Energy Planning Support to Europe and Central Asia: Case Studies

Contents

RER2017

Assessing the Role of Low Carbon Energy Technologies for Climate Change Mitigation

27 participating Member States

2020 – 2021 project duration

200+ participants and experts

10 meetings and training courses

RER2018

Analyzing Low Carbon Pathways towards an Ambitious Decarbonized Energy Sector by 2050

2022 – 2025 project duration

24 participating Member States

Introduction

The Paris Agreement aims to keep the increase in the global average temperature to well below 2°C above pre-industrial levels and pursues efforts to limit the increase to 1.5°C above pre-industrial levels.

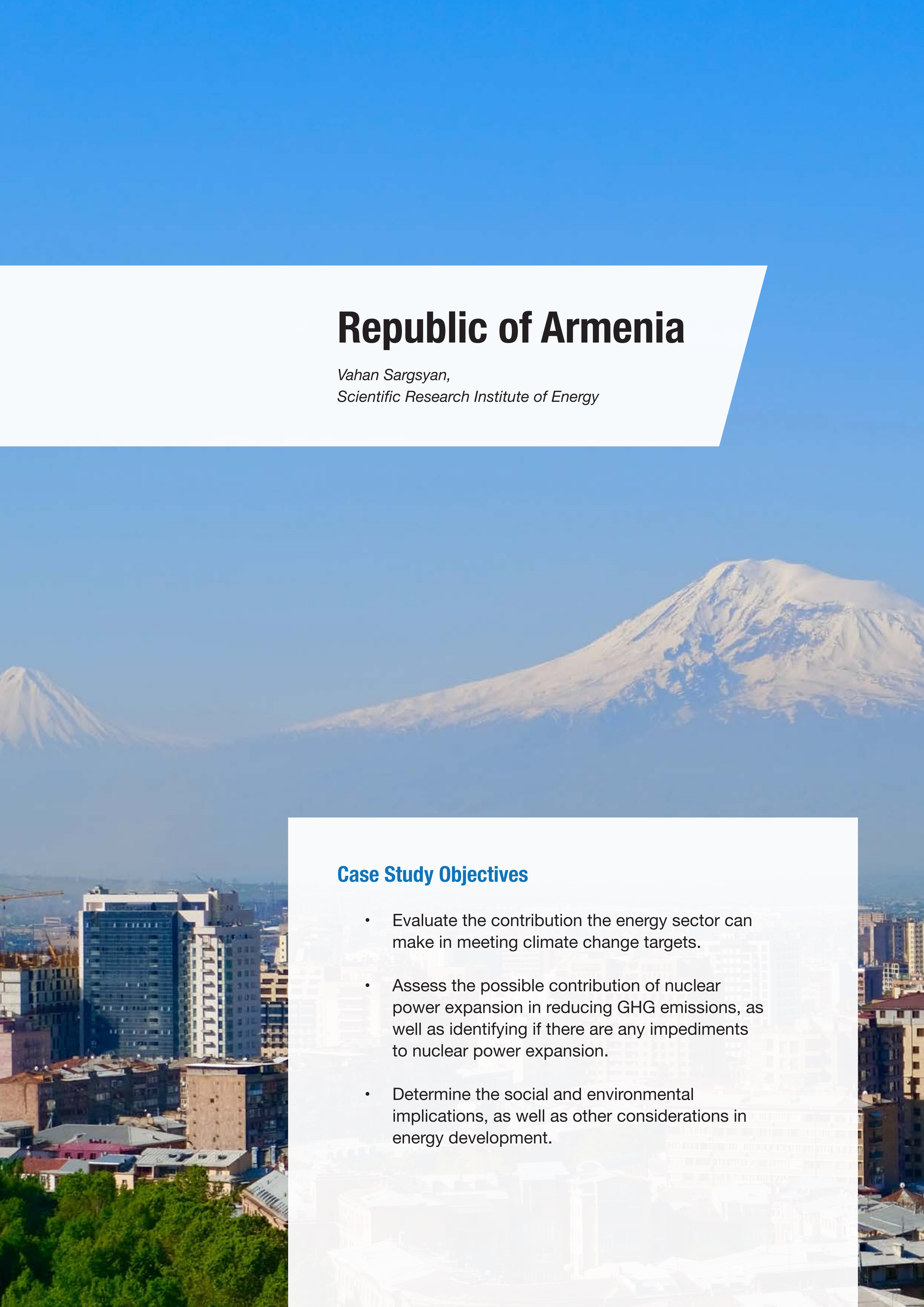
This brochure presents key energy modelling highlights from studies focusing on the Republic of North Macedonia, Georgia, the Republic of Moldova, the Republic of Armenia, Romania and the Russian Federation. It was developed in the framework of the Technical Cooperation project RER2017 'Assessing the Role of Low Carbon Energy Technologies for Climate Change Mitigation'. From 2020 until 2021, this project supported 27 Member States in Europe and Central Asia by strengthening their expertise in evaluating and assessing energy technologies and their potential contribution to climate change mitigation.

During the period 2022 to 2025, energy planning support is provided to 24 countries from the Europe and Central Asia through the Technical Cooperation project RER2018 'Analyzing Low Carbon Pathways towards an Ambitious Decarbonized Energy Sector by 2050'. This project supports the participating IAEA Member States in their development of energy strategies for climate change mitigation in line with the Paris Agreement, including country plans for the implementation of Nationally Determined Contributions (NDCs) and National Energy and Climate Plans (NECPs).

The project is a platform for energy and climate specialists to discuss the main features and challenges of such strategies and plans. Through a series of meetings, trainings and expert assignments, it supports assessments of related energy pathways and associated technology mixes, including nuclear power for those countries considering this option.

The IAEA tools used for supporting analysis include, among others, the Model for Energy Supply Strategy Alternatives and their General Environmental Impacts (MESSAGE), the Model for Analysis of the Energy Demand (MAED), as well as other tools adapted or developed at the national level.

Authors are listed under each case study. Please note that the studies may be exploratory in nature and may not reflect official country strategies.



Republic of Armenia

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Case Study Objectives

- Evaluate the contribution the energy sector can make in meeting climate change targets.
- Assess the possible contribution of nuclear power expansion in reducing GHG emissions, as well as identifying if there are any impediments to nuclear power expansion.
- Determine the social and environmental implications, as well as other considerations in energy development.

Energy Sector Overview

3.0 million
population

3.6 GW
total installed capacity in 2020

7 759 GWh
electricity generation in 2019

There are no coal power plants operating.

All oil is imported, with the transport sector being the largest final consumer.

All gas is imported, representing over 76% of Armenia's energy imports. The residential sector is the largest final consumer of gas. Gas generated about 40% of electricity in 2020.

Currently, PV only contributes a small amount of electricity (about 21 GWh in 2020).

One unit at Armenia's nuclear power plant is in operation, providing 35% of electricity, and expected to be decommissioned by 2027.

There are two large hydro power cascades and 185 small plants. Hydro power generated about 23% of the total electricity supply in 2020.

Currently, wind power only contributes a small amount of electricity (2 GWh in 2020).

Scenarios

The scenarios were analysed over the period 2020-2050 in 5-year intervals, assuming a discount rate of 6%. The IAEA MESSAGE model was used in the analysis.

BAU (business as usual)
Assumes the continuation of current trends: Economic development with increasing use of fuel and energy resources, inadequate energy efficiency and alternative sources of energy, and considerable construction of local co-generation systems for heat supply, installation of autonomous energy efficient heating systems in public buildings, and introduction of new renewable energy sources, including small hydro power plants, solar PVs, heat pumps, and biogas plants.

Mitigation
Considers certain measures for sectorial development programs, contributing to the reduction of GHG emissions. Energy saving policies are implemented and the use of alternative sources of energy is extended, including small and medium hydro plants, solar PV and wind energy. In both the Mitigation and BAU scenarios high-efficiency gas-fired combined cycle units replace the decommissioned NPP in 2040-2045.

Nuclear-1
Assumes the development of a nuclear programme with SMR technology. It considers the commissioning of two units and dismantling of existing units at the same site.

Nuclear-2
Includes the assumptions of the Nuclear-1 scenario. In addition, it includes the commissioning of one SMR unit in the period 2040-2045 and the commissioning of a second SMR-300 MW unit immediately after the shutdown of the existing WWER-440 unit in the period 2045-2050.

Key Results

Figure 4 shows that by 2050 the BAU and Mitigation scenarios would see the phase out of electricity produced by nuclear and an approximately doubling of gas power plants' share in electricity production compared with 2020 levels. In the Nuclear-1 and 2 scenarios the share of electricity produced by nuclear would increase about 1.5 times compared with 2020 levels. Accordingly, the share of electricity production from gas power plants will reduce from about 40% in 2020 to 25% in 2050. In all three scenarios electricity produced by renewables would more than double compared with 2020 levels. This would mean that the entire planned renewable potential is utilized, amounting to 4.5 GW per year.

Figure 5 shows the importance of the expected shutdown of unit 2 at the Armenian NPP in 2040 and its impact on GHG emissions. The BAU and Mitigation scenario assume unit 2 is replaced by a gas powered plant. As a result the graph shows GHG emissions increasing thereafter. The Nuclear 1 and 2 scenarios assume unit 2 is replaced with a new NPP, with GHG emissions either stabilising or temporarily

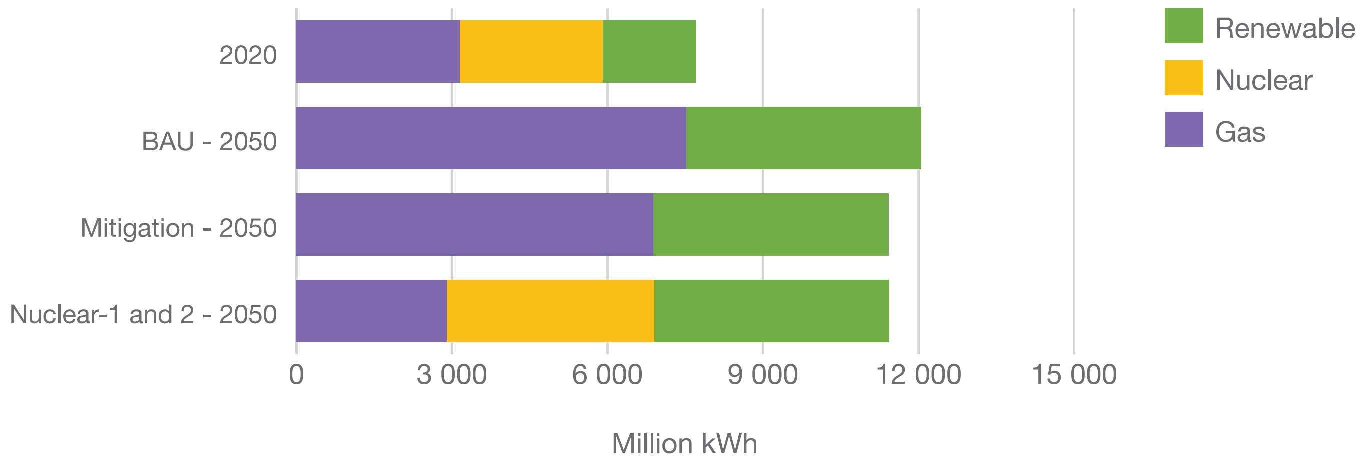


Figure 4.
Total electricity produced by energy source for the year 2020 (actual data), and the BAU, Mitigation and Nuclear-1 and 2 scenarios in 2050 [million kWh].

decreasing. The NDC specifies a 40% reduction from 1990 emission levels by 2030 (about 15,000 GHG CO_2 equivalent). By 2030 this target would be met for all four scenarios. This 'reserve' in the NDC target can be explained by a variety of reasons, including the specific recent history of Armenia, as well as a lack of large industries. Its population decreased from about 3.5 million to 2.9 million over the past 30 years and electricity production also reduced by more than 50%.

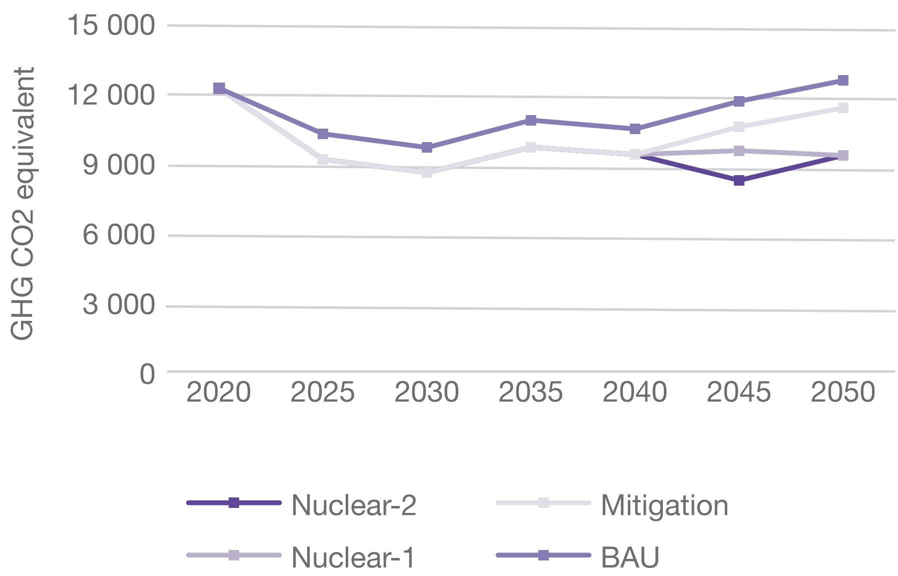
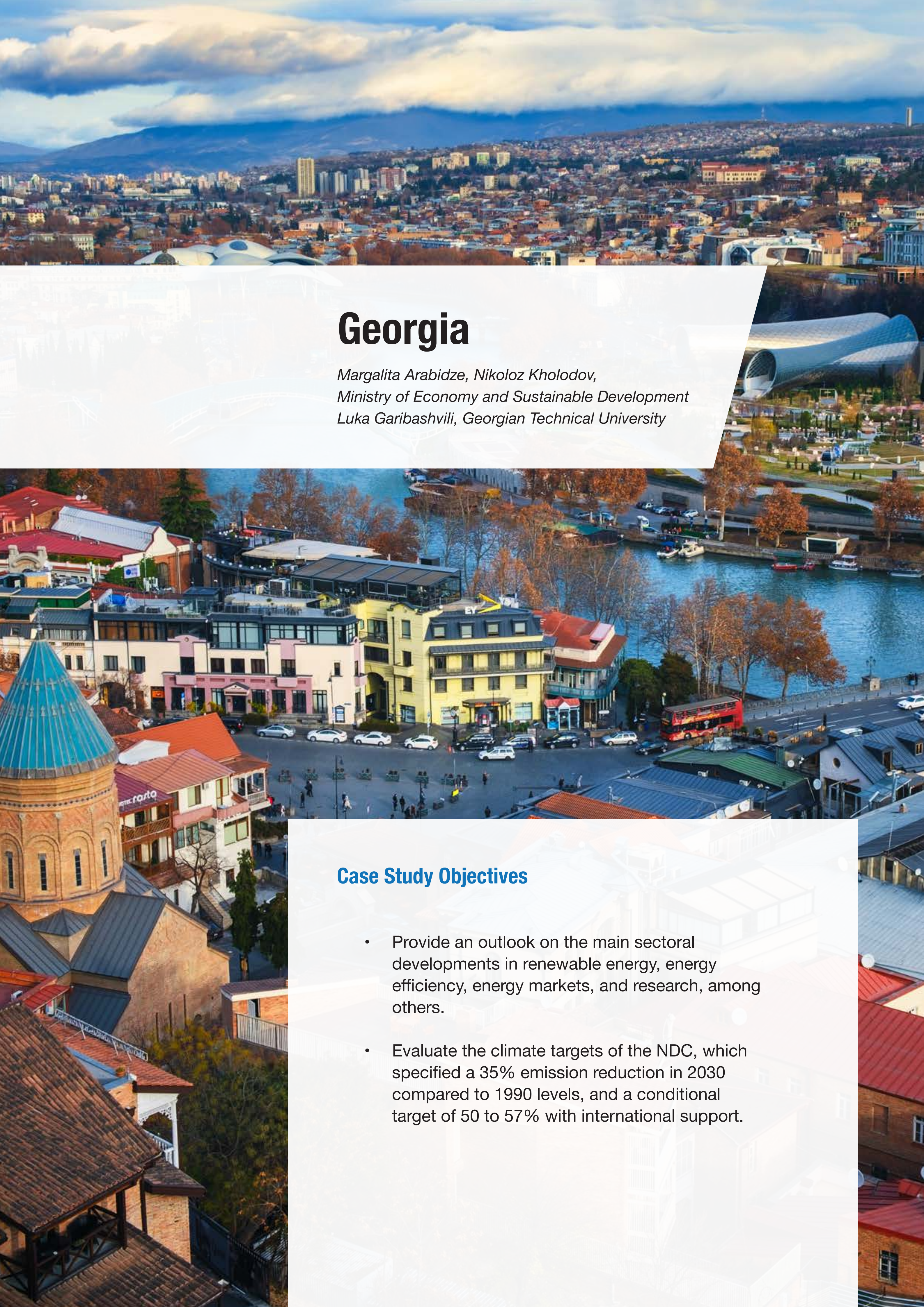


Figure 5.
Estimated GHG CO_2 equivalent emissions for the BAU, Mitigation and Nuclear-1 and 2 scenarios up to 2050 [GHG CO_2 equivalent].

Recommendations

- Significant efforts will be required to implement all economically feasible renewable projects. This should preferably be in partnership with the private sector.
- A demand side management programme should be instigated, as well as cost-effective measures.
- Priority should be given to the refurbishment and lifetime extension of the existing NPP.
- Replacing the existing NPP with a new NPP (rather than a gas powered plant) has a significant impact on emissions, highlighting the importance of its contribution to the global goal of net zero emissions.
- Actions will need to be taken to mitigate potential obstacles to the development of a new NPP, such as financing and human resources.
- Further analysis will be required to evaluate the impact on the cost of electricity for the consumer, as well as system costs.



Georgia

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Ministry of Economy and Sustainable Development
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Case Study Objectives

- Provide an outlook on the main sectoral developments in renewable energy, energy efficiency, energy markets, and research, among others.
- Evaluate the climate targets of the NDC, which specified a 35% emission reduction in 2030 compared to 1990 levels, and a conditional target of 50 to 57% with international support.

Energy Sector Overview

3.7 million
population

4.5 GW
total installed capacity in 2020

11 900 GWh
electricity generation in 2019

Georgia relies heavily on imported fossil fuels (such as petrol and gas), particularly for covering seasonal demand.

The transport sector is the largest final consumer of oil.

Gas-fired power plants provide over ¼ of the installed capacity.

No coal power plants operate currently.

The development of a nuclear power programme is not a priority.

80% of electricity is generated by hydropower plants.

Georgia is largely self-sufficient in electricity generation during months with high water levels (April-July). However, especially in winter the country is reliant on direct electricity imports.

As of 2022, one wind power plant has been installed with a capacity of 21 MW (less than 1% of the total installed capacity).

Ensuring the integration of variable renewable energy sources is a priority, including: developing the necessary infrastructure, reservoir hydro power plants, storage technologies and optimizing the grid.

Scenarios

The TIMES (The Integrated MARKAL-EFOM System) model of the International Energy Agency, adapted as a national version – TIMES-Georgia – was used in the analysis.

BAU (Business As Usual)
Focused on already implemented sectoral measures and does not account for possible new projects and significant developments in the near future. This scenario includes some of the measures present in the NECP that have been partially or fully implemented.

NECP (including Minimal and TYNDP)
Focused on the impact of measures presented in the NECP and includes energy efficiency, construction of new power plants, improvements in transmission, decarbonization and environmental sustainability, among others. Two further independent assumptions were developed for this scenario: 'Minimal' assumes self-sufficiency in electricity generation, and 'TYNDP' (Ten-Year Network Development Plan of Georgia) allows for significant electricity exports, aligned with the expansion plan from 2021-2031.

Key Results

Figure 2 shows an almost 60% increase in total final energy consumption in the BAU scenario compared with the year 2019. Whereas for the NECP scenario, total final energy consumption would only increase by 20%. In both the BAU and NECP scenarios the agricultural sector will see increase of 16% in final energy consumption compared with 2019. In the BAU scenario the industry sector will increase by 65% compared with 2019 (an increase of about 30000 to 50 000 TJ), whereas the NECP scenario will increase by 50%.The residential sector will inclrease by 1/3 in the BAU scenario while in the NECP scenario the increase will be about 1/10 compared with 2019. The transport sector will remain about the same in the NECP scenario, whereas in the BAU scenario final energy consumption will approximately double. Others (non-specified energy consumption), will increase by about 2/3 in both the BAU and NECP scenarios, compared with 2019.

Figure 3 shows that the installed power system capacity will need to be about 6.5 GW in the Minimal scenario. This is necessary to ensure national energy security and minimise electricity imports. The following minimal investments are required by 2030: 667 MW hydro power plants, 750 MW wind power plants, 546 MW of solar power plants, and two combined cycle gas power plants (total 500 MW), alongside the optimization of transmission systems.

A further approximately 3 GW could be installed when following the TYNDP scenario. The amount of gas capacity installed would remain about the same in the TYDNP scenario compared with 2021. Twice as much hydro capacity could be installed under the TYNDP scenario compared with 2021 and also with the Minimal scenario. In addition,

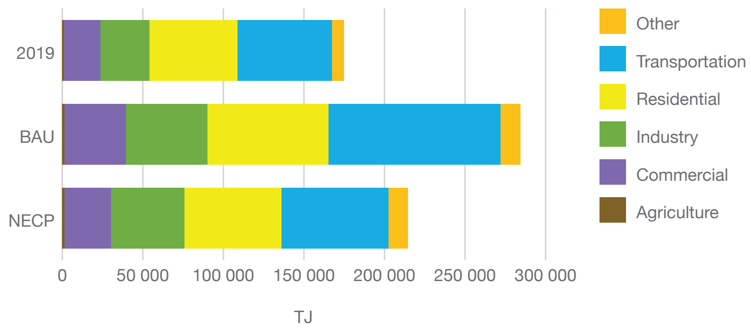
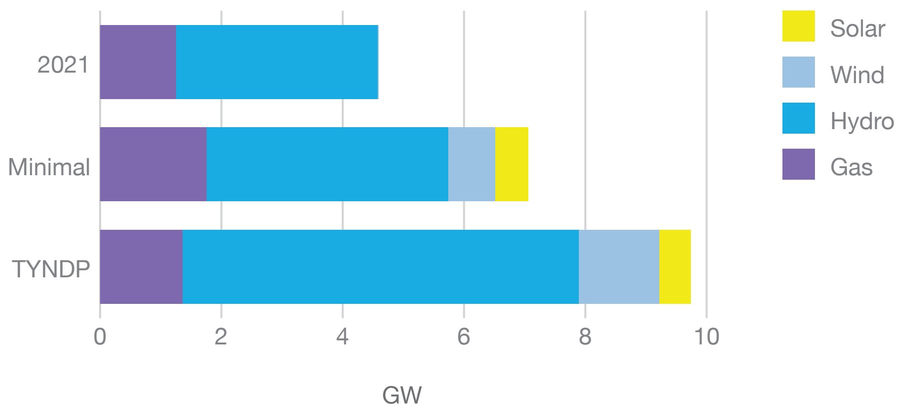


Figure 2.
Final energy consumption by sector for the year 2019, and for 2030 for the BAU and NECP scenarios [TJ].

almost twice as much wind capacity could be installed in the TYNDP scenario compared with the Minimal scenario. As in the Minimal scenario, in the TYDNP scenario about 0.5 GW capacity of solar PV could be introduced.

The analysis preformed in the TIMES model considering measures provided in the NECP and Climate Strategy and Action Plan (CSAP), indicates that, unlike in the BAU scenario, the climate change targets can be met. The model yielded emissions of 6 338 GHG $CO_{2,eq}$ for the BAU scenario and 4 335 GHG $CO_{2,eq}$ for the optimistic scenario of the NECP.

Figure 3.
Total installed power system capacities for the year 2021, and for 2030 for the Minimal and TYNDP scenarios [GW].



Recommendations

- The modelling indicated that a more ambitious target of 30% is possible, compared with the CSAP (reduction target of 15%).
- The BAU and NECP scenarios show that the largest consumers of energy will be transport and households, therefore improving energy efficiency in buildings and decarbonization of transport should be a priority.
- The availability of detailed statistical data will be required to evaluate progress in these sectors, and in the energy sector overall.
- In addition, to ensure national energy security and minimise electricity imports energy resources need to be diversified, including the development of locally available renewable sources.

Republic of Moldova

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Case Study Objectives

- Provide an outlook on the main developments of the energy sector, including renewable energy, energy efficiency, and energy markets, among others.
- Present projections of energy sector developments, based on modelling conducted for the Integrated National Energy and Climate Plan.
- Assess the demand for new technologies for achieving climate targets, including among others technologies related to the electrification of space heating in buildings, renewable energy sources, and electrification of the transport sector.

Energy Sector Overview

2.6 million
population
without Transnistria

3.032 GW
total installed capacity
in 2020

3 807 GWh
electricity generation
in 2020

78% of the electricity demand was met by imports in 2020.

Coal provides critical base load, drawing on lignite reserves of 110 million tonnes.

All petrol and diesel are imported, amounting to 946 thousand tonnes of oil equivalent (toe) in 2020 which are mainly used in the transport sector.

About 25% of the domestic electricity demand is met by three gas-fired combined heat and power plants (CHPs), which all operate well beyond their economic life.

100% of gas is imported, or 3.8 billion m^3 in 2020, of which 3.4 billion is imported from Russia, and 0.4 billion from Romania. Out of total imports - 1.1 billion m^3 is consumed on the right bank of the Dniester River, of which 43% is used for electricity and heat generation

There is no nuclear power programme in the country.

The total installed hydro power capacity amounts to 16 MW on the right bank of the Dniester River, and 46 MW in Transnistria.

About 73.4 MW of wind power were installed as of 2022, with an expected additional capacity of 120 MW by 2025.

About 24.5 MW of PV were installed capacity as of 2022, with an expected additional capacity of 200 MW by 2025.

Biomass is mainly used for heating in the residential sector. The consumption in 2020 amounted to 941 000 tce (23% of total energy consumption). The biogas CHPs have 6.3 MW of installed capacity as of 2022, with an expected additional capacity of 90 MW by 2025.

Scenarios

The TIMES (The Integrated MARKAL-EFOM System) model of the International Energy Agency was used in the analysis.

Baseline
Trends in the development of the energy system continue as they do currently: limited connections with neighbouring countries' systems, no CO_2 emission limits, no subsidies for building renovations, and the slow implementation of new technologies.

Sustainable
Greater connection with neighbouring countries' systems, CO_2 emissions limited to 36% compared with 2019 levels by 2030 and 65% compared with 2019 levels by 2050, increased subsidies for buildings, and fast implementation of new technologies.

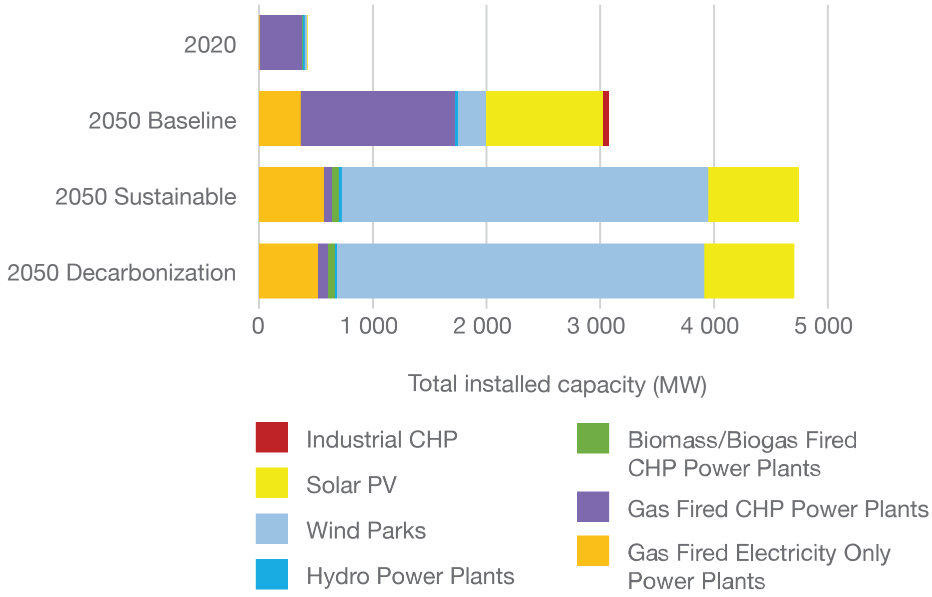
Decarbonization
Considerable connection with neighbouring countries' systems, CO_2 emissions limited to 52% compared with 2019 levels by 2030 and 85% compared with 2019 levels by 2050, increased subsidies for buildings, and fast implementation of new technologies. New technologies to support, among others, the demand-side electrification for space heating in buildings, renewable energy sources, and electrification of the transport sector.

Table 1.

	Baseline	Sustainable	Decarbonization
Final energy consumption in 2050 compared to Baseline scenario	-	-18% (33 PJ)	-18% (33 PJ)
Total system costs	-	+3%	+8%
Average annual electricity costs by 2050	~ 9 cents kW h-1	~ 9 cents kW h-1	17[a] cents kW h-1
CO_2 emissions compared to 2016	+40%	-50%	-76%
Electricity generation (renewable energy sources share by 2050)	40%	86%	~100%
Transport sector (biofuels and electrification share by 2050)	8%	56%	68%
Biomass and biogas share in total final energy use by 2050	19%	76%	82%

a. Peaking at 24 cents kW h-1 in 2030.

Figure 4.
Total installed capacity by energy source for the year 2020 (actual data), and the Baseline, Sustainable and Decarbonization scenarios in 2050 [MW] (without Transnistria).

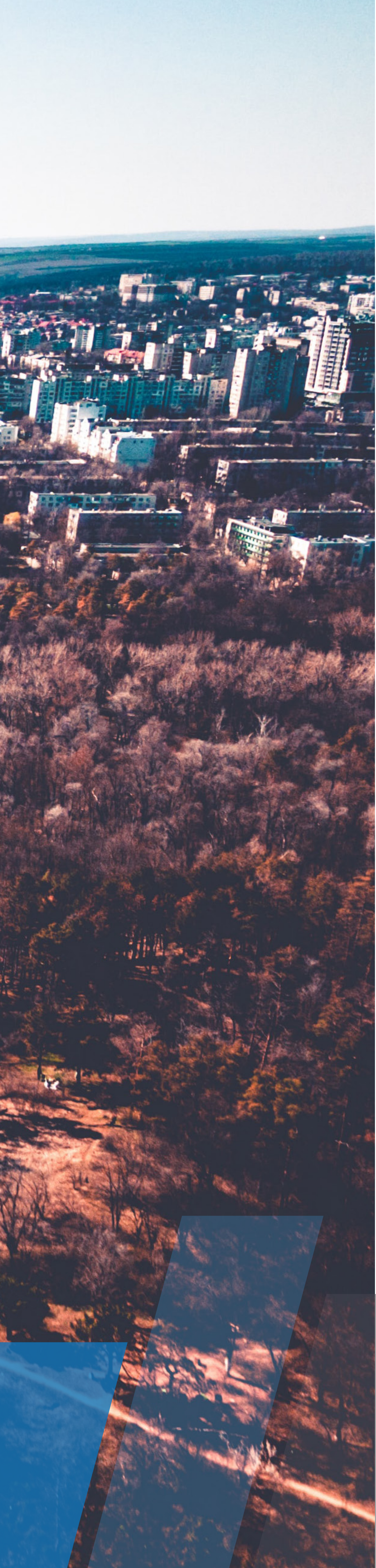


Key Results

Table 1 shows there would be a 40% increase in CO_2 emissions for the Baseline scenario compared with 2016 levels – from 5 363 kt in 2020 to almost 7 000 kt in 2050. By 2050, the CO_2 emissions for the Sustainable scenario would be less than half the emissions of the Baseline scenario, or a decrease of 50% compared with 2016 levels. The lowest CO_2 emissions would be the Decarbonization scenario, with a decrease of 76% compared with 2016 levels. The unconditional target specified in the NDC is to reduce greenhouse gas emissions by 70% below 1990 levels by 2030, with a conditional target of 88% below 1990 levels. Total emissions in the base year are 44.9 Mt (without LULUCF) and 43.4 Mt (with LULUCF). All three scenarios would meet the unconditional target, whereas only the Sustainable and Decarbonization scenarios would meet the conditional target.

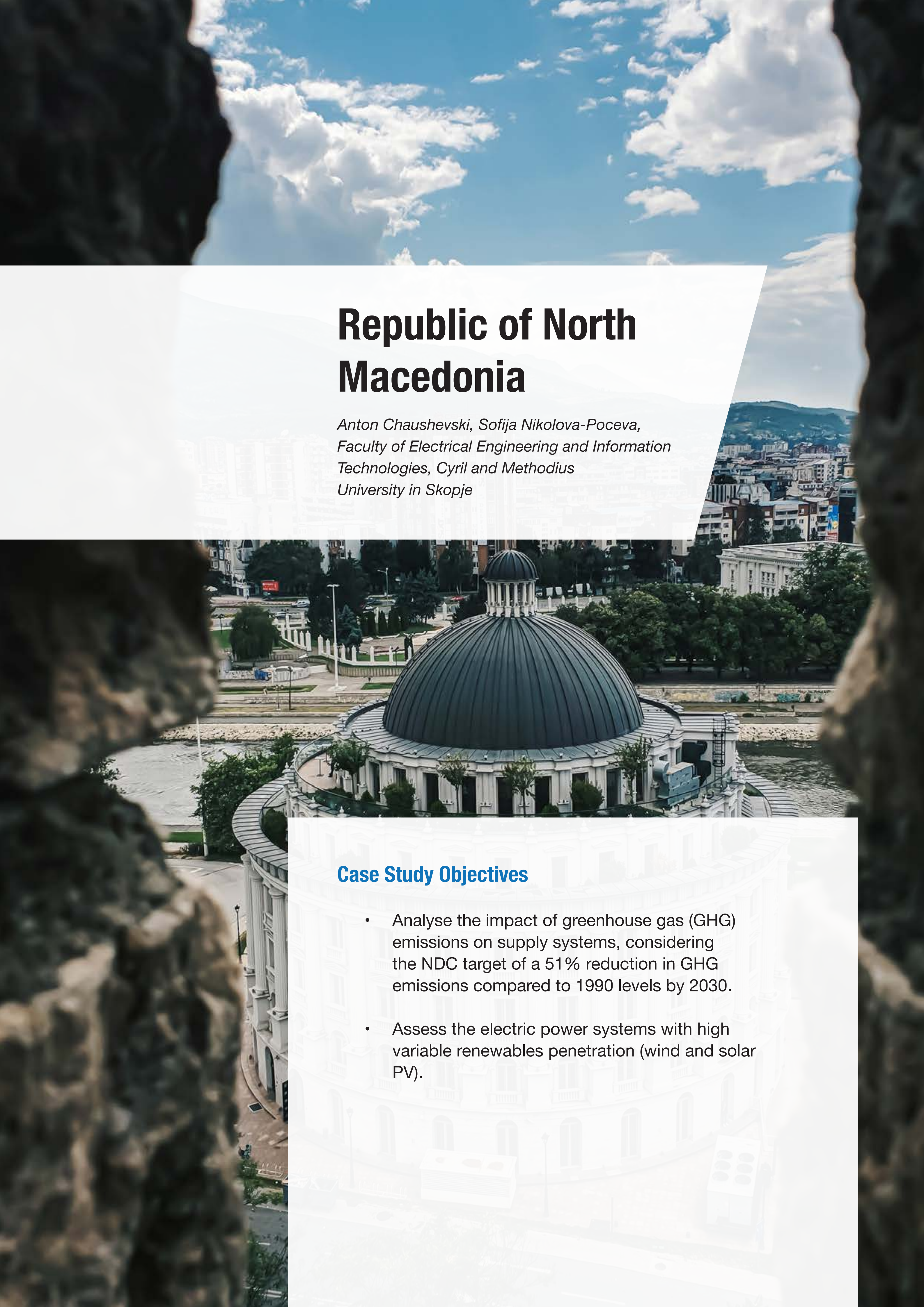
Figure 4 shows that by 2050 the Baseline scenario would see a substantial increase of installed capacity from about 420[1] MW in 2020 to about 3 073 MW in 2050 mainly based on new gas-fired CHPs and solar PV. In the Sustainable and Decarbonization scenarios the demand for new installed capacity would increase about 11 times compared with 2020 levels, to about 4 700 MW of installed capacity, mainly wind farms. Accordingly, the share of gas-fired CHPs will reduce from about 90% in 2020 to 2% in 2050, being replaced by electricity-only gas-fired power plants for balancing renewables. In all three scenarios the installed capacity of renewables would increase more than 4 times compared with the national target of Moldova for 2025 (410 MW consisting of 120 MW wind, 200 MW PV and 90 MW bio). This would mean that the entire planned capacity for renewable potential is utilized, and the Government would require to search for new solutions for electricity production, including the assessment of the role of SMRs for Moldova.

1 Excluding Transnistria. The TIMES Study is done only for Right Bank of Dniester River, without Transnistria.



Recommendations

- Efforts should be focused on the residential and service sectors as they have the highest energy and climate potential due to electrification (mainly with heat pumps for heating) replacing biomass and gas consumption.
- In the Decarbonization scenario the use of biofuel resources would be at its technical limits. The country will face a biofuel shortage from 2040 if no actions are taken now.
- Consideration will need to be given to the substantial increase in the annual average cost for electricity in the Decarbonization scenario which is caused by the significant costs of electrification to replace gas.
- The Small Modular Nuclear Reactor (SMR) role in the future energy mix needs a separate assessment in comparison with Carbon Capture and Storage technologies, hydrogen, and the high share of variable renewables in the energy system; considering the limited potential for renewable sources and climate change targets.



Republic of North Macedonia

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Case Study Objectives

- Analyse the impact of greenhouse gas (GHG) emissions on supply systems, considering the NDC target of a 51% reduction in GHG emissions compared to 1990 levels by 2030.

- Assess the electric power systems with high variable renewables penetration (wind and solar PV).

Energy Sector Overview

2.1 million
population

2.1 GW
total installed capacity in 2020

5 128 GWh
electricity generation in 2020

Coal provides critical base load, drawing on lignite reserves of around 100 million tonnes. Coal power plants are almost 40 years old and will need to be replaced, preferably with new technologies (gas combined cycle gas turbine and/or NPPs).

All oil is imported. One single 210 MW power plant operates as cold reserve.

A 284 MW gas-fired combined heat and power plant is in operation. All gas is imported. New infrastructure will be required to secure gas supplies, with additional pipeline capacity expected to be available in 2025.

There is no nuclear power programme in the country, but an interest in acquiring preliminary knowledge on the role of nuclear power in the future energy mix.

Hydro power plants under operation have an installed capacity of over 600 MW (large and small units), with an additional potential of 1500 MW.

Wind is currently limited to few locations, providing less than 1.8% of the total installed capacity. However, there is potential for hundreds of MWs in some areas.

PV currently provides less than 1.5% of the total installed capacity.

Currently, biomass energy is mainly provided by biodigesters on animal farms.

Scenarios

All three scenarios were analysed over the period 2020-2050 in five-year intervals, assuming a discount rate of 8%. Electricity demand was assumed to increase from 7 000 GW at a 2.5% growth rate and heat demand from 0.07 GW at 3%. The IAEA MESSAGE model was used in the analysis.

BAU (business as usual)
Current developments of the energy sector continue. Base load is coal and gas. Coal power plants are equipped with new technologies for desulphurization and reduction of oxides of nitrogen, and operate at a higher efficiency than the existing fleet. Hydro power and other renewables provide variable electricity generation. No nuclear power programme. Electricity imports are considerable.

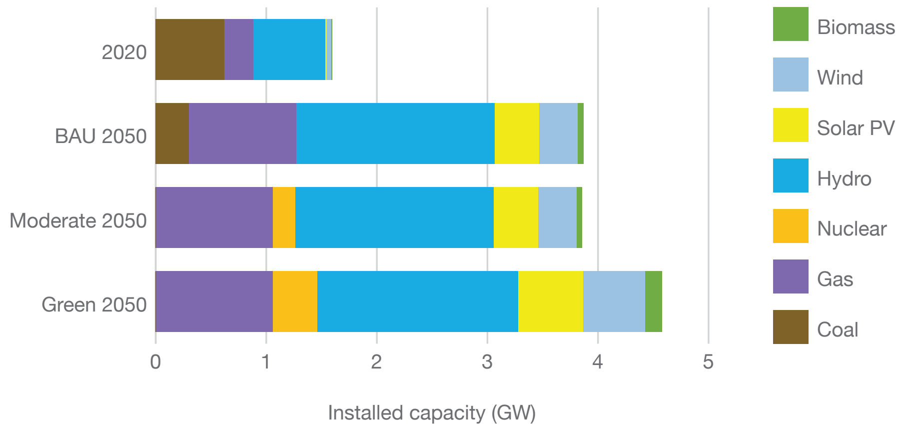
Moderate
Existing coal technologies are replaced with combined-cycle gas turbines as base load (operated as cogeneration plants to generate heat, having a higher overall efficiency). Ambitious introduction of renewables. Investment in one 200 MW small modular reactor (SMR).

Green
Existing coal technologies are replaced with combined-cycle gas turbines (operated as cogeneration plants to generate heat, having a higher overall efficiency) and nuclear power as base load (two 200 MW SMRs). More ambitious introduction of renewables than the Moderate Scenario. Electricity imports are reduced.

Key Results

Figure 1 shows that for all three scenarios hydro power will be an important energy source, with capacity almost tripling by 2050. In the BAU scenario coal capacity will halve, and in the Moderate and Green scenarios coal will be completely phased out by 2050. Gas will increase fourfold in all three scenarios. In the Green scenario wind and solar PV will have more than 0.5 GW capacity installed (about 15 and 35 times more than current capacities, respectively). A modest nuclear capacity will be installed at 0.2 GW (Moderate scenario) and 0.4 GW (Green scenario). Biomass will increase its capacity sevenfold for the BAU and Moderate scenarios, but would be more than twenty times the current capacity in the Green scenario.

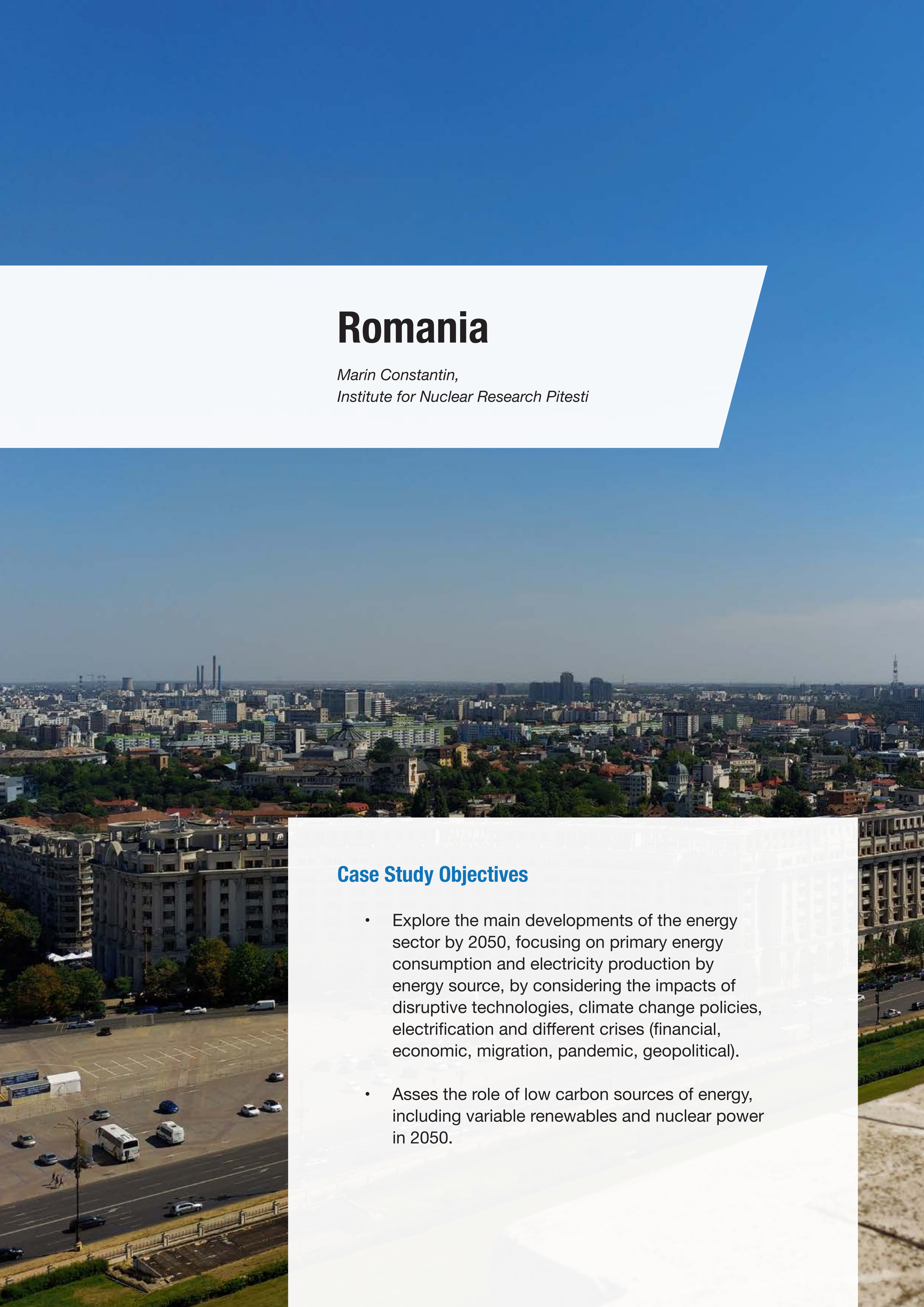
Figure 1.
Installed capacity for the year 2020 and projected for the BAU, Moderate and Green scenarios in 2050 [GW].



The most significant reductions in GHG emissions are in the Moderate and Green scenarios because the coal power plants are decommissioned by 2030. When disaggregating by sector the NDC target of 51% reduction in GHG emissions compared to 1990 levels by 2030 (absolute emission reduction in 2030 compared to BAU: 7603 Gg CO_2-eq), the energy sector will require a 66% reduction (mainly through decommissioning of the two coal-fired power plants that provide base load power). In addition, the NDC specifies a 66% share of renewable energy sources in gross electricity production. Therefore, the Moderate and Green scenarios would be in line with the NDC target, with the Green scenario projected to have the lowest GHG emissions overall.

Recommendations

- Replacing aging coal power plants with low-carbon base load power (e.g., gas and nuclear) is necessary in order to meet national climate change targets.
- Consideration needs to be given to the social impact of energy policies, as the coal sector has almost 3500 employees. This could be aided by the creation of new domestic green jobs.
- Substantial investments are required, particularly for new combined-cycle gas turbines and hydro power plants. This would reduce energy and electricity imports.
- Significant efforts are needed to install the required capacity of variable renewables (wind and solar PV). More than 500 MW capacity will be required by 2050 in the Green Scenario.
- Existing and new hydro power plants will contribute to the integration of variable renewables.
- While challenging for countries with no experience in nuclear technology, SMRs are a potential option once commercially available.



Romania

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Case Study Objectives

- Explore the main developments of the energy sector by 2050, focusing on primary energy consumption and electricity production by energy source, by considering the impacts of disruptive technologies, climate change policies, electrification and different crises (financial, economic, migration, pandemic, geopolitical).
- Asses the role of low carbon sources of energy, including variable renewables and nuclear power in 2050.

Energy Sector Overview

19.2 million
population

19.6 GW
total installed capacity in 2020

59 600 GWh
electricity generation in 2019

Coal contributes almost 25% to the total electricity generation, drawing on an ageing fleet of coal-fired power units (some more than 50 years old) with quite low efficiencies.

Oil contributes about 1% to the total electricity generation.

Gas provides about 15% of the total electricity generation.

One nuclear power plant with two units is in operation, with two more units being planned at the same site.

Hydro power is the main source of electricity generation. Over 500 hydro power plants provide more than 25% of the total electricity.

There is a huge potential for the deployment of variable renewable energy sources (both wind and solar PV).

About 3 GW of wind power are installed (15% of the total installed capacity).

PV contributes about 3% to the total electricity generation.

Biomass currently provides less than 1% of the total electricity generation but has significant potential for future expansion.

Scenarios

Estimates were based on the following assumptions for all three scenarios: population declining to 17.9 million (2050), increase in GDP per capita from $12 920 (2019) to $20 900 (2050), reduction of consumption by 32% in 2030, 40% electrification of the transport sector (train and cars), share of solid fuel for heating will be reduced to 15%. The IAEA MESSAGE and MAED models were used in the analysis.

Pessimistic
Disruptive technologies (artificial intelligence, internet of things, blockchain, biotechnologies and material science) will have a minor impact. Compared with the other two scenarios, economic crises would have the greatest impact and migration crises the lowest impact. The electrification of transport, heating and cooling would have the lowest impact in this scenario, as well as energy efficiency, and the inter-connectivity with neighbouring countries. As the main result, the energy demand in 2050 was estimated to be +15% compared with 2019 levels.

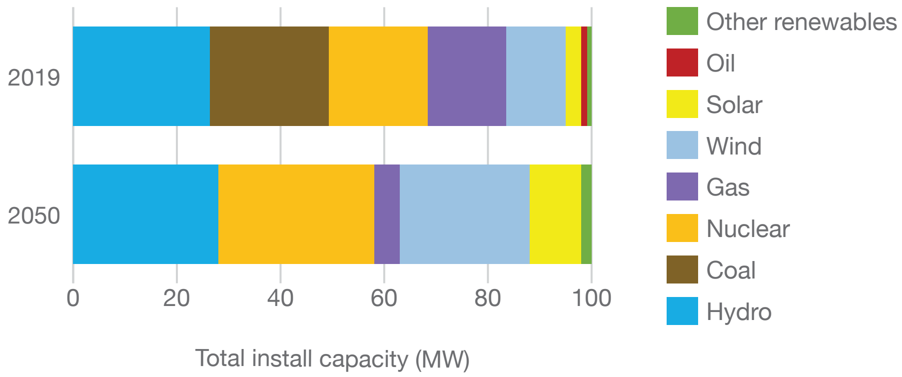
Moderate
There would be a modest impact from the implementation of the disruptive technologies. Economic and migration crises would have a medium-level impact in this scenario, as well as electrification (transport, heating and cooling), energy efficiency and the level of connectivity with neighbouring countries. Energy demand in 2050 will be +30% compared with 2019 levels.

Optimistic
Disruptive technologies would have the most significant impact in this scenario. Economic crises would have the lowest impact and migration crises the greatest impact, compared with the other two scenarios. The impact of electrification (transport and heating and cooling), energy efficiency and the level of connectivity with neighbouring countries would be the largest compared with the other two scenarios. Energy demand in 2050 will be +45% compared with 2019 levels.

Key Results

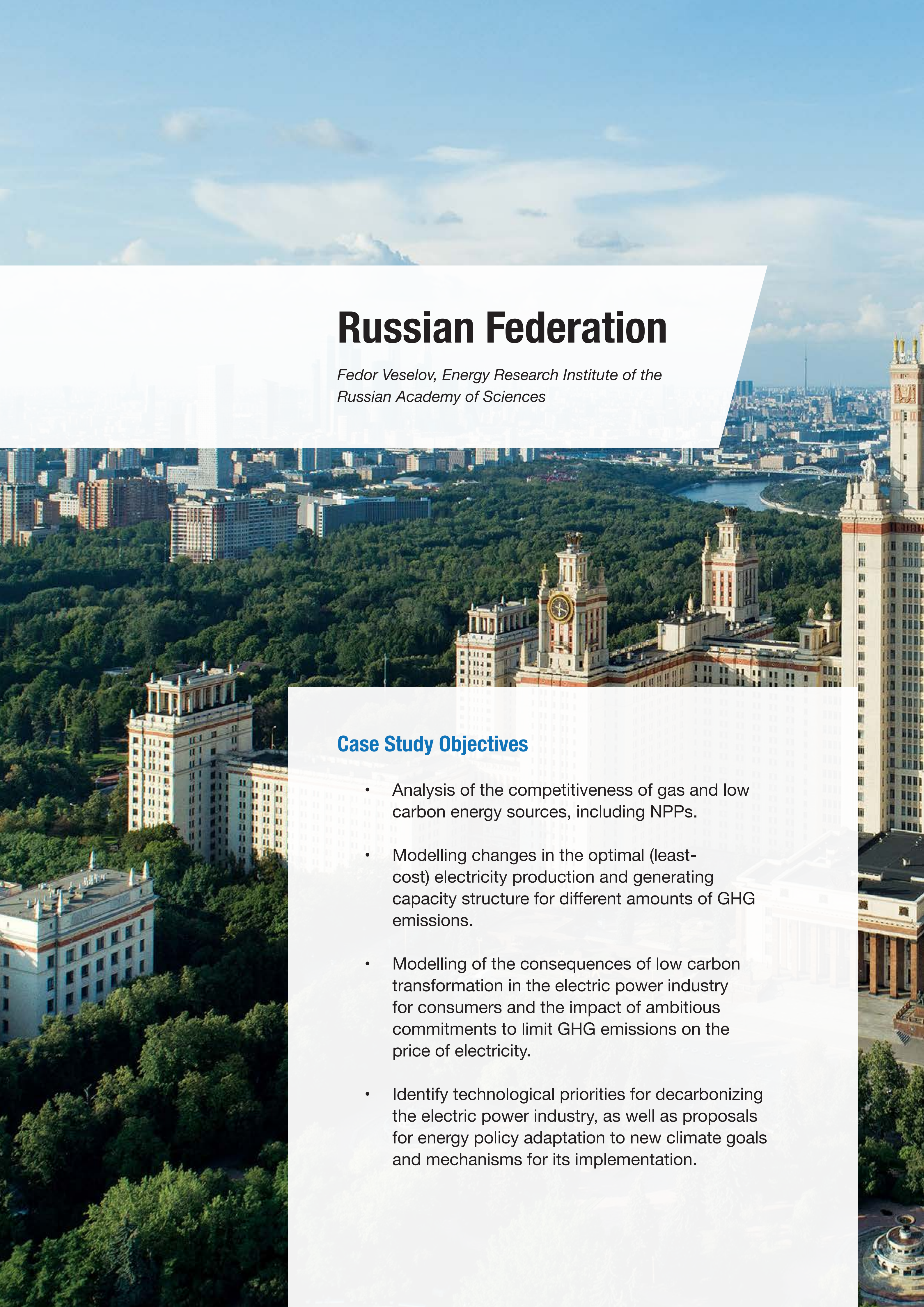
The pessimistic, moderate and optimistic scenarios are defined in terms of the total energy demand with an increase of +15%, approximately +30%, +45% compared with 2019 energy consumption. These scenarios are related to the expected economic development of Romania and with the evolution of different factors (e.g. implementation of energy efficiency measures or impact of disruptive technologies). The projected share of each energy source in 2050 for all three scenarios is presented in Figure 6. The figure shows in 2019 fossil fuels provided about 40% of electricity production, and low carbon energy sources providing the remainding 60%. By 2050, the share of fossil fuels will be reduced to 5% (gas only) with coal and oil being phased out. Thus, the share of low carbon energy sources will increase by 35 percentage points, the majority of which is hydro and nuclear at a cummulative value of 58%. The complete phase out of coal and oil, in combination with increases in low carbon energy sources, such as nuclear and hydro, would result in the attainment of national climate change targets.

Figure 6.
Electricity production by energy source for the year 2019 and projected for 2050 [%].



Recommendations

- Climate targets can be reached by a major reduction of coal electricity production (phase-out by 2050) and increasing the share of low-carbon energy (renewables and nuclear).
- The scenario with dominant renewables in the low carbon energy production is constrained by the security of supply and availability of large storage capacities. Therefore a progressive development of the renewable sector with nuclear power as load-base is recommended for the next decades.
- Future development of nuclear power would need to ensure: flexibility, integration with variable renewable energy sources, adaptability to non-electrical applications, reduction of water consumption, and ability to withstand extreme weather conditions.
- Further analysis is needed to evaluate the impact of different scenarios on the cost of electricity for the consumer, the system costs, GHG emissions and meeting national climate targets.



Russian Federation

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Case Study Objectives

- Analysis of the competitiveness of gas and low carbon energy sources, including NPPs.
- Modelling changes in the optimal (least-cost) electricity production and generating capacity structure for different amounts of GHG emissions.
- Modelling of the consequences of low carbon transformation in the electric power industry for consumers and the impact of ambitious commitments to limit GHG emissions on the price of electricity.
- Identify technological priorities for decarbonizing the electric power industry, as well as proposals for energy policy adaptation to new climate goals and mechanisms for its implementation.

Energy Sector Overview

146.2 million
population

246.6 GW
2021 data from Unified Energy System

1 114.6 TWh
2021 data from Unified Energy System

This data does not include capacity and generation in remote regions and the area of decentralized power supply.

Thermal power plants are the largest domestic consumer of gas and coal, generating 63% of the total electricity supply. More than half of the installed capacity of thermal power plants are combined heat and power plants.

Gas is the main resource for the power sector, contributing 55% to the total primary energy used for electricity generation and co-generation of heat. Gas-fired power plants provides 41% of the total electricity production

In the next decades most of the existing aging fleet of steam turbines must be replaced by units with higher efficiency and (partially) by non-carbon sources.

Russia is one of the largest oil producers and exporters. Oil product plays a minor role (mainly as a backup and peaking fuel) for the electricity production.

30 GW of nuclear power generate about 20% of the total electricity supply. The nuclear power fleet consists of water and fast neutron reactors as well as a floating SMR.

Hydro power provides about 18% of the total electricity production. Most hydro plants are located in the eastern part of the country, where they provide more than 50% of electricity production.

From 2015 onwards 4 GW of variable renewable power plants (both 2 GW of wind and 2 GW of solar PV) have been commissioned.

The installed RES capacity is expected to increase to 15 GW by 2035. Both the wind and solar PV potential is significant, but unevenly distributed across the country.

Small amounts of biomass are used for co-firing with gas or coal.

Scenarios

It is assumed that in all scenarios electricity demand by 2050 will increase by 1.5 times with a stable growth of the country's economy by 3% per year. Case 100 and 80 differ in the target level of CO_2 emissions reduction by 2050, at different degrees of NPP development. In all scenarios, there are no carbon taxes. A nationally developed model - Super Complex For Active Navigation in Energy Research (SCANER) and the IAEA MESSAGE model were used in the analysis.

Base Case
Current policy measures to support investments in efficiency improvements of thermal power plants, as well as the development of nuclear and renewable power plants. Determines the optimal pace of development of modern gas technologies and low carbon power plants, including NPPs, without CO_2 emissions restrictions.

Case 100
Stabilization of emissions at the level of 2019 with limited (Case100) and maximum (Case100N) NPP development

Case 80
Emissions reduction by 20% relative to 2019 with limited (Case80) and maximum (Case80N) NPP development.

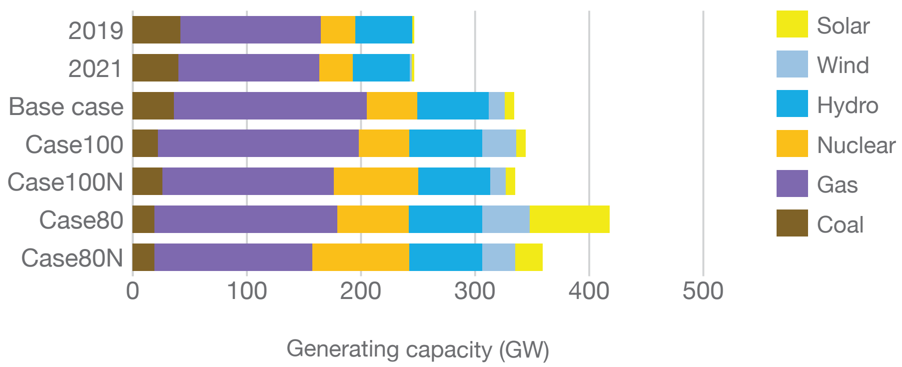
Table 2.

	100	100N	80	80N
Total capital costs in 2050	+21.2	+13.9	+73.8	+55.6
Nuclear	+0.3	+76.3	+49.3	+106.2
Hydro, wind and solar PV	+139.1	-3.1	+440.7	+237.9
Thermal (coal & gas)	+6.9	-12.7	+9.8	-6.5
Wholesale electricity price in 2050	+8.0	+1.5	+29.5	+18.2

Key Results

By 2030 the Base Case would result in about a 10% increase in CO_2 emissions in the electric power industry compared with 2019 levels. This is in line with the NDC until 2030. In the long term, current policy measures will not be sufficient and after 2030, more intensive development of low carbon energy sources will be required. Figure 7 shows that to revert emissions to 2019 levels by 2050, the share of low carbon energy sources in the total electricity production should increase from 37% to 40-50% (Case 100 and 100N). To reduce CO_2 emissions by 20% of 2019 levels by 2050, this share should increase to 55-60% (Case 80 and 80N). NPPs can play a leading role in the decarbonization of the electric power industry. With low (2 200-2 500 USD/kW) domestic capital costs, NPPs are the cheapest (in terms of levelised cost of electricity) low carbon technology, competitive with new gas-fired (CCGT) power plants. It was also estimated that

Figure 7.
Generating capacity for the year 2019 and in 2050 for the scenarios Base Case, Case 100 and 100N, Case 80 and 80N [GW].



reverting CO_2 emissions to 2019 levels by 2050 (Case 100 and 100N), NPP electricity production would need to increase by about 60-160 %. To reduce emissions by 20% (Case 80 and 80N) the increase would be about 130-200%. An alternative to the expansion of low carbon energy sources is the development of coal-fired power plants with CCS. This option still has high economic and technological risks: (1) coal-fired power plants with CCS are not competitive in the cost of electricity to domestically producted NPPs, and (2) there remains high uncertainty in the availability and cost of CO_2 transport and storage technologies.

Table 2 presents the % estimates for the capital costs (total and by energy source) and wholesale electricity price (including capacity payments) increases and decreases in 2050 relative to the Base Case. Financial calculations of required gross revenue and electricity prices show the same trend: the lower the carbon emissions, the greater the price consumers will pay for electricity. But more intensive NPP development may suppress the price growth considerably.

Recommendations

- Decarbonization of the electric power industry will require significant additional investments. To revert CO_2 emissions to 2019 levels by 2050 (Case 100 and 100N), an increase of about 14-21% in investments will be required. To reduce emissions by 20% compared with 2019 levels (Case 80 and 80N), additional investments are estimated at 56-74%.

- To revert CO_2 emissions to 2019 levels by 2050 (Case 100 and 100N), an additional increase in the wholesale price of electricity (taking into account capacity payments) will be about 2-8% relative to the Base Case. However, with a target reduction of emissions to 20% compared with 2019 levels (Case 80 and 80N), the wholesale price is estimated to increase by about 18-30%.

- The lower bounds of economic estimates correspond to cases with intensive development of NPPs. The active development of this industry will significantly reduce the burden on electricity consumers and make the transition to low-carbon energy sources more economical and acceptable for consumers.

Concluding on the Case Studies and the Road to 2050

The case studies revealed that the road to 2050 and net zero emissions will not be straightforward. Many countries face similar challenges over the next 30 years that require significant effort to shape their energy systems for a low-carbon future. Supported by the IAEA, energy and climate specialists drew on insights from modelling tools to better understand national energy needs to determine regulations, policies and approaches to achieve climate neutrality. Some of the common challenges and insights identified in the case studies include:

Electricity

Several countries will rely on a substitution of fuels with electricity to meet their decarbonization ambitions, as well as a reduction in energy intensity and electricity intensity, for example as highlighted in the Georgian case study. Improving energy efficiency in buildings is a priority, for example, of the Republic of Moldova, because this sector offers one of the highest potentials to help meet climate change targets.

Fossil fuels

To meet climate targets and ensure net zero is reached by 2050, the majority of countries will need to phase out fossil fuels, except gas, for electricity production. Some countries, such as Romania and the Russian Federation, have an ageing fleet of fossil-fuelled power plants with quite low efficiencies. However, consideration needs to be given to the social impact of energy policies, as the coal sector can employ a significant number of people. This could be aided by the creation of new domestic green jobs as indicated in the case study of the Republic of North Macedonia.

Variable renewables

As noted in the Romanian case study, significant efforts are needed to install the required capacity of variable renewables (wind and solar PV) and ensuring their integration into the energy system, including developing the necessary infrastructure, storage capacities and grid optimization. For many countries, such as the Republic of North Macedonia, further analysis is necessary to improve understanding of the impact of variable renewable energy sources on the energy system.

Nuclear power

For those countries with nuclear power programmes, refurbishment and lifetime extensions of existing power plants are key considerations as outlined in the case study of the Republic of Armenia. In addition, replacing retiring carbon-intensive thermal power plants with a new NPP (rather than, e.g., a gas powered plant) has a significant impact on emission levels as it is in the case study of the Russian Federation. This highlights the importance of nuclear's contribution to the global goal of net zero emissions. Actions will need to be taken to mitigate potential obstacles to the development of new NPPs, such as financing and human resources. Some countries without nuclear power programmes, such as the Republic of Moldova, would like to conduct further analysis to evaluate the possible role of nuclear in the energy system.

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