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Building a Resilient and Carbon-neutral Energy System in the Republic of Moldova

Sustainable Energy Division
United Nation Economic Commission for Europe (UNECE)

Executive Summary

- ✓ The Republic of Moldova is importing almost 100% of fossil energy resources (gas, gasoline, diesel, LPG,…) and about 70% of its electricity demands. To transition towards a carbon-neutral future, the Republic of Moldova should untap its renewable energy potential and invest in renewable energy infrastructure.
- ✓ Over the past years, the Republic of Moldova has shown strong political will to implement energy market reforms as a precondition for energy transition, enhanced energy security and climate change mitigation. Within the Energy Community Treaty, the Republic of Moldova has adopted the core EU energy and environment legislation.
- ✓ The Republic of Moldova's power system interconnections with Romania and Ukraine are critical for regional energy security and regional integration.
- ✓ While today's final energy mix in the Republic of Moldova still heavily depends on fossil fuels and biomass, more ambitious climate mitigation policies are expected to lead to greater energy savings and a shift to lower carbon technology options. To reach net-zero, deep electrification across the sectors is needed resulting in greater share of electricity in the final energy mix.
- ✓ Today the domestic renewable energy potential remains relatively untapped but the committed renewable energy capacity in the Republic of Moldova by 2030 is expected to reach 700MW. In 2023, renewable energy generation met 10.5% of the energy demand, compared to 5.5% in 2022.
- ✓ Status quo implies that natural gas fired power plants will dominate the mix until 2040. However, to attain net-zero by 2050, the renewable energy capacity in the Republic of Moldova will have to increase 4 times from the 2024 levels. Today about 400MW of renewable energy capacity has been installed in the Republic of Moldova – of which about 230MW of solar PV, and 170MW of wind capacity. To reach net-zero by 2050, the renewable energy installed capacity in Moldova will have to increase from 400MW in 2024 to 1600MW in 2050.
- ✓ Today's transport sector in the Republic of Moldova is characterized by old infrastructure and vehicles fleet. Decarbonizing the transport sector in Moldova will require a structural change across the sector as well as the consumers behavioral changes. Significant investments would be needed across the sector to allow deep penetration or lower polluting fuels.
- ✓ Mining of sand/ limestone and food processing are the two main industries in the Republic of Moldova contributing with 9% and 11% of value added of GDP, respectively, and combined accounting for about 90% of the sector's energy demand. Decarbonization of the industry sector in the Republic of Moldova will require energy efficiency measures and deep electrification of the industrial processes.

Overview of the Moldova’s Current Energy System

The Republic of Moldova's reliance on imported natural gas and oil products as well as electricity makes it vulnerable to geopolitical shifts and market volatility, exposing its energy security and economic stability.

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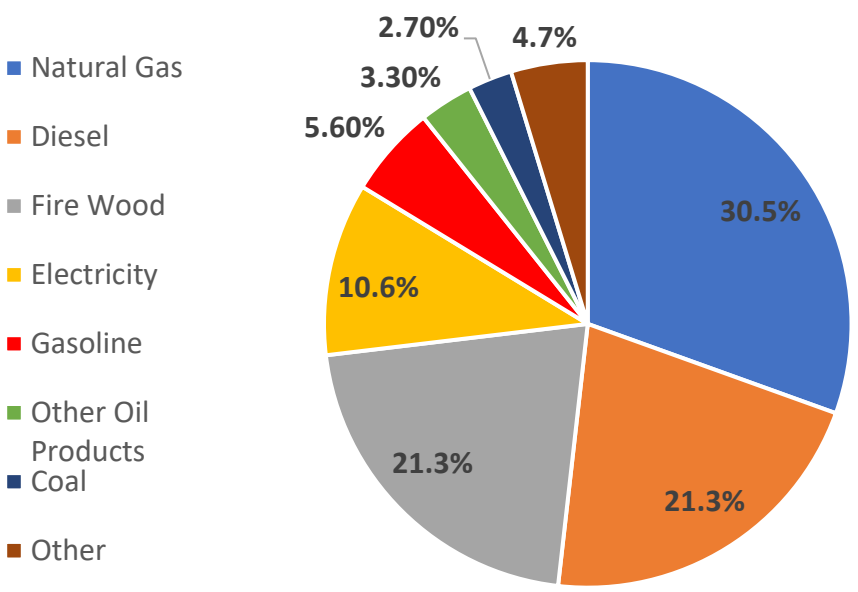
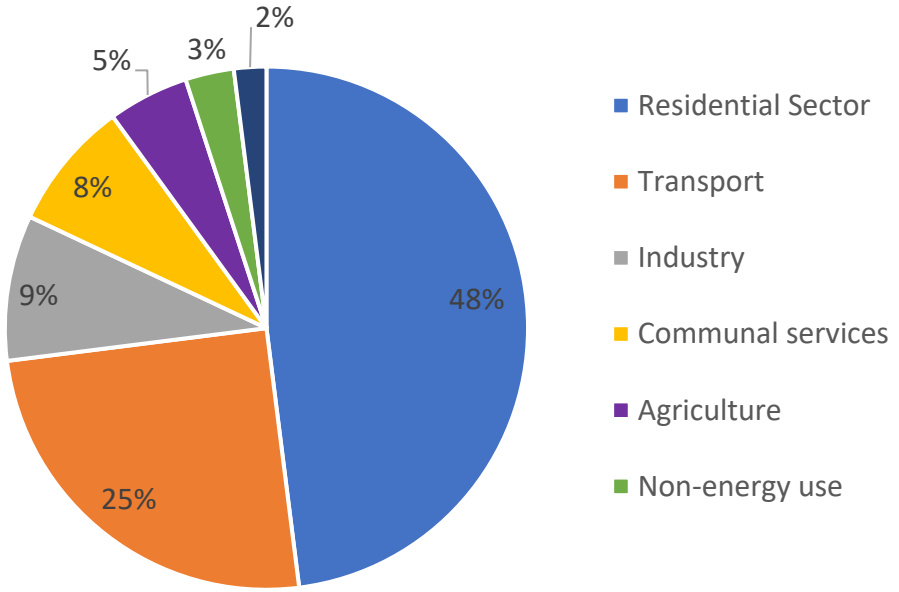
Energy Balance, 2020, 4078 ktce



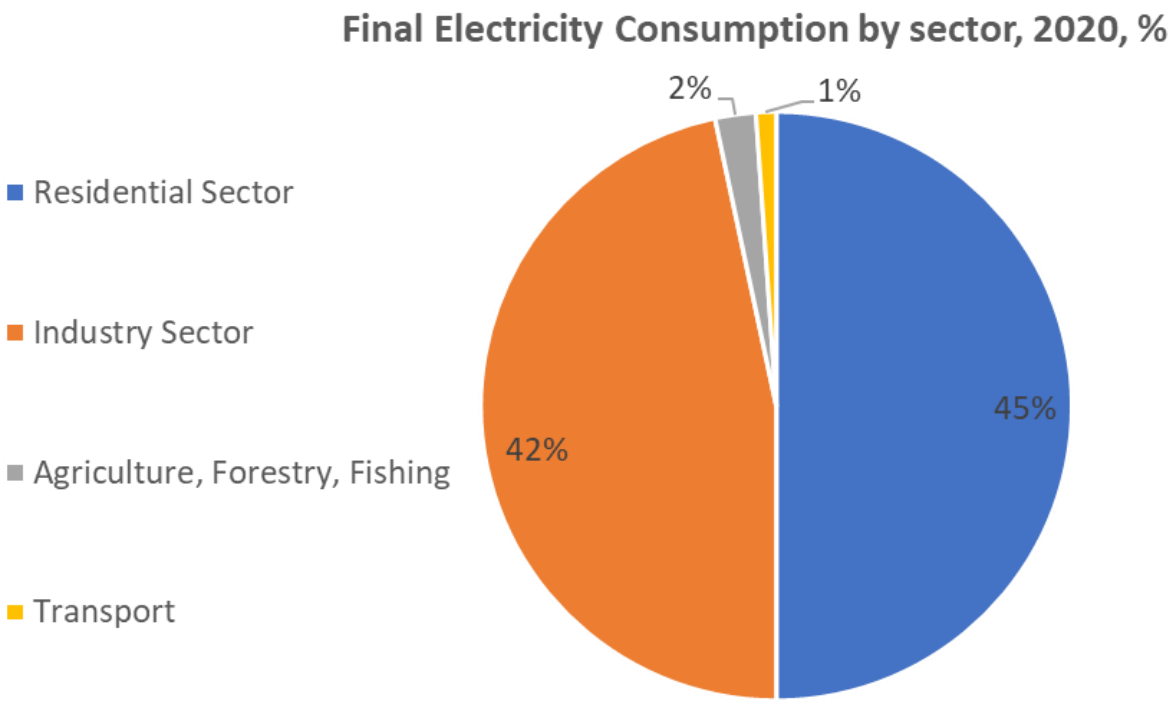
Energy Consumption, 2020, 3816 ktce



- The Republic of Moldova's low energy self-sufficiency, covering only about 21% of its energy needs domestically, makes it heavily reliant on imports, particularly from the Russian Federation for natural gas and Romania for oil products. This dependence on external sources exposes the Republic of Moldova to geopolitical risks and price volatility, impacting both energy security and economic stability
- High percentages of diesel and gasoline shows substantial GHG emissions – 8.8MT CO2 emissions, suggesting urgent need for cleaner alternatives.
- Reducing coal usage could significantly lower carbon footprint, aligning with global decarbonization trends.
- It is important to increase share of renewable energy, especially wind and solar. Enhanced domestic renewable energy capacity would help reduce the current vast electricity imports.

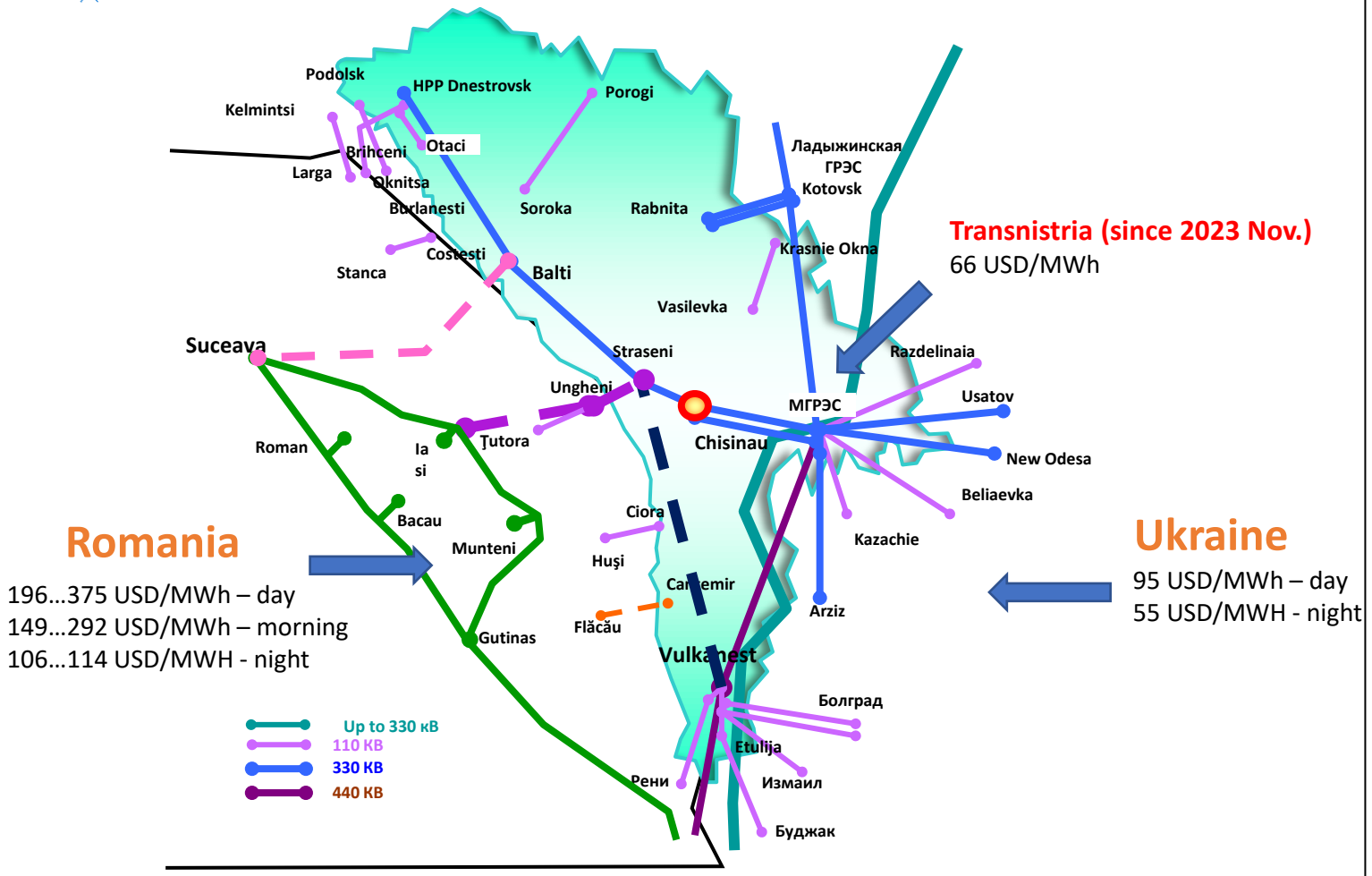
- The residential sector consumes about 48% of the Republic of Moldova's total energy. This high energy demand is driven by inefficient heating systems and poorly insulated buildings. Upgrading residential energy efficiency through better insulation, modern heating systems, and energy-efficient appliances can reduce overall energy consumption and lower household energy costs.
- The transport sector accounts for 25% of total energy consumption and is a primary driver of oil consumption growth in the Republic of Moldova. This reliance on oil products for transportation highlights the need for modernization and transition to more sustainable alternatives. It can be mitigated by investing in electric vehicle infrastructure, enhancing public transportation systems, and promoting alternative fuels, such as biofuels.

Majority of the imported electricity is consumed by the residential sector followed by the industry sector. The use of electricity remains very limited in the transport sector.



- The Republic of Moldova's energy sector is heavily reliant on imports, with 80% of its electricity being imported in 2020. Prior to the war in Ukraine, the electricity was mainly imported from Ukraine. Since November 2023, the MGRES gas-fired power plant in Transnistria is making up for the electricity import deficit from Ukraine. This heavy reliance on external sources, particularly from politically sensitive regions, makes the Republic of Moldova’s electricity supply extremely vulnerable.
- To transition towards a carbon-neutral future, the Republic of Moldova should untap its renewable energy potential and invest in renewable energy infrastructure.
- Implementing solar panels, improving building insulation, and promoting energy-efficient appliances can reduce electricity consumption and GHG emissions. Additionally, construction of the gas interconnector and enhancing cross-border electricity connections with Romania and other EU countries will ensure a stable supply of low-carbon electricity. The Republic of Moldova’s strategic position and ongoing projects like the interconnection with Romania will facilitate better integration with the European electricity market and reduce reliance on natural gas imported from the Russian Federation.

The Republic of Moldova's power system interconnections with Romania and Ukraine are critical for regional energy security and regional integration.



Transnistria (since 2023 Nov.)
66 USD/MWh

Romania

196…375 USD/MWh – day
149…292 USD/MWh – morning
106…114 USD/MWH - night

Ukraine

95 USD/MWh – day
55 USD/MWH - night

Source: by author based on desk review, spot price from Romania. http://energocom.md

- Geographically positioned between Romania and Ukraine, the cross-border power system of the Republic of Moldova is critical for regional energy security and regional integration with the European and Moldova-Ukraine energy markets.
- Before the war in Ukraine, the Republic of Moldova used to import about 75% of its total electricity imports from Ukraine through 14 high voltage lines. In order to make up for the electricity import shortage since November 2023, the Republic of Moldova has been importing the electricity from Transnistria and Romania with about 50% and 25% respectively.
- Currently, domestic power capacity is limited meeting only about 25% of total demand through natural gas-fired combined heat and power plants. However, it is important to note that the installed capacity in Transnistria that accounts for about 2560 MW is reported as electricity import in national statistics, and currently makes up for the import electricity deficit from Ukraine.
- Synchronisation of the Republic of Moldova's and Ukraine's power grid with the European Network of Transmission System Operators for Electricity (ENTSO-E) was completed in 2022. Further improving interconnections with Romania would improve the grid stability, increase electricity trade opportunities, and reduce the Republic of Moldova's dependency on non-EU countries.
- There is need for increased capacity and the high voltage interconnection lines of Balti-Suceava and Ungheni-Iasi. In addition, the main bottlenecks that need to be addressed are the power flows in Cuciurgan electricity node and the finalization of construction of the Vulcanesti – Chisinau line to enable unloading overflows from/to Ukraine via Cuciurgan electricity node.

Current installed power generation capacity in the Republic of Moldova in 2024

Power Plant	Installed capacity, MW	Start of commercial operation of first unit	Electricity supplied to the network, GWh		Location
		year	GWh	% of total	
CET-1 Chisinau	66	1951	15.3	0.3	Right Bank of Dniester
CET-2 Chisinau	240	1976	680.2	14.6	Right Bank of Dniester
CET Balti	37.4	1952	102.4	2.2	Right Bank of Dniester
HPP Costesti	16	1978	67.5	1.5	Right Bank of Dniester
Other sources	87	1965	78.0	1.7	Right Bank of Dniester
Import MGRES, Transnistria	2520	1964	3445.6	74.1	Transnistria
Import HPP Dubasari, Transnistria	46	1954	100.3	2.2	Transnistria
Import Ukraine	--	--	161.4	3.5	Ukraine
TOTAL	3000		4650.7	100	

Source: by author based on desk review, spot price from Romania. http://energocom.md

- Total installed power generation in the Republic of Moldova – including the capacity in Transnistria – accounts for 3000 MW.
- All installed power plants in the Republic of Moldova are gas-fired units and aging with soon approaching the end of their lifecycles. There is an urgent need for retirement and replacement by new units or new additional low- and zero-carbon power generation capacity in near future.
- All power plants of the Right Bank (without Transnistria) are combined heat and power plants - CHPs, and electricity production is driven by heat load. This means that in summer CHPs are off, and the imports from Transnistria meet about 90% of the total domestic electricity demand.

Committed renewable energy capacity in the Republic of Moldova by 2030 is expected to reach 700MW. In 2023, renewable energy generation met 10.5% of the energy demand, compared to 5.5% in 2022.

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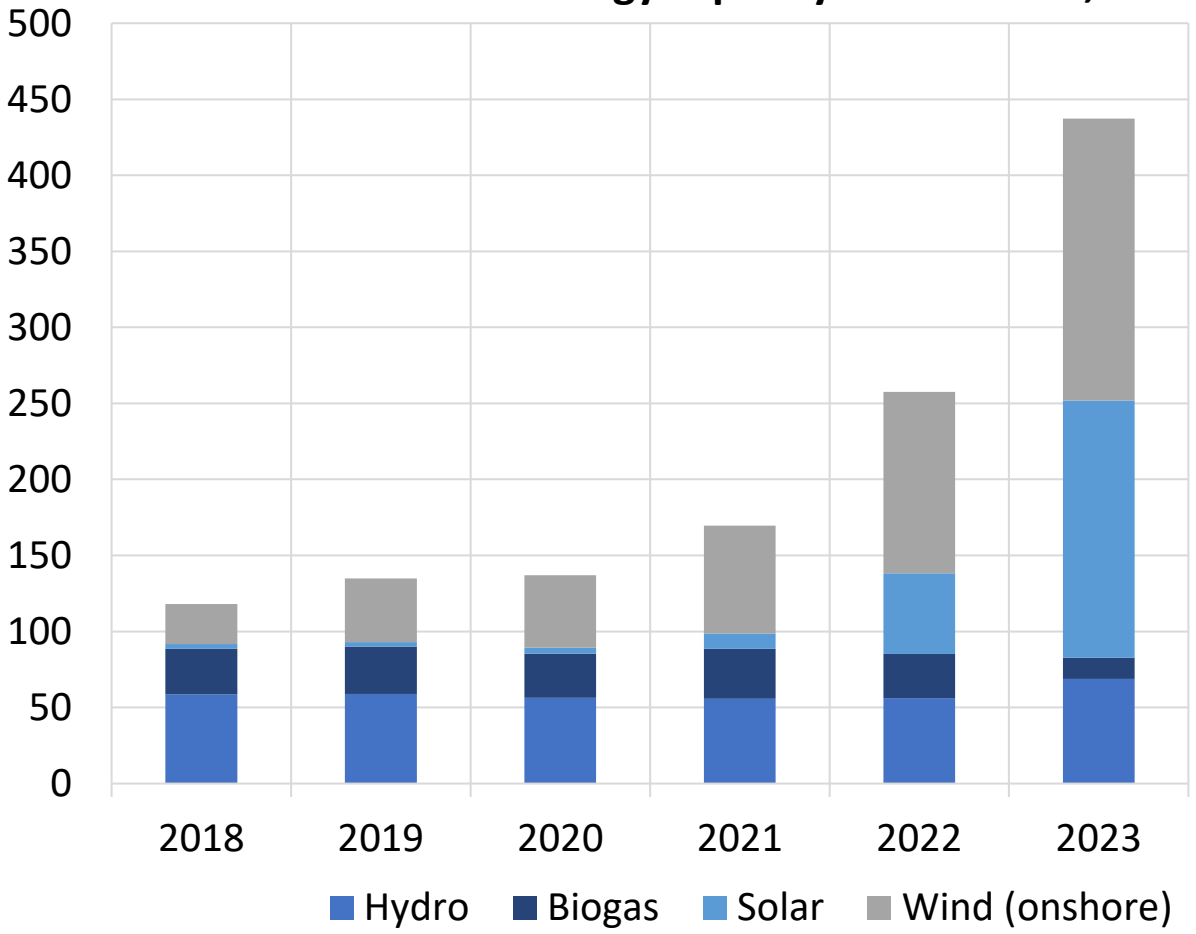
Domestic renewable energy capacity 2018 – 2023, MW

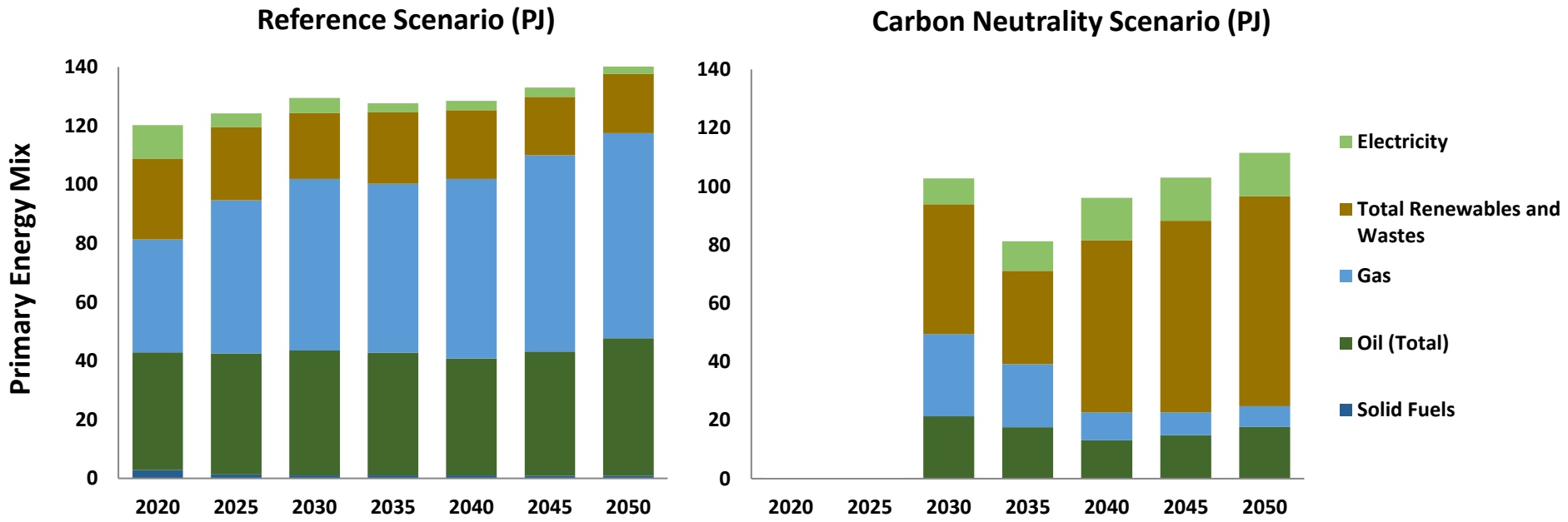


Source: by author based on desk review, spot price from Romania. http://energocom.md

Technology	**Additional units by 2030, MW**
Wind	400
Solar	200
Biogas	80
Waste	20
Total RES	700

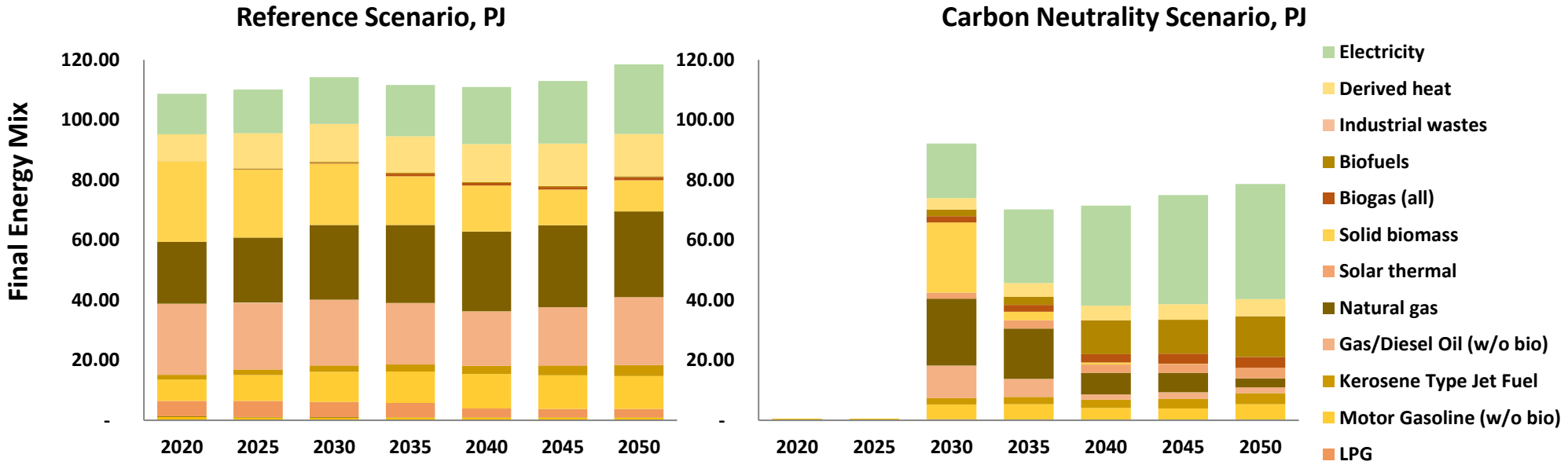
Pathways to a Carbon Neutral and Resilient Energy System in the Republic of Moldova

Today the primary energy mix of the Republic of Moldova heavily depends on natural gas and oil imports. Achieving a carbon neutral energy system will require structural changes and a substantial increase in domestic renewable energy capacity from 2030.



- In the reference scenario, natural gas, primarily imported from the Russian Federation, remains the main component of the Republic of Moldova's generation mix accounting for over 30% and followed by oil. The electricity share represented in the chart is the imported electricity. with limited climate mitigation policies, the energy mix is expected to remain constant without significant changes in the fuel mix. In this case, the Republic of Moldova will remain dependent on the import of fossil fuels, despite its vast renewable energy potential. In such case the vulnerabilities of the energy system of the Republic of Moldova are expected to continue over the long run.
- In the carbon neutrality scenario, the domestic potential of the renewable energy is expected to be vastly exploited with the share of renewable energy in the primary energy mix almost doubling towards by 2050. In this scenario, there is a structural change in the energy mix where the imported natural gas is replaced by the domestic renewable energy production. The imported electricity from Romania and Ukraine is expected to increase on the back of the improved cross-border connectivity capacity and regional integration but still at the slower rate compared to the domestic renewable energy scale up.
- A shift from the reference to the carbon neutrality scenario implies a structural shift from an energy mix that is based on imported fossil fuels to the energy mix that is mainly based on the domestically produced renewable energy. In the Republic of Moldova the shift towards a carbon neutral energy mix not only reduces the carbon footprint on its energy system but also improves country's energy security and its energy system resilience.

While today's final energy mix in the Republic of Moldova still heavily depends on fossil fuels and biomass, more ambitious climate mitigation policies are expected to lead to greater energy savings and a shift to lower carbon technology options. To reach net-zero, deep electrification across the sectors is needed resulting in greater share of electricity in the final energy mix.



- In the reference scenario, the final energy mix in the Republic of Moldova is diversified reflecting various energy sources that meet the energy demand across different sectors, including residential, industrial and transportation. Natural gas dominates the mix and is used for power generation, residential heating and industrial processes. It is followed by the solid biomass which is mainly being used for heating in rural and peri-urban households. For many lower income households it is still a traditional and most accessible source. The electricity comes from still relatively small domestic generation – 25% of the total; and the imports from Transnistria and Romania – 75%. Electrification is still low in the Republic of Moldova - the potential it is dominated by the residential and to some extent industrial sectors.
- In the carbon neutrality scenario, significant structural change in the final energy mix is expected. Over the shorter term (until 2030) the demand for final energy is expected to decline thanks to improved energy efficiency in the residential sector on the back of the retrofitting of the buildings. From 2035 further energy saving is expected across the sectors resulting in even lower final energy demand. This is mainly driven by national programme for energy efficiency in residential sector which provides technical and financial support for implementation of energy efficiency best practices in the residential sector.
- Carbon neutrality targets are expected to result with deeper electrification of all sectors: i) transportation sector: a shift from the combustion engines to the electric vehicles; ii) residential sector: phasing out of natural gas and biomass and greater penetration of electricity for the residential heating through introduction of heat pumps; iii) industry sector: greater electrification of some industrial processes.

Today's transport sector in the Republic of Moldova is characterized by old infrastructure and vehicles fleet. Decarbonizing the transport sector in Moldova will require a structural change across the sector as well as the consumers behavioral changes. Significant investments would be needed across the sector to allow deep penetration or lower polluting fuels.

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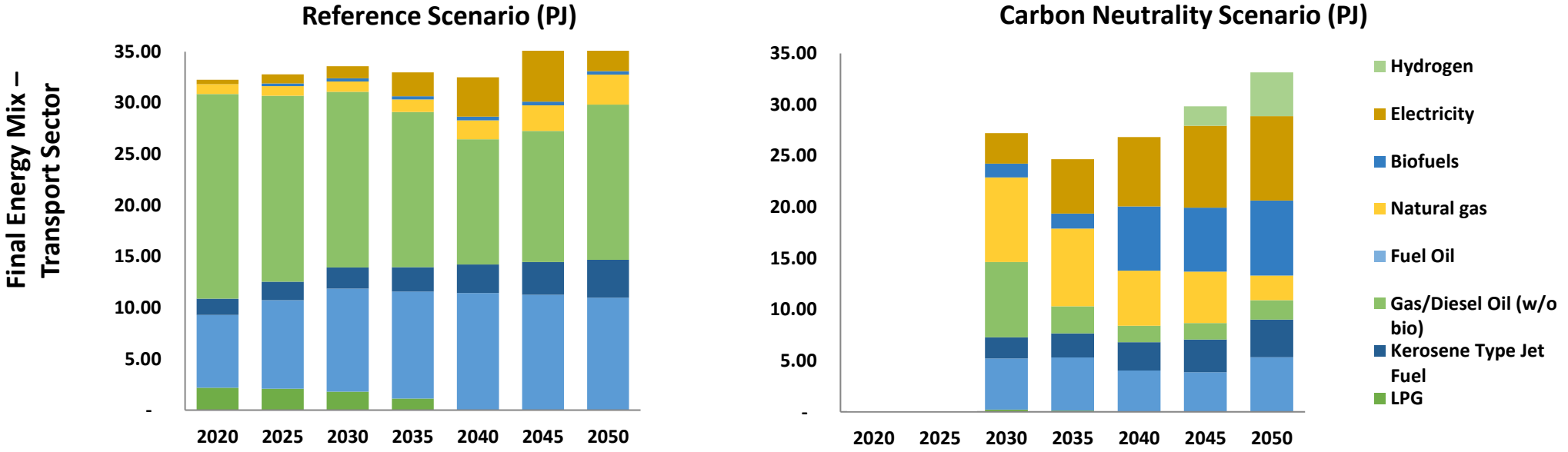
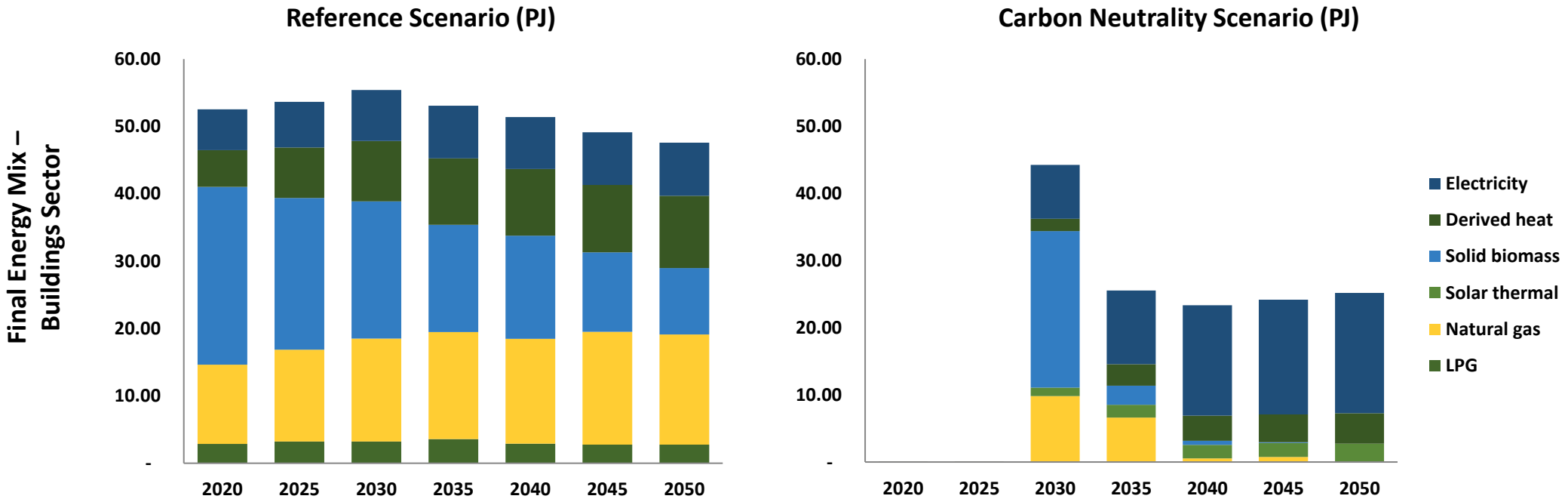


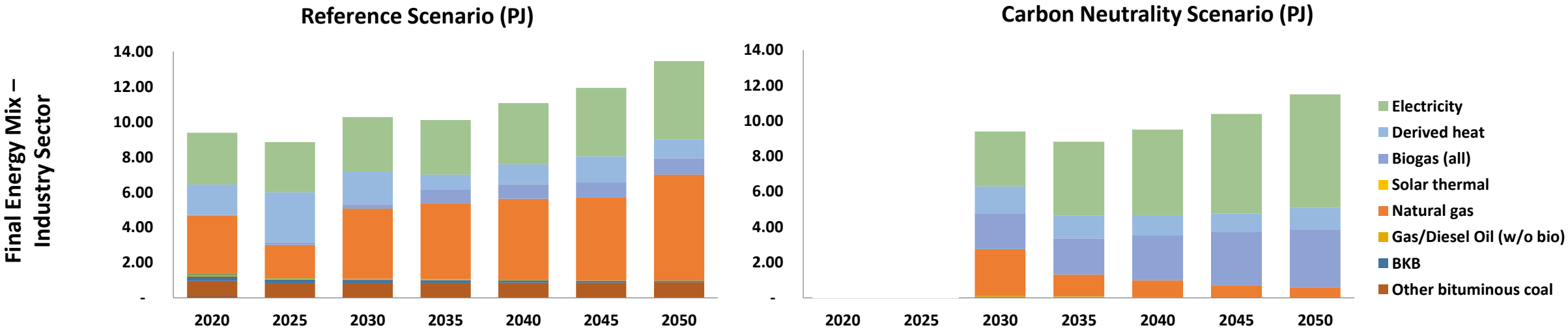
- In the reference scenario, oil products, such as gasoline and diesel, dominate the energy mix. There is a slight increase in the use of biofuels and electricity from 2040, but overall, fossil fuels are expected to remain the primary energy source over the long term. In contrast, the carbon neutrality scenario shows a significant structural shift towards deeper electrification of the sector and the penetration of natural gas as cleaner fuel for transport. By 2050, hydrogen, electricity, and biofuels become the primary fuels for transport, drastically reducing the reliance on traditional fossil fuels and improving the overall sector efficiencies. This indicates a major transition towards cleaner energy to meet carbon neutrality goals.
- Several factors need to be considered in the Republic of Moldova to transition to a carbon-neutral transport sector. The infrastructure for electric vehicles (EVs) and hydrogen fuel cell vehicles must be developed extensively. This includes establishing a network of EV charging stations, hydrogen refueling stations, and upgrading the electricity grid to handle increased loads. Policy incentives such as subsidies for EV purchases, tax breaks for renewable energy investments, and stringent emissions regulations are crucial. Additionally, substantial investments in research and development for biofuels and advanced energy storage solutions are essential to improve efficiency and reduce costs.

Today the energy demand from the residential sector is largely met by the natural gas and the biomass. A decarbonization of the buildings sector will require significant investments into the buildings insulation to improve the energy savings across the sector as well as the technology switch from natural gas and biomass to zero-carbon electricity.



- Today natural gas and biomass are the main source of energy in the residence sector. In the reference scenario, natural gas and Solid biomass remains the dominant energy sources until 2035. There is a steady reliance on solid biomass and derived heat, with minimal changes over the years.
- However, the Carbon Neutrality scenario presents a transformative shift. By 2050, the use of natural gas and LPG significantly diminishes, while electricity and renewable sources like solar energy become predominant. Upgrading building insulation and adopting energy-efficient appliances in Moldova's residential sector will significantly reduce energy demand and lower greenhouse gas emissions, leading to cost savings and environmental benefits. This trend is driven by the national programme for energy efficiency in residential sector which provides technical and financial support for implementation of energy efficiency best practices in the residential sector. The derived heat production in Reference scenario is increasing from present 5.5. PJ in 2020 to 10.7 PJ in 2030. The Carbon Neutrality scenario shows a decrease to 4.5 PJ in 2030 of derived heat due to electrification and implementation of heat pumps. Derived heat is the heat produced from centralized district heating systems.
- To achieve carbon neutrality in the residential sector, Moldova must focus on enhancing energy efficiency through smart technologies, integrating renewable energy sources like heat pumps driven by renewables; solar thermal and solid biomass, implementing supportive policies with rigorous building codes and incentives for renewable energy adoption, and encouraging households to adopt energy-saving practices through public awareness campaigns and educational programs.

Mining of sand/ limestone and food processing are the two main industries in the Republic of Moldova contributing with 9% and 11% of value added of GDP, respectively, and combined accounting for about 90% of the sector's energy demand. Decarbonization of the industry sector in the Republic of Moldova will require energy efficiency measures and deep electrification of the industrial processes.



- In the reference scenario, the industry sector heavily relies on natural gas and electricity, with substantial use of coal and LPG, indicating an increasing trend in fossil fuel consumption without significant shifts towards cleaner energy sources. In contrast, the Carbon neutrality scenario shows a major transition where electricity and biogas dominate, and solar thermal energy is introduced, drastically reducing the reliance on natural gas, coal, and LPG.
- Achieving carbon neutrality in the industry sector requires implementing advanced, energy-efficient technologies, promoting renewable energy sources like solar thermal and biogas, and establishing stringent policies that mandate lower emissions and incentivize renewable energy adoption. These steps are critical for reducing energy consumption and integrating cleaner energy within industrial processes.
- Biogas is an important source of energy replacing natural gas in high temperature processes. Low and medium temperature processes can be easily replaced by electrification and derived heat.
- To transition towards a carbon-neutral industry sector, the Republic of Moldova must invest in renewable energy infrastructure, enhance energy efficiency first through technology upgrades, strengthen policy frameworks with strict emissions regulations, and leverage international collaboration for funding and expertise. These strategic pathways will reduce the industrial sector's carbon footprint, improve energy security, and support a sustainable industrial landscape.

Today the domestic renewable energy potential remains relatively untapped. Status quo implies that natural gas fired power plants will dominate the mix until 2040. In the carbon neutrality scenario, on the contrary, significant structural changes are needed. To attain net-zero by 2050, the renewable energy capacity in the Republic of Moldova will have to increase by 4 times from the 2024 levels.

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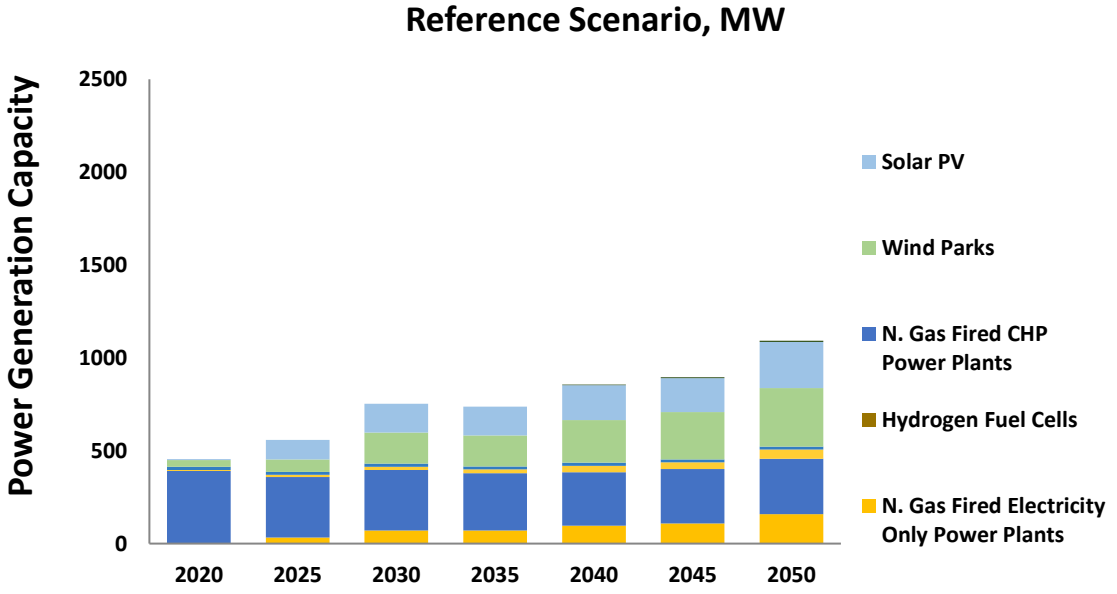

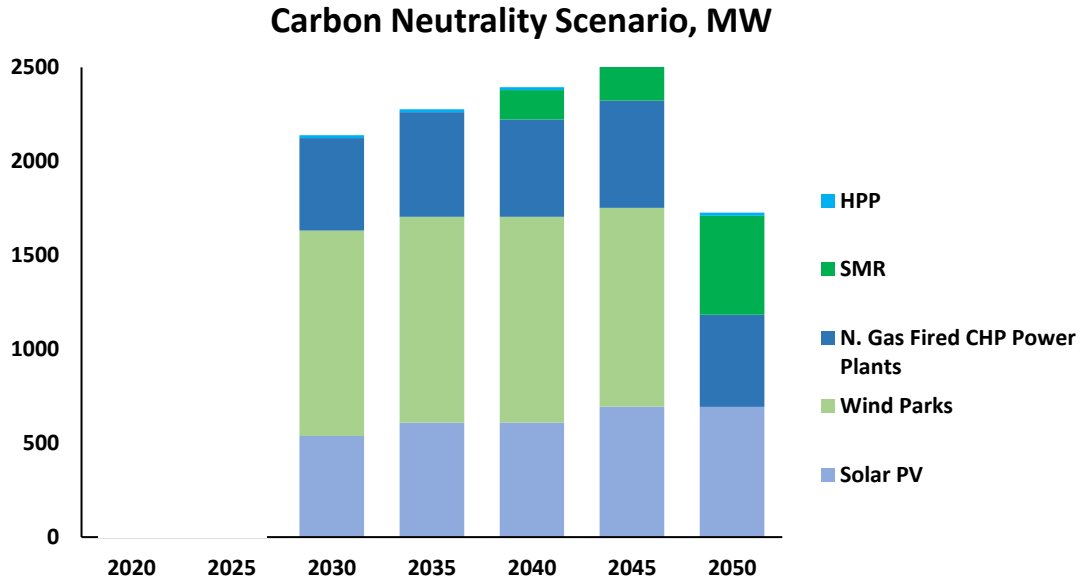

- In the reference scenario, the domestic renewable energy potential remains still relatively untapped. The power generation capacity remains low, increasing by a factor of 2 towards the end of the forecast. The composition of the mix is dominated by natural gas fired power plants that are reaching the end of the lifecycle. In 2024, installed renewable energy capacity accounts for about 400MW. In the baseline scenario, the solar and wind capacity is expected to continue growing at a very slow rate celling at about 550MW of capacity by 2050. Compared to the reference scenario, the carbon neutrality scenario, on the contrary, is expected to see significant structural changes.
- Today about 400MW of renewable energy capacity has been installed in the Republic of Moldova – of which about 230MW of solar PV, and 170MW of wind capacity. To attain net-zero by 2050, the renewable energy installed capacity in Moldova will have to increase by 4 times - from 400MW in 2024 to 1600MW in 2050. The role of natural gas CHP will remain in the mix even under the more ambitious climate mitigation policies. In the carbon neutrality scenario, the capacity of CHPs is even expected to increase to provide the system balance to the vast intermittent renewable energy capacity. Meaning that there is a minimum CO_2 emissions that will come from CHP balancing renewables of 670 $ktCO_2$, net-zero by 2050 is possible if nuclear energy is considered as a technology for decarbonization. In addition, since the expected lifetime of wind is 20 years towards the end of the forecast the modelling shows that it is more feasible to invest in nuclear small modular reactors compared to new wind capacity. This is due to the capacity factor of 0.3 for wind turbine compared to SMRs - 3MW of wind instead of 1MW of SMR. Moreover, while SMRs have higher CAPEX compared to wind, the lifetime of SMRs is three times longer - 60 years for SMRs compared to 20 years for wind turbines.

Demand for electricity in the Republic of Moldova is expecting to grow at a steady rate of 2% p.a., increasing in the both scenarios from about 3800 GWh today to 6900 GWh in 2050. In the carbon neutrality scenario, the Republic of Moldova will continue importing electricity but natural gas will be replaced by domestic renewable energy power generation in mid-term and by small nuclear reactors in the long term.

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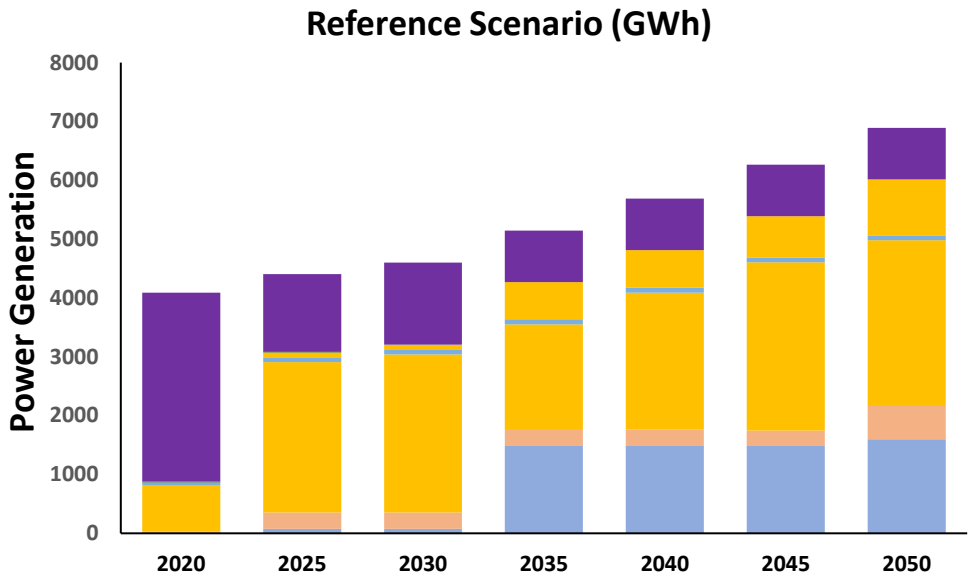

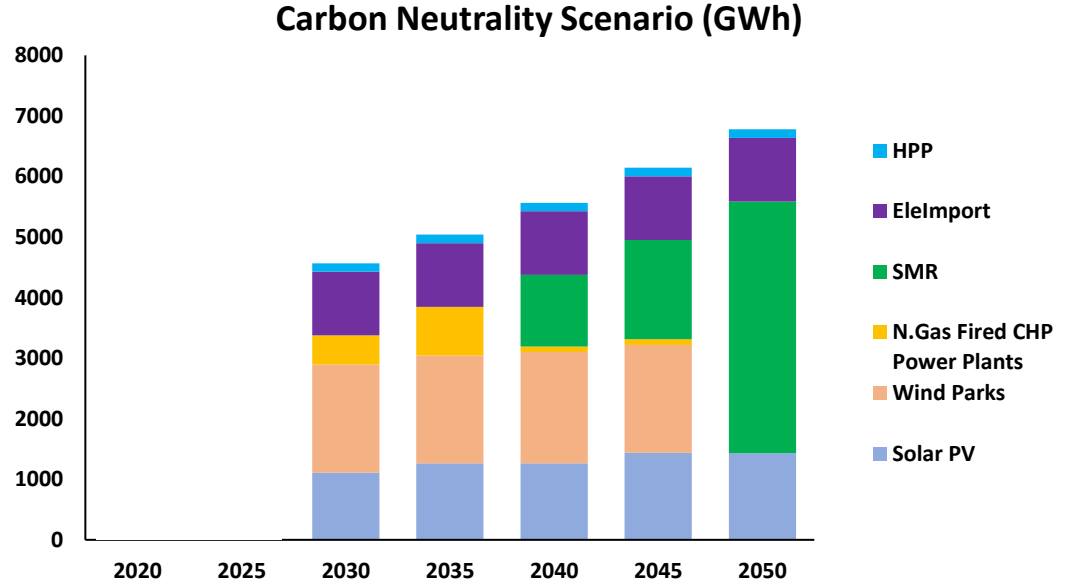

- The demand for electricity in the Republic of Moldova is expecting to grow at a steady rate of 2% annually, increasing in the both scenarios from about 3800 GWh today to 6900 GWh by 2050. In the reference scenario, natural gas will remain the major source of power generation through to 2050. Renewable energy power generation, mainly solar PV and some limited wind, is expected to penetrate the mix from 2030, picking up from 2035.
- In the more ambitious climate mitigation scenario, the carbon neutrality scenario, the Republic of Moldova will continue importing electricity but natural gas capacity will be replaced by domestic renewable energy power generation. In this scenario, wind power will be more prominent compared to the reference scenario, but interestingly not throughout the whole forecasting period. Wind projects that will come online in 2030 are expected to be decommissioned at the end of their lifetime in 2045. New nuclear small modular reactors are expected to make up for the decommissioned natural gas and wind power generation capacity providing low-carbon electricity in the Republic of Moldova.

Modelling exercise was based on the MESSAGE Model - A modeling framework for medium to long-term energy system planning, energy policy analysis, and scenario development

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INPUT

- Energy system structure (Energy Chain / Reference Energy System)
- Energy demand projections (MAED)
- Technology and resource options, incl. techno-economic performance
- Technical, environmental and other policy constraints

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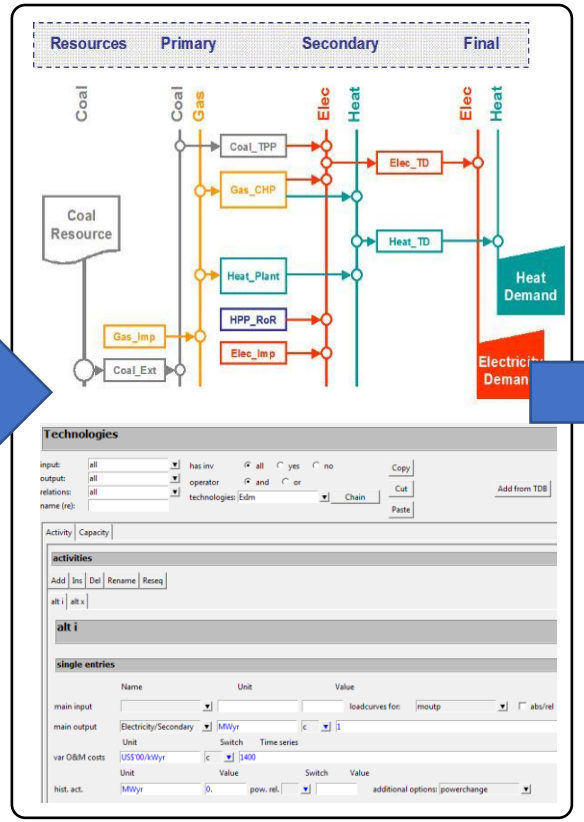
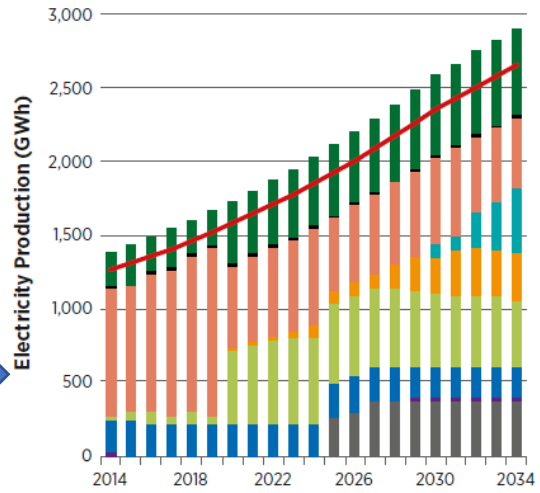


OUTPUT



- Capacity mix & investments
- Primary & final energy mix
- Emissions/Environ. Impacts
- Resource use
- Import dependence
- Land & water use, etc.

- The modelling exercise and the development of the reference scenario and the carbon neutrality scenario was based on the MESSAGE Model. MESSAGE (Model for Energy Supply Strategy Alternatives and their General Environmental Impact) has been developed by the International Institute for Applied Systems Analysis (IIASA) in Austria. It is a systems engineering optimization model used for the planning medium to long-term energy systems, analysing climate change policies, and developing scenario, for national or global regions.

Source: IAEA, IIASA

Modelling approach and overall assumptions in MESSAGE Model adapted for the energy system in the Republic of Moldova

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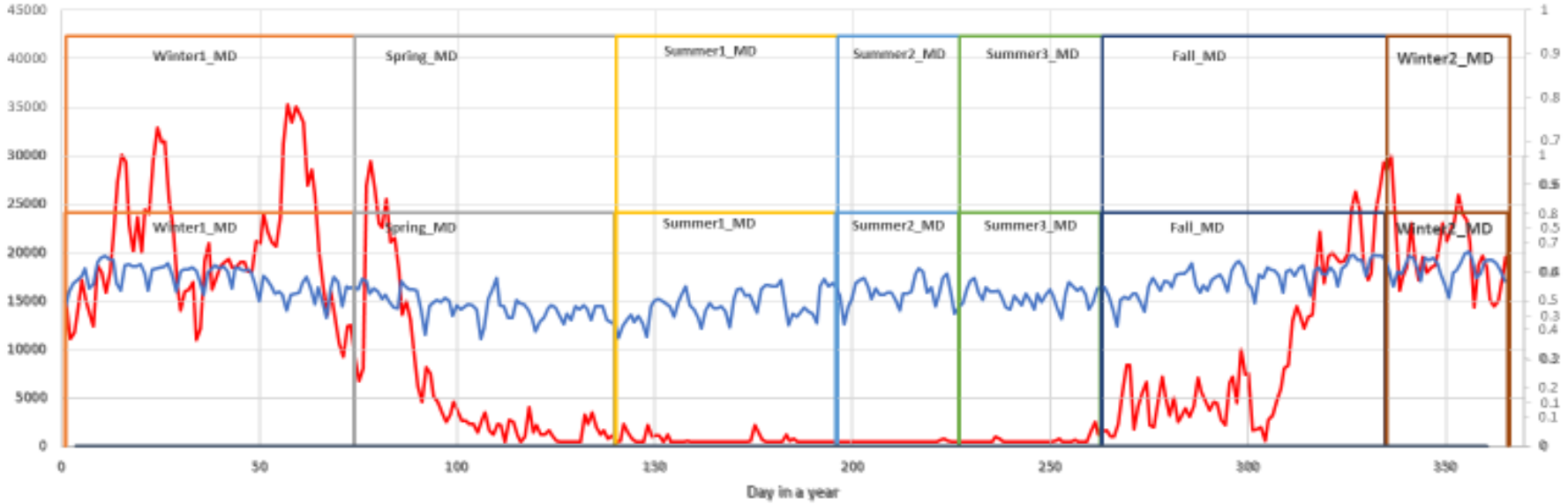
Heat and Electricity Load in Moldova



- The graph represents heat and electricity load in the Republic of Moldova. Both heat and electricity load is divided into 7 seasons and each season is divided in 8 parts per day.
- To model the optimization of the functioning of the national electricity supply system, the hour-by-hour electricity demand (blue line in the Graph) and hour-by-hour heating demand (red line in the Graph) are used. As result it was possible to model the interplay of national production and imports of electricity.

Modelling approach and overall assumptions in MESSAGE Model adapted for the energy system in the Republic of Moldova

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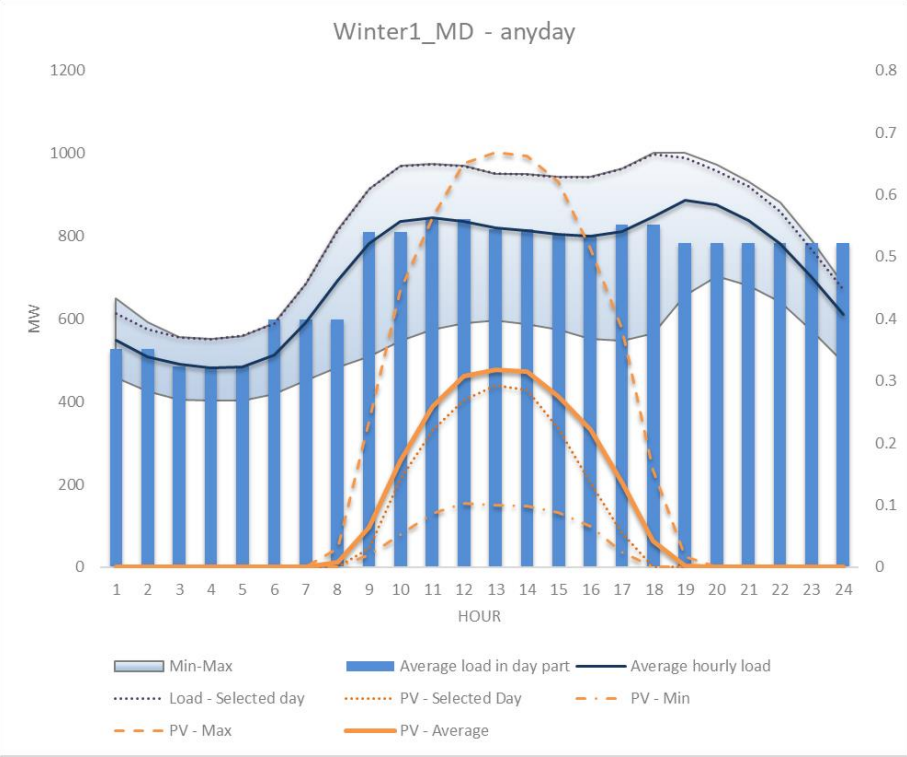
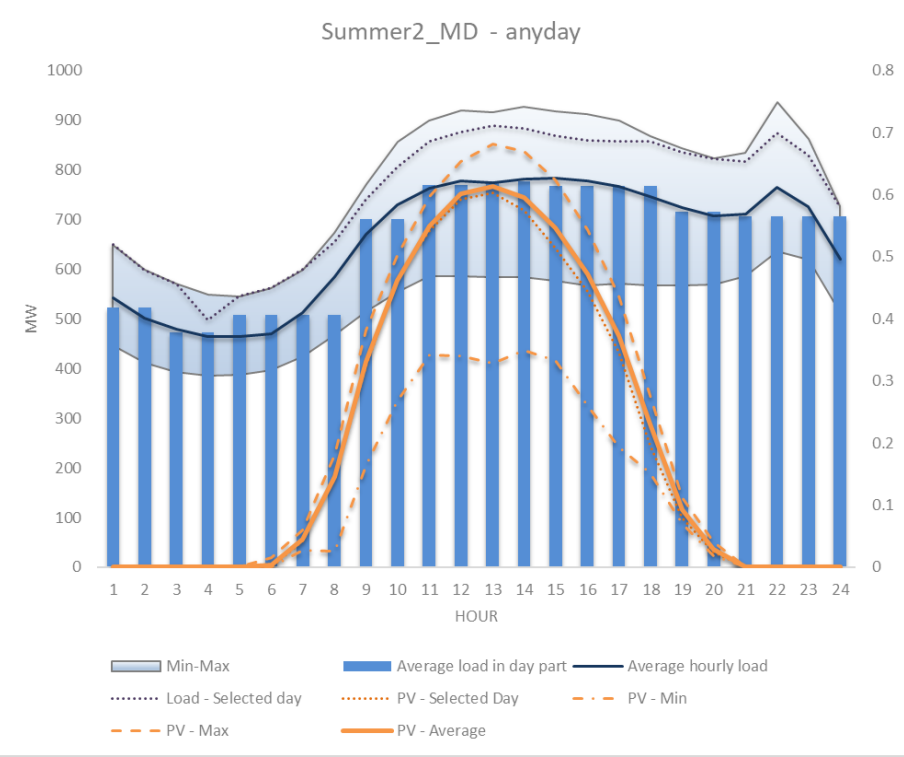
Electricity Load Profile in MESSAGE Calibrated Moldova





- The charts above represent assumptions of the summer and winter day profile as well as the profile of daily solar PV load. The orange line shows the periods of the day when solar PV systems can produce electricity comparing to daily load profile of electricity demand. The same approach is used for wind power plants. Understanding this data and trend allows domestic renewable energy sources optimization in order to satisfy the expected domestic electricity demand. In addition, understanding these trends allows assessing the balancing needs for renewables and maximize the production capacity of the technology.
- It is important to note that for the purposes of this modelling activity the impact of climate change on the development and the long-term potential of the renewable energy in the Republic of Moldova was not taken into consideration.

Modelling approach and overall assumptions in MESSAGE Model adapted for the energy system in the Republic of Moldova

Reference Scenario

- This scenario is developed on a set of baseline assumptions based on historical trends and current policies. It describes an evaluation of the energy system in Moldova as it stands right now. A reference scenario enables analysis of whether the Moldova will be able to decarbonize its energy system along its current trajectory. Future emissions are determined by the relative economics of a portfolio of current and future supply alternatives and the rates of technology learning and innovation assumptions and trends underlying the reference scenario.

Carbon Neutrality Scenario

- A future characterized by carbon neutrality is distinctly different from the reference scenario and equitable technology assumptions. The Carbon Neutrality scenario in Moldova, assumes faster rates of GHG emissions reduction from 2024 towards the end of the modelling horizon. Under this scenario the model is calibrated to achieve net-zero emissions by 2050. This scenario envisages that the small modular reactors nuclear technology is available in 2040, and economic development of Moldova will be based on green and clean technologies.

Specific qualitative and quantitative assumptions

- Massive penetration of solar PV and Wind by 2050
- By 2050 – existing old natural gas CHP Power Plant will be replaced
- New gas fired power plants of 330 MW are considered as a new technology, to retrofit the old power plants
- Nuclear SMRs are considered as a viable new technology from 2040
- Moldova will join EU Emissions Trading System (ETS) market by 2030
- The power generation capacity in Transnistria is included in the modelling
- All diesel and gasoline cars to be replaced by electric cars by 2050 in the carbon neutrality scenario
- Biofuels to replace gasoline in hybrid cars by 2050
- AVIA kerosene will be replaced by biofuel
- Railways will be electrified by 2050, replacing diesel
- Significant increase in electricity prices in the short/medium term reflecting the current energy crisis (electricity cost increased from around 60€/MWh, - in 2030 to 120€/MWh)
- Significant increase of gas prices in the short/medium term reflecting the current energy crisis (gas cost increased from around 20€/MWh, - in 2030 to 60€/MWh)
- Increase of CO2 EU ETS price in the short to medium term reflecting current EU ETS market prices (from 50€/tCO2, to +100€/tCO2 in 2030) ...100 €/tCO2 – 2030-2050