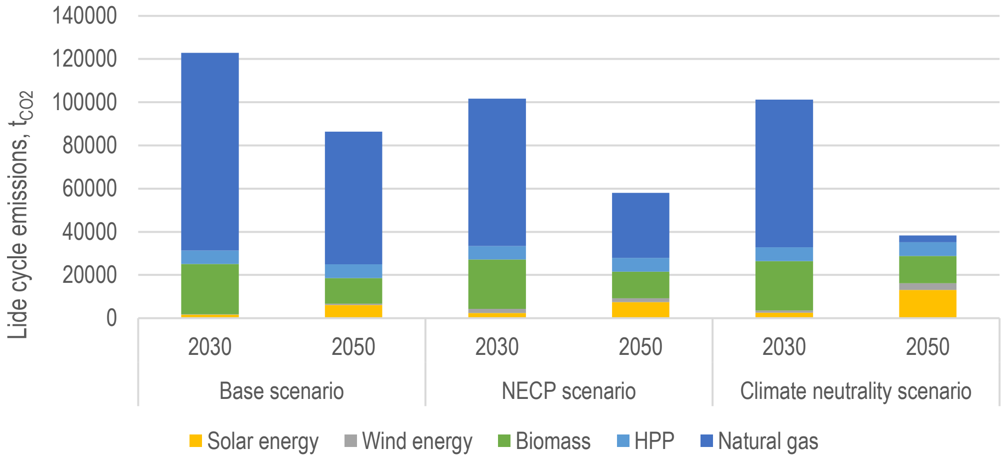


Fig. 5.6. Comparison of lifecycle emissions in different scenarios

The use of water is assessed by calculating how much water is used in each technology, litres per MWh produced (Jin et al., 2019). In previous studies, the authors present an inventory of water use in energy production from different technologies. Significant water consumption (Fig. 5.7) In the RES sector, it is limited to producing energy from biomass. Although the water used by HPPs is included in consumption, the losses of the resource do not occur directly, and the impact changes are not anticipated in any of the scenarios of the energy sector.

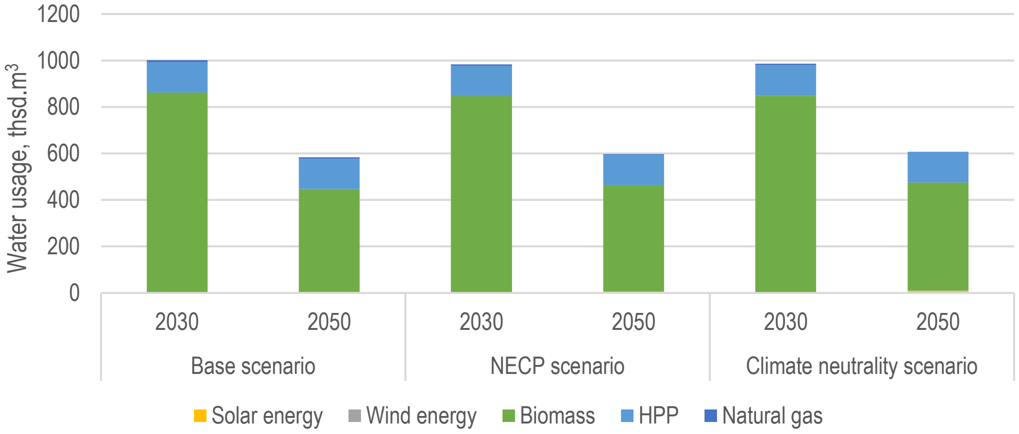


Fig. 5.7. Comparison of water consumption in different scenarios

The consumption of biomass resources is assessed as an additional factor applying it to the expected availability of available biomass resources in the energy sector. The results obtained by the SD model are shown in Figure 5.8.

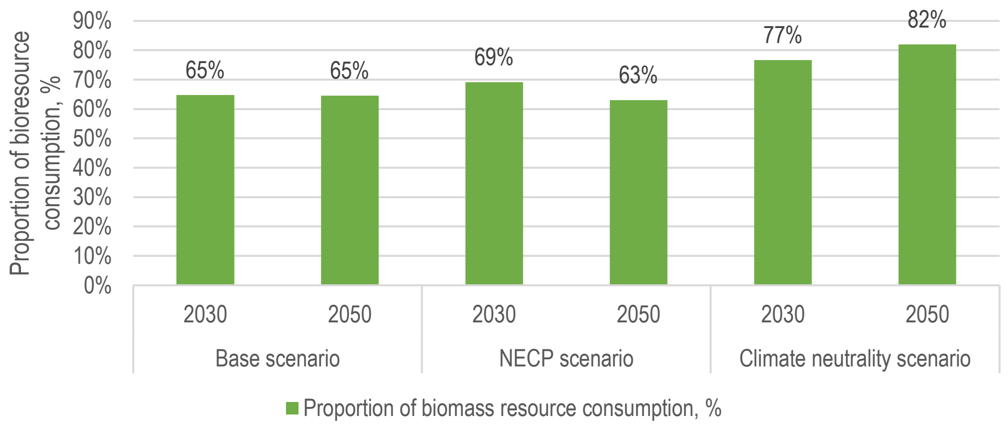


Fig. 5.8. Availability of consumption of biomass resources

As can be seen in Figure 5.8, in the Baseline scenario, by 2050, around 65% of available energy wood will be consumed, while the share of biomass consumed in the NECP scenario by 2050 even slightly decreases due to the use of other RES technologies. In turn, in the Climate neutrality scenario until 2050, 82% of the amount of wood available per year are consumed.

5.2.3. Technological factors

The general technical parameters are shown in Figure 5.9. Energy availability is defined as the time for which the required amount of energy can be produced, divided by the total period of time and measured as a percentage (Chatzimouratidis & Pilavachi, 2009). The efficiency of energy production is measured as a percentage, and it shows how much energy is used effectively for the specific technology. The power factor is expressed as a percentage, and it is the ratio of the electricity produced by a generating unit during the respective period of time, which could have been produced in continuous full capacity mode during the same period (Stein, 2013).

Only electricity is analysed in the determination of the criterion, and therefore, in the case of biomass production efficiency, the heat produced is not included. The resulting comparison of the technological criteria for the various modelled scenarios is summarised in Figure 5.9.

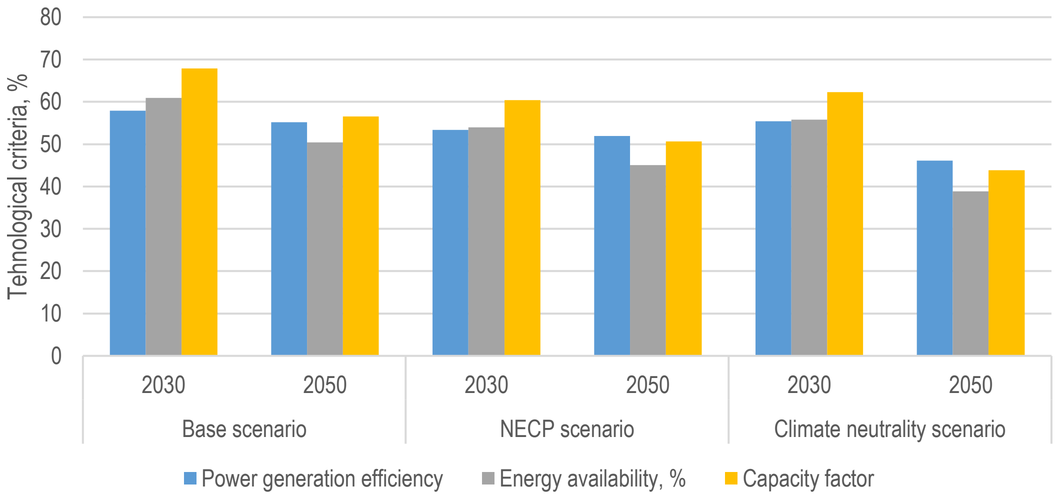


Fig. 5.9. Technological capabilities, percentage

Taking into account that solar and wind technologies have lower energy availability and energy production efficiency, as well as capacity utilisation factors, it can be seen that in the Climate neutrality scenario until 2050, the technological criteria are lower than in the NECP or Baseline scenario. This factor should be taken into account when planning the transformation of the energy sector and providing support for storage systems that increase technological capabilities.

5.2.4. Economic factors

The necessary investment costs, the costs of the financial support provided and the tax payments are used as the main economic criteria. The financial support granted to promote the implementation of RES technologies in the different scenarios is summarised in Figure 5.10. The total amount of funding provided in the Baseline scenario is limited to funding that has already been approved for 2017-2021. In the NECP scenario, the total support provided for the implementation of the various policy support mechanisms amounts to 605 million EUR, but the support granted in the Climate neutrality scenario amounts to 765 million EUR in 2030 and 1545 million EUR until 2050. Most or 44% of the funding in the NECP scenario is allocated to the heating sector and 37% to the transport sector. In the Climate neutrality scenario, additional funding is also allocated to the power supply and individual sectors – households, industry and commercial sector.

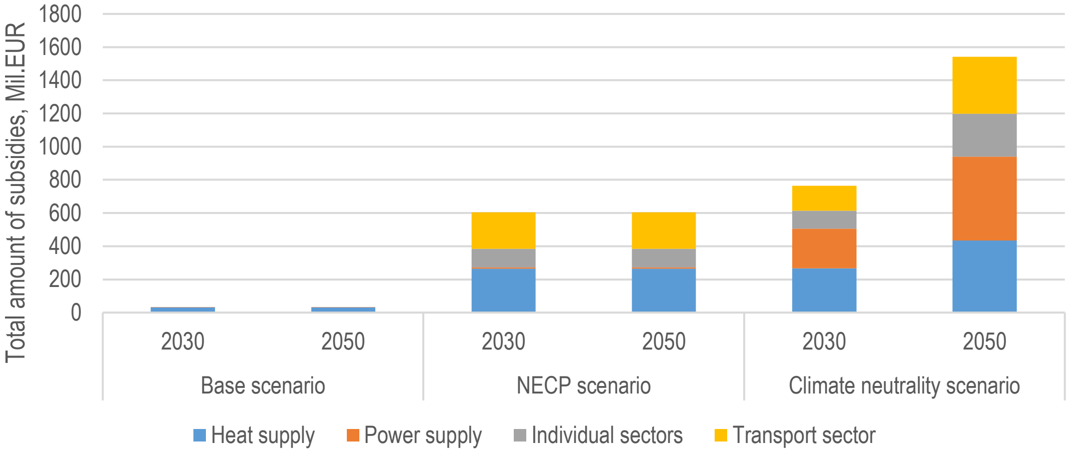


Fig. 5.10. The total amount of funding provided in different scenarios

The results of the SD model for the total investment needed for the replacement of energy production infrastructure in the various scenarios are shown in Figure 5.11. Comparing the total investment needed in the Baseline scenario with investment in the NECP and Climate neutrality scenarios, an increase of around 46% is observed compared to the results of 2030. On the other hand, the Climate neutrality scenario shows a 9% increase in investment needed in 2050 compared to the NECP scenario amounting to a total of 18,187 million EUR. As can be seen in Figure 5.11, in all scenarios, the largest investment occurs in the transport sector. In the Climate neutrality scenario, investment also increases for the transition of the electricity sector to the use of RES technologies.

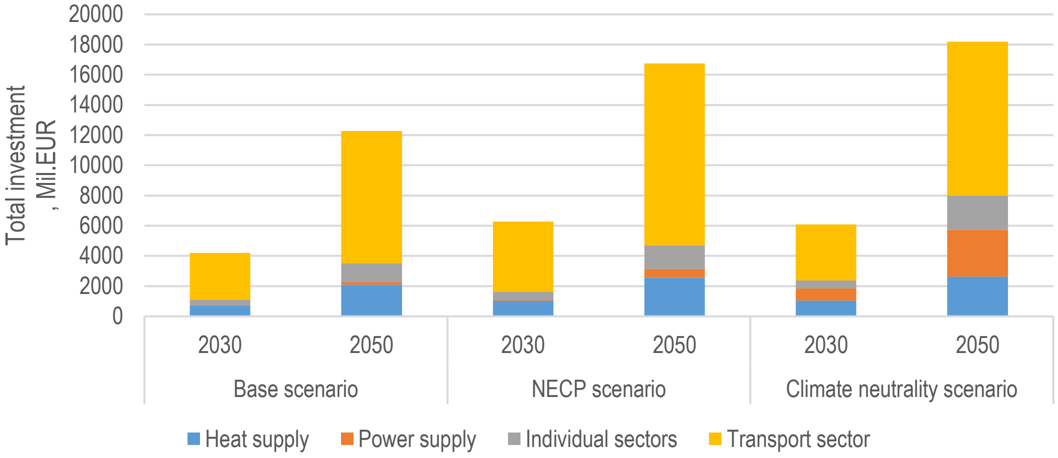


Fig. 5.11. The total investment needed in each of the scenarios

Table 5.3 summarises the results obtained by the SD model on cumulative tax payments in different analysed scenarios.

TABLE 5.3 OVERVIEW OF CUMULATIVE TAX PAYMENTS IN EACH OF THE ANALYSED SCENARIOS

Tax payments, million EUR	**Baseline scenario**		**NECP scenario**		**Climate neutrality scenario**	
	2030	**2050**	**2030**	**2050**	**2030**	**2050**
Natural gas excise duty	247	525	267	642	272	775
Natural resources tax	119	274	130	330	135	398
Transport fuel excise duty	6415	16309	6494	20579	6307	17767

As shown in Table 5.3, increasing fossil taxes also significantly increases the cumulative tax costs that would need to be covered by energy producers and merchants consuming fossil energy resources. However, in the Climate neutrality scenario, the cumulative amount of excise duties on transport fuels obtained in 2050 is lower than in the NECP scenario, as the consumption of fuels not subject to excise duty increases significantly.

5.3. Impact assessment using a multi-criteria analysis method

Since the criteria analyzed above include different impacts and are not directly comparable, the multi-criteria decision-making method (MCDM) has been used to assess the different aspects of the scenarios assessed. Scientists use MCDM to compare different alternatives using several criteria. AHP is one of the most popular MCDM methods because it is understandable and easy to implement (Mastrocinque et al., 2020). AHP is a valuable tool for comparing alternatives, using both quantitative and qualitative criteria that have contributed to its use to address various problems around the world. In addition, the method is flexible and adaptable to perform comparisons. It is also possible to carry out a consistency check (Mwanza & Ulgen, 2020).

AHP is a tool that uses hierarchical levels to structure the decision-making process (Chatzimouratidis & Pilavachi, 2009). The aim is to define the choice of the best renewable energy policy in Latvia. The multi-criteria analysis method is suitable for assessing impacts caused in the short term (until 2030) and in the long term (until 2050).

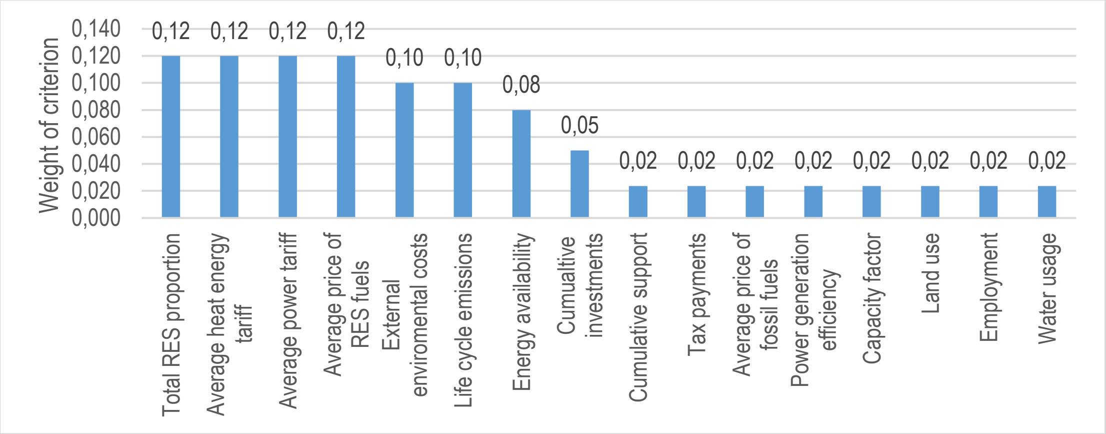


Fig. 5.12. Weights used for different factors

Not all of the factors analysed have the same impact in terms of sustainable development. Therefore the criteria analysed have been prioritized using the AHP paired comparisons method. Several experts involved in the project in order to provide a comprehensive assessment have carried out the assessment. Higher priority is given to the share of RES achieved, the prices of heat, electricity and RES fuels. The lower impact is applied to land use, employment, water use and fossil fuel price criteria.

5.3.1. Assessment of the results until 2030

The criteria obtained in Chapter 5.2 have been normalised to harmonise units of measure and to obtain a single assessment of scenarios. The normalised values of the obtained criteria are summarised in Table 5.4. Figure 5.13 shows the result obtained for different scenarios, applying prioritised criteria values and equivalent criteria values.

TABLE 5.4 NORMALISED DECISION-MAKING MATRIX FOR COMPARING DIFFERENT SCENARIOS UNTIL 2030

Criterion	**Baseline scenario**	**NECP scenario**	**Climate neutrality scenario**
Cumulative support	0.03	0.62	0.78
Cumulative investment	0.43	0.65	0.63
Total share of RES	0.51	0.61	0.61
Tax payment	0.58	0.59	0.57
Average heat tariff	0.57	0.58	0.58
Average electricity tariff	0.58	0.57	0.59
Average price of fossil fuels	0.55	0.59	0.59
Average price of RES fuels	0.59	0.62	0.52
Energy availability	0.62	0.55	0.57
Energy production efficiency	0.60	0.55	0.58
Capacity utilisation factor	0.62	0.55	0.57
Land use	0.58	0.57	0.58
Employment	0.50	0.63	0.59
Externalities	0.61	0.57	0.56
Lifecycle emissions	0.65	0.54	0.54
Use of water	0.58	0.57	0.57

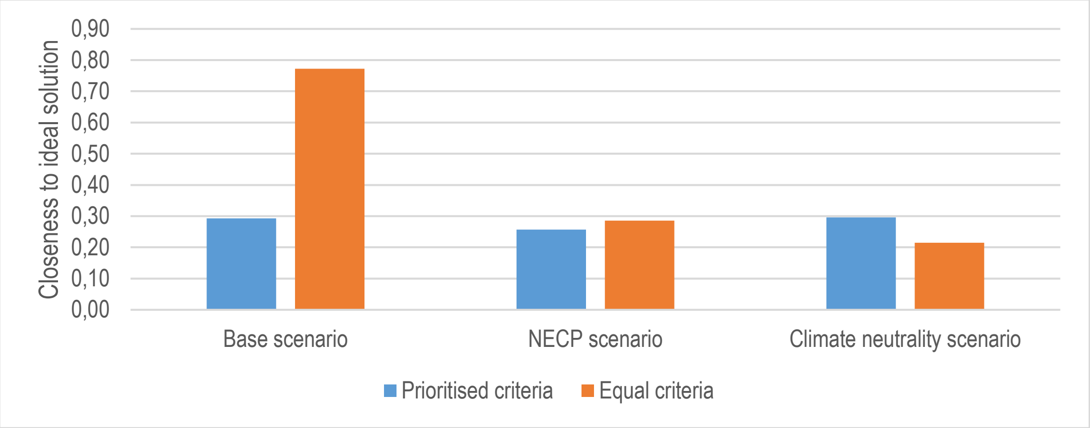


Fig. 5.13. Results of the multi-criteria analysis for assessment until 2030

The results obtained show that using equivalent weights for all the criteria analysed, the Baseline scenario with the lowest investment, necessary subsidy support, heat tariff and price of fossil fuels has been assessed as the best solution. On the other hand, if the criteria analysed are prioritised, a higher assessment is reached for the climate neutrality scenario.

5.3.2. Assessment of the results until 2050

The values of the criteria achieved until 2050 have been normalised and summarised in Table 5.5. The results obtained from the long-term assessment are shown in Figure 5.14.

Table 5.5

Normalised decision-making matrix for comparing different scenarios until 2050

Criterion	**Baseline scenario**	**NECP scenario**	**Climate neutrality scenario**
Cumulative support	0.02	0.37	0.93
Cumulative investment	0.45	0.61	0.66
Total share of RES	0.48	0.57	0.67
Tax payment	0.51	0.65	0.57
Average heat tariff	0.63	0.57	0.53
Average electricity tariff	0.58	0.56	0.60
Average price of fossil fuels	0.56	0.58	0.58
Average price of RES fuels	0.70	0.52	0.49
Energy availability	0.65	0.58	0.50
Energy production efficiency	0.62	0.59	0.52
Capacity utilisation factor	0.65	0.58	0.50
Land use	0.55	0.57	0.61
Employment	0.43	0.51	0.75
Externalities	0.64	0.55	0.54
Lifecycle emissions	0.78	0.52	0.35
Use of water	0.57	0.58	0.59

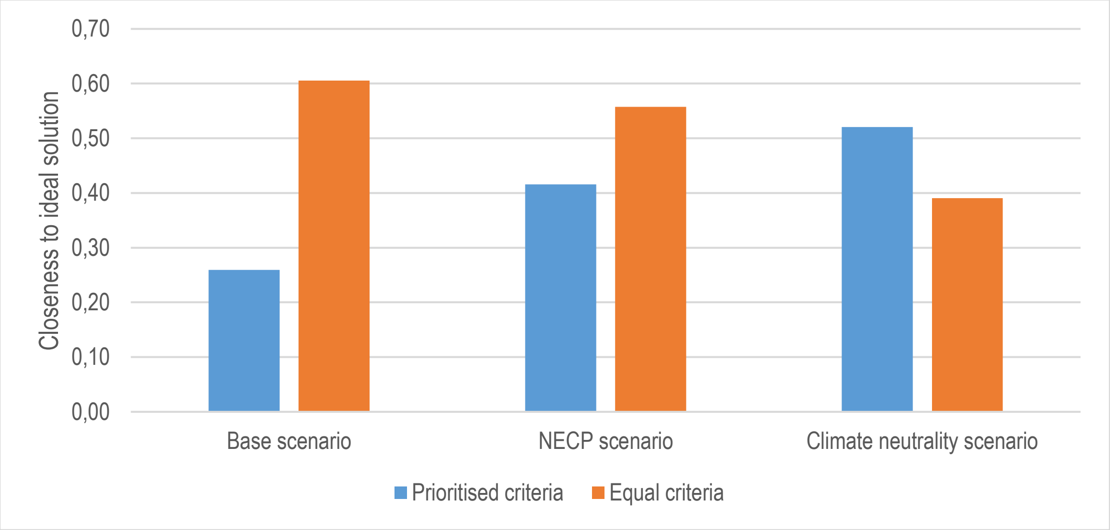


Fig. 5.14. Results of the multi-criteria analysis for assessment until 2050

Similarly to the results of the short-term assessment, the long-term assessment shows that, when equivalent values of the criteria analysed are used, the Baseline scenario gives the highest results in the multi-criteria analysis. In contrast, the prioritisation of impact factors shows that the Climate neutrality scenario provides an assessment closer to an ideal solution or a more sustainable energy sector.

5.4. Risk assessment

The risk analysis of the defined scenarios is presented in Table 5.6, which analyses the different risks associated with the implementation of RES technologies. Risks have different impacts and likelihood assessed as high, medium or low. The table also presents potential actions to prevent or mitigate risks.

The risk of the lobby of fossil energy sources, which would delay support to the implementation of RES promotion policies, has been identified as the risk with high likelihood and high impact. The reduction of such a risk requires setting ambitious national targets and concrete actions to achieve climate neutrality, excluding political impacts on their implementation.

Another high-impact risk in the case of wider use of solar and wind energy is insufficient electricity grid capacity and complex balancing. The prevention of such a risk requires developing a long-term strategy for uniting sectors and balancing networks to utilise RES electricity surpluses effectively. The development of such a strategy should involve all key players in the energy sector – network operators, district heating operators, electricity traders, local governments and policy makers – to achieve high sector integrity. In addition, it is possible to shift consumption loads by introducing consumer management with an aggregator as a market participant. Support should be provided for the integration of storage systems into the power supply and heat supply, including the integration of large-scale heat pumps.

TABLE 5.6 OVERVIEW OF IDENTIFIED RISKS

Potential risk	Risk assessment		Action to prevent or mitigate risk
	Likelihood	Impact	
The lobby of fossil energy sources, which delays support to the implementation of RES promotion policies	High	High	Setting ambitious national targets and concrete actions to achieve climate neutrality, excluding political impacts on their implementation
Insufficient electricity grid capacity and complex balancing in case of high RES share	High	High	Developing a long-term strategy for uniting sectors and balancing networks to effectively utilise RES electricity surpluses. Introducing consumer management with an aggregator as a market participant. Support for the integration of storage systems into the power supply and heat supply
Insufficient public involvement in the decarbonisation of the transport sector	High	High	Introducing a more comprehensive support policy to replace existing transport infrastructure
The rapid rise in energy prices and energy tariffs	High	Medium	More extensive use of hydropower, solar and wind energy to eliminate dependence on imported energy sources and electricity
Use of high-value wood in the energy sector, reducing the added value generated	High	Medium	Development of long-term planning documents for the use of bioresources at the national level. Implementation of bioresources cascading principles. Reduction of wood exports
Significant increase in RES technology investment	Medium	High	Steady support for investment in RES technologies to maintain supply-demand balance
Insufficient action for the implementation of RES technologies at the local level	Medium	High	Support for the development of long-term energy sector development documents for municipalities. Support mechanisms for municipalities to promote the implementation of RES technologies
Significantly increased production costs in case of increase in fossil taxes	Medium	High	Combining tax policy changes with support mechanisms for integrating more RES technologies into the industrial sector
Reduction in the availability of biomass resources for the energy sector	Medium	High	Support for efficient use of biomass and diversification of energy sources. Promoting sustainable management of bioresources. Reduction of exports of energy wood
Installation of excess production capacity and insufficient economic return on investment	Medium	Medium	Introduction of the “Energy Efficiency First” criterion in any RES technology support programme
Dismissive public attitudes to the transition to a climate-neutral energy sector	Medium	Medium	Combining comprehensive information campaigns with support mechanisms for local communities for the implementation of RES technologies.
Installing poor quality RES technologies without achieving high-efficiency levels	Medium	Medium	Long-term support for science and research for the implementation of efficient solutions and innovative RES pilot projects. Creating catalogues of technology standards.
Insufficient monitoring system to monitor the achievement of RES targets	Medium	Medium	Improving the availability of energy sector data. Establishment of a comprehensive monitoring system
Increase in final consumption due to increased economic welfare	Medium	Medium	Implementing information campaigns by promoting the use of energy-efficient equipment and changing habits to reduce final consumption in different sectors
Significant regional differences in the development of the energy sector and the transition to climate neutrality	Medium	Low	Setting and including regional RES targets in the planning documents. Monitoring the current situation

The transport sector is one of the most important sectors needed to be transformed to achieve climate neutrality. Therefore, the lack of public involvement in the decarbonisation of the transport sector is a high-impact risk. Introducing a more comprehensive support policy to replace existing transport infrastructure is needed to facilitate the transition of society to RES fuels and electricity vehicles. This would include both information campaigns and support for the purchase of environmentally-friendly vehicles and the increase of fossil taxes.

In the current situation, rapid increases in the prices of fossil resources and imported electricity have been identified as a major risk to the energy sector. However, the transition to more extensive use of RES technologies and local energy sources would also increase resilience to significant price fluctuations. On the other hand, the use of RES technologies could be significantly affected by the increase in investment in solar panels, wind turbines, heat pump technologies. It would be necessary to ensure long-term, rather than periodic co-financing of these technologies so as not to contribute to the loss of supply-demand market balance to prevent this.

As the results of the model predict an increase in the share of biomass in electricity and heat production, the use of high-quality wood in the energy sector is a major risk, which would not contribute to the sustainable use of bioresources. Such a risk could be avoided by introducing cascading principles by setting clearly that only low-quality wood, which cannot be processed into higher-value products, should be used in energy production.

Other risks have been identified as a medium, but it is essential to ensure that the implementation of different RES technology support mechanisms includes criteria to mitigate the impacts of these risks.

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