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Development of Low-Carbon Energy Supply System in Romania

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Abstract

Despite the declining trends in total energy consumption, greenhouse gas emissions, energy intensity, and emission intensity over the past two decades, Romania still emits more greenhouse gas per unit of output than many other members of the European Union. The country is looking for further greening of its energy supply system to achieve the clean energy and climate change mitigation goals included in the European Union's 2030 target and 2050 Roadmap. Using an energy supply optimization model, TIMES, this study develops energy supply mixes for Romania under a baseline scenario that satisfies the European Union's current energy and climate targets for 2020, a green scenario that satisfies the European Union's 2030 energy and climate targets, and a super green scenario that satisfies the European Union's prospective 2050 energy road map. The study finds that although Romania could achieve the green scenario at a moderate cost, it would be challenging and costly to achieve the super green scenario.

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Development of Low-Carbon Energy Supply System in Romania[1]

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JEL Classification: Q41, Q42

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1. Introduction

Romania's economic growth and energy consumption have been decoupling since the early 1990s, and the energy intensity of the economy has been continuously decreasing. Over the last two decades, the country has been experiencing either declining or slow growth of energy demand due mainly to the economic downturn in early 1990s, followed by significant structural shifts of the economy toward higher-value-added manufacturing and services and away from energy-intensive industries, as well as significant improvements of energy efficiency within industries. However, the trend is expected to change as the energy consumption patterns of the country are expected to converge toward those of high-income EU countries and energy demand will increase, in particular, due to growth in demand for transportation and services. These changes are already occurring since 2000. During the 2000-2013 period, energy consumption in the transport sector grew by 48% and in the services sector by 165%, while residential and industrial demand declined by 9% and 38%, respectively (IEA, 2003 and 2015).

Romania's energy supply system is dominated by fossil fuels, with almost 75% of total primary energy requirement is supplied through fossil fuel sources in 2013 (IEA, 2015). Almost half of total electricity generation comes from power plants fired with fossil fuel sources.[3] Moreover Romania has the sixth-largest proven natural gas reserves in Europe, 3.9 trillion cubic feet, and the fourth-largest proven crude oil reserves in Europe, 600 million barrels as of the beginning of 2015 (BP, 2015). Romania also holds 51 trillion cubic feet of technically-recoverable shale gas resources, and there are plans to develop the domestic shale gas industry.[4] This implies that the energy supply system would remain carbon intensive unless policy interventions are placed to significantly alter the energy supply mix.

Following the existing EU rules and regulation as well as future aspirations on climate change mitigation, Romania is working to move forward with a low-carbon sustainable economic development path. It is a participant of the EU emissions trading system (EU-ETS), which is designed to secure 21% of GHG reductions from energy intensive sectors, such as power and heat production sectors, across the EU member states by 2020, compared to their 2005 level of GHG

[3] In 2013, non-fossil energy sources contributes to 26% of the total primary energy supply and 49% of the total power generation in Romania (IEA, 2015). These numbers indicate that Romania already has a relatively low carbon energy supply system as compared to many EU member states.

[4] Technically Recoverable Shale Oil and Shale Gas Resources. http://www.eia.gov/analysis/studies/worldshalegas/

emissions from those sectors (EC, 2015a). The EU and member states have set a binding target of limiting their GHG emissions 40% below in 2030 from their 1990 levels along with their renewable energy to shares at least 27% of their total primary energy supplies as part of their Intended Nationally Determined Contributions (INDC) agreed in the Paris Accord (EU, 2015b). EU also has developed a long-term energy road map with an aspiration of limiting its GHG emissions 80% below 1990 levels by 2050 (EU, 2012). As a member state of EU, Romania will need to meet these targets. In addition, while the energy intensity of Romania's economy has been decreasing, it is still one of the highest in the EU. In the absence of further de-carbonization efforts in the energy sector with a large substitution of fossil fuel based energy supply sources with cleaner non-fossil fuel based ones, Romania will not be able to meet the climate change mitigation targets implied by EU climate policies beyond 2020.

Few studies are available in the public domain on Romania's long-term energy planning and particularly low-carbon energy system development in the country. Prisecaru et al. (2007) highlight the importance of nuclear power in Romania and in Europe as a whole for low-carbon energy system expansion and suggest to replace aged, inefficient and highly polluting thermal power plants with new nuclear power units for the sustainable energy sector development in Romania. Other studies, such as Naăulea (2014), Baloi, (2010) and Carstea et al. (2010) highlight the role of renewable energy (e.g., wind, solar) in promoting clean energy in Romania's energy supply mix. However, these studies present a fragmented picture of a particular energy source's role instead of posturing the whole picture of energy supply mix based on economics, resource potential, and Romania's obligation under the EU climate change and energy directives. This study aims to fill this gap. Moreover, the study presents a long-term (next 35 years until 2050) view of sustainable and environmentally friendly development of the energy sector in Romania.

This study offers a scenario based analysis that develops least cost energy supply systems for Romania for the 2015-2050 time horizon using an energy supply optimization model TIMES. We first developed a 'Baseline' scenario which incorporates EU 2020 targets, this is followed by a 'Green' scenario where Romania will meet EU obligations they committed in their INDC (i.e., 40% reduction of GHG emissions in 2030 from its 1990 level).[5] Finally, we developed a 'Super

[5] As set out in the EU's 2030 Climate and Energy Policy Framework approved in October 2014 and confirmed in the EU's INDC to the UNFCCC in 2015.

Green' scenario where Romania will meet EU's long-term road map of reducing 80% of GHG emissions in 2050 from 1990's level.[6] The study finds that Romania can meet the mitigation obligations likely under the EU 2030 framework in energy and electricity at moderate costs. However, meeting the prospective requirements of the EU 2050 Roadmap (i.e., super-green scenario) is both expensive and challenging to implement.

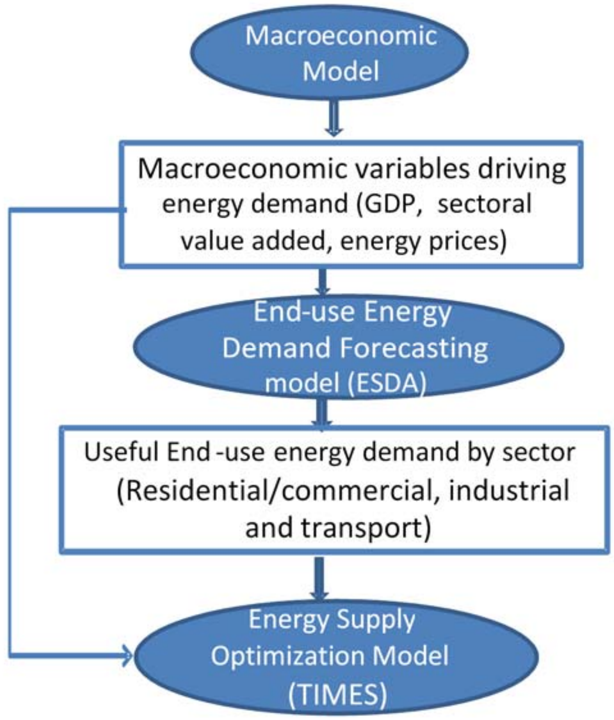
The paper is organized as follows. Section 2 briefly introduces the TIMES model and data used for the analysis. This is followed by discussions of results generated by the model under the alternative scenarios in Section 3. Section 4 highlights key policy implications drawn from modeling exercise carried out for this study and finally key conclusions are drawn in Section 5.

2. Methodology, Data and Scenarios

The study employs the TIMES model to develop optimal supply mix under the various scenarios considered. The overall modeling framework is illustrated in Figure 1. As shown in the figure, a macroeconomic model (actually a CGE model) first provided projections on key macroeconomic variables, such as GDP, sectoral value added and outputs, household income, and commodity price indices for the 2015-2050 period.[7] These variables together with many other input data serve as the main drivers for end-use energy demand projections in various sectors of the economy (i.e., residential, non-residential, industrial, transportation) over the same time horizon (i.e., 2015-2050).[8] Demand side energy efficiency measures were considered in the demand modeling thereby developing two cases for energy supply projections. The first case assumed that energy efficiency measures will not be materialized due to several implementation barriers. We call it the high energy demand case. In the second case, we assumed that energy efficiency measures will be gradually implemented over the planning horizon (2015-2050). We refer this case as the low demand case. Each supply scenario (i.e., Base, Green and Super Green) is run under both demand cases thereby making six runs of the TIMES model.

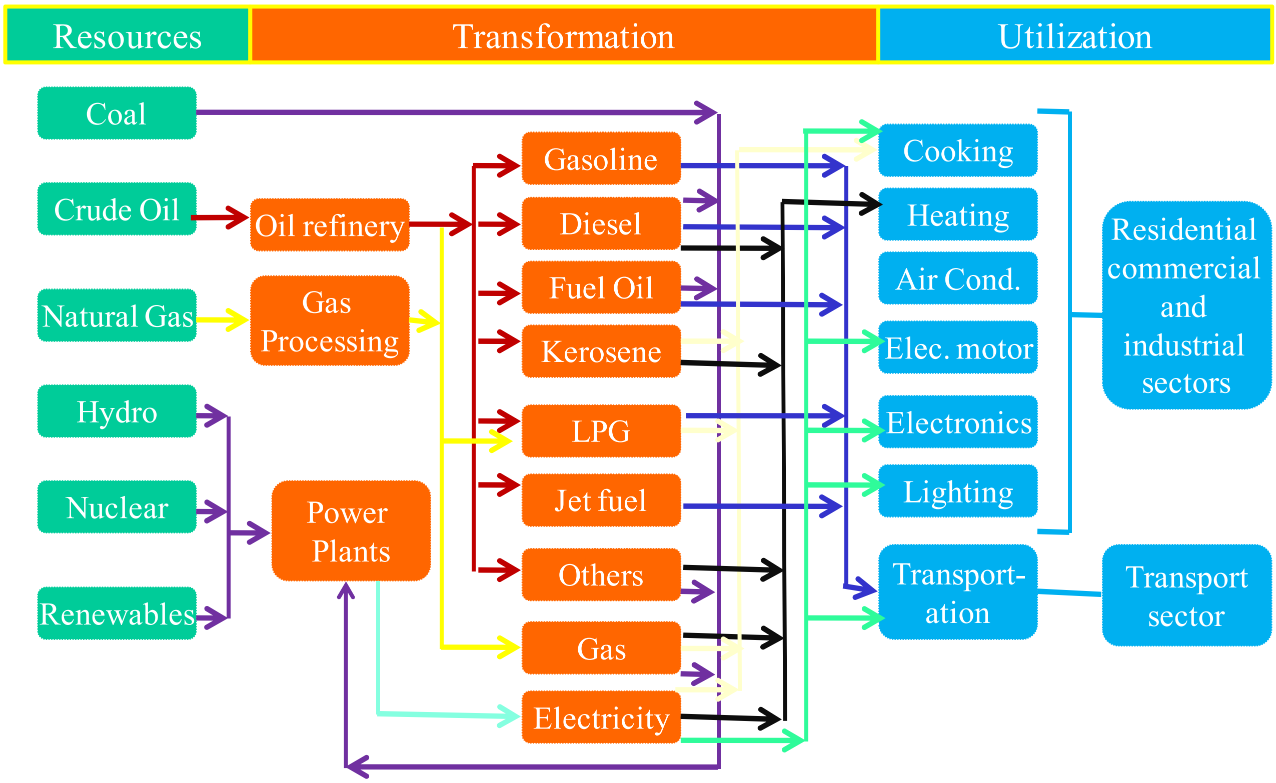
Figure 1. Overall methodological framework

[6] The European Union has laid out a vision for mitigation through 2050 in a "Roadmap for moving to a competitive low carbon economy in 2050" was published in March 2011 by the European Commission.
[7] Please see Jorgensen and Shkaratan (World Bank, 2016) for detailed information.
[8] For the projection of end-use energy demand for Romania, which is used exogenously in this study, please refer to Malla and Timilsina (2016).



The basic theory behind the TIMES model is replicated in the reference energy system presented in Figure 2. The model finds a mix of energy sources along with transformation/ transmission/transportation paths among the thousands of such possible mixes in such a way that the selected energy mix confirms that it is the least cost option to meet the given demand with available supply sources. While meeting projected end-use energy demand, the model satisfies all resources, technological, policy and any other constraints specified. Thus, the model produces an optimal mix of energy supply sources (e.g., coal, oil, gas, LNG, hydro, solar, wind, biomass) to meet the end-use energy demand (e.g., space heating, space cooling, lighting, electric motors, motive power) in various sectors (i.e., residential, commercial/service, industrial and transport). While determining the optimal energy supply mix, the model simultaneously determines the cheapest path to transform/transmit/transport these energy commodities to energy end-uses.

Figure 2. Theoretical Foundation of TIMES model (Reference Energy System)



The structure of TIMES is defined by variables and equations determined from the data input provided by the user. This information collectively defines each TIMES regional model database, and therefore the resulting mathematical representation of a Reference Energy System for the region. The database comprises both qualitative and quantitative data. The model requires a large set of input data. The major data items and their sources are summarized in Table 1.

The study considered three scenarios for energy system optimization: a Baseline, a Green scenario, and a Super Green scenario. The scenarios, consistent with those used in macroeconomic analysis were defined as shown in Table 2.

Table 1: Key Data and Sources

Data Requirement	Source
Energy Balances of Romania	• National Institute of Statistics, Romania; International Energy Agency (IEA)
Resource Potential, including imports/exports	• Various sources published by Romanian Regulatory Authority for Energy (ANRE), Ministry of Economic Affairs
Installed capacity and characterization of new technologies for electricity generation, heating and CHP plants	• ANRE, Electricity Utilities (Electrica, Hidroelectrica, Nuclearelectrica) • IEA Clean Coal Centre Database, Energy Information Administration of USDOE • World Bank: Private Participation in Renewable Energy Database
Load Profile	• European Network of Transmission System Operators for Electricity
Fuel prices projections	• IEA World Energy Outlook (2013)

Table 2. Definition of scenarios considered in the study

Scenario Name	Scenario Definition
Baseline	It is an extrapolation of the current state of the energy sector including already planned or implemented mitigation measures, in particular ongoing implementation of the current EU 2020 climate and energy package, which sets an EU-wide target to reduce GHG emissions by 21 percent in energy-intensive sectors, which participate in EU emissions trading, compared to 2005. However, it does not include broader reforms that the energy supply system needs to implement in line with the EU's long-term plan to reduce carbon emissions.
Green	It assumes the implementation of the proposed EU 2030 framework for climate and energy policies, which sets overall GHG mitigation at 40% compared to 1990 levels. For the power sector and other ETS participants, EU 2030 target corresponds to the reduction of GHG emissions of 43% for the EU as a whole compared to 2005. This scenario basically assumes full implementation of EU INDC.
Super Green	This scenario is driven by the EU's prospective 2050 Roadmap which aims for the EU to reduce GHG emissions by at least 80% below 1990 levels by 2050, to a large extent by almost total decarbonisation of the power sector.

Each of these three scenarios was implemented under two cases: 'low demand' case and 'normal demand' case. The low demand case considers large-scale energy efficiency improvements in the demand side or energy end-use sectors (e.g., residential and commercial sectors). Major energy efficiency improvement measures include use of more efficient lighting and electric appliances, retrofitting buildings with wall, window and roof insulation, heating system improvement in the residential, commercial and public buildings, and use of efficient electric motor and thermal energy equipment in the industry sector. The implementation of these measures leads to 26% reduction of residential sector energy consumption by 2050 from that in the normal demand case. The energy efficiency measures in the non-residential buildings sector (e.g., more energy efficient space heating and space cooling) results in about 30% reduction in services energy demand. However, the size of service (or commercial) sector in the total energy consumption is small. In the case of industrial sector, the introduction of more energy-efficient technologies especially electric motors and boilers reduces leads to about 16% reduction of industrial sector energy consumption from that in the normal demand case by 2050. The design of the low demand scenario reflects Romania's commitment to EU's energy and climate strategies.

3. Results

In this section we present discussions of results produced by the TIMES model. These results include primary energy supply, electricity and heat supply, total system costs and investment requirement and CO_2 emission reductions.

3.1. Primary Energy Supply

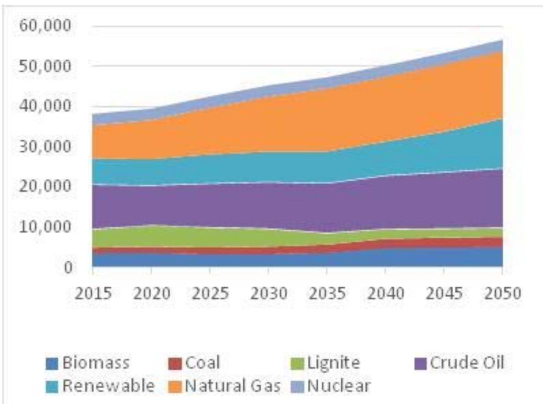
Primary energy supply projections in Romania under different scenarios are presented in Figure 3a to 3f. Under the baseline scenario, Romania's total primary energy supply in 2050 is projected to increase by approximately 49% from the 2015 levels, from about 38,184 ktoe to about 56,779 ktoe. Under the low demand baseline scenario, total primary energy supply in 2050 would be 14% smaller compared to that in the baseline scenario.

Oil and natural gas are the most important sources of primary energy. While the share of oil in the baseline drops slightly from 29% in 2015 to 26% in 2050, share of gas increases by 8 percentage point, from 22% in 2015 to 30% in 2050 because Romania needs cleaner fuels to meet the EU's GHG mitigation targets. For the same reason, share of coal drops from 16% in 2015 to 8% in 2050 in the baseline.

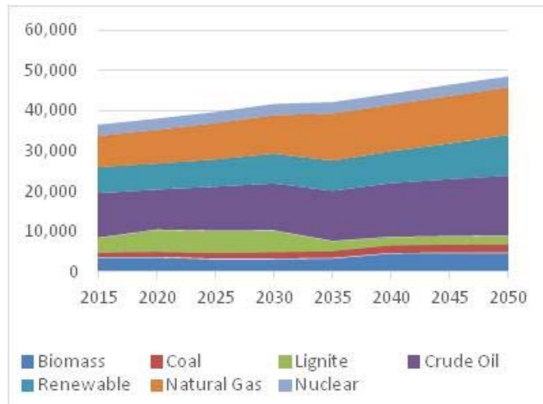
As expected the primary energy supply mixes in the green and super-green scenarios are different from that in the baseline scenario because of substitution of fossil fuels with renewables and nuclear. For example, in the green scenario, the shares of renewables (hydro, wind and solar) in 2050 increases to 23% from 21% in the baseline. The reverse would happen in the case of natural gas, where its share decreases from 30% in 2015 to 24% in 2050. The share of biomass increases dramatically under the super-green scenario where Romania reduces energy sector emissions by more than 40% from the 2005 level. Please note that the super green scenario is an extreme scenario which assumes no GHG emissions from power generation and heat production activities. This is included here to test what the energy supply system will look like in case Romania adopts such an extreme measure.

Figure 3. Primary Energy by Fuel Group (percent share), 2010 -2050

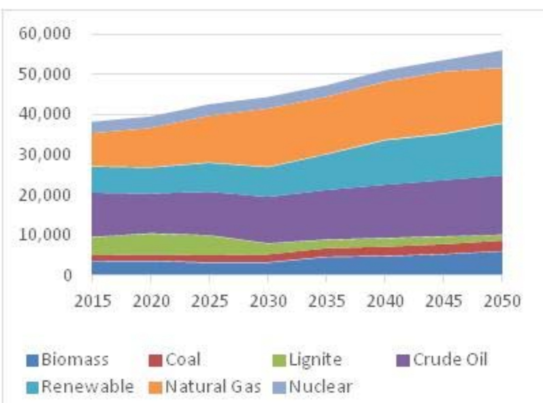
(a) Baseline



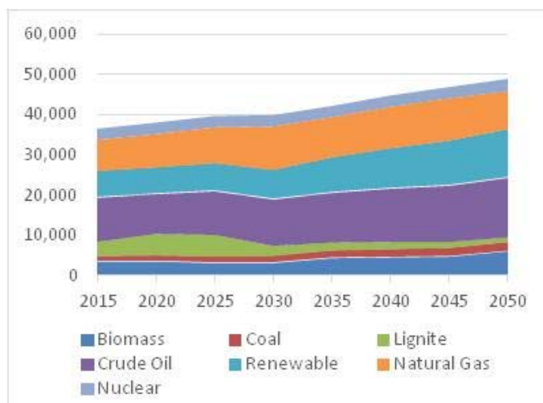
(b) Baseline with low demand



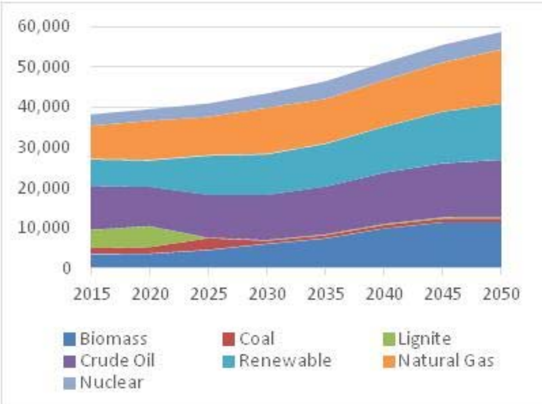
(c) Green



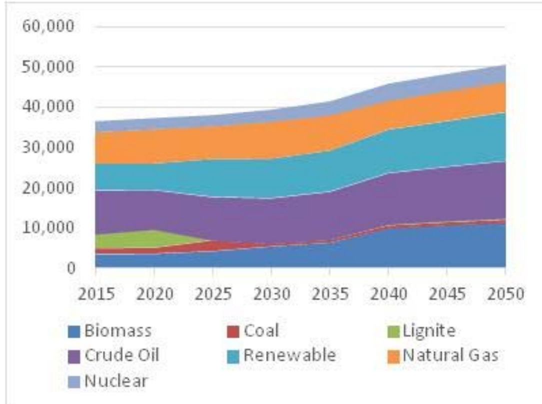
(d) Green with low demand



(e) Super green



(f) Super green with low demand



3.2. Electricity Supply

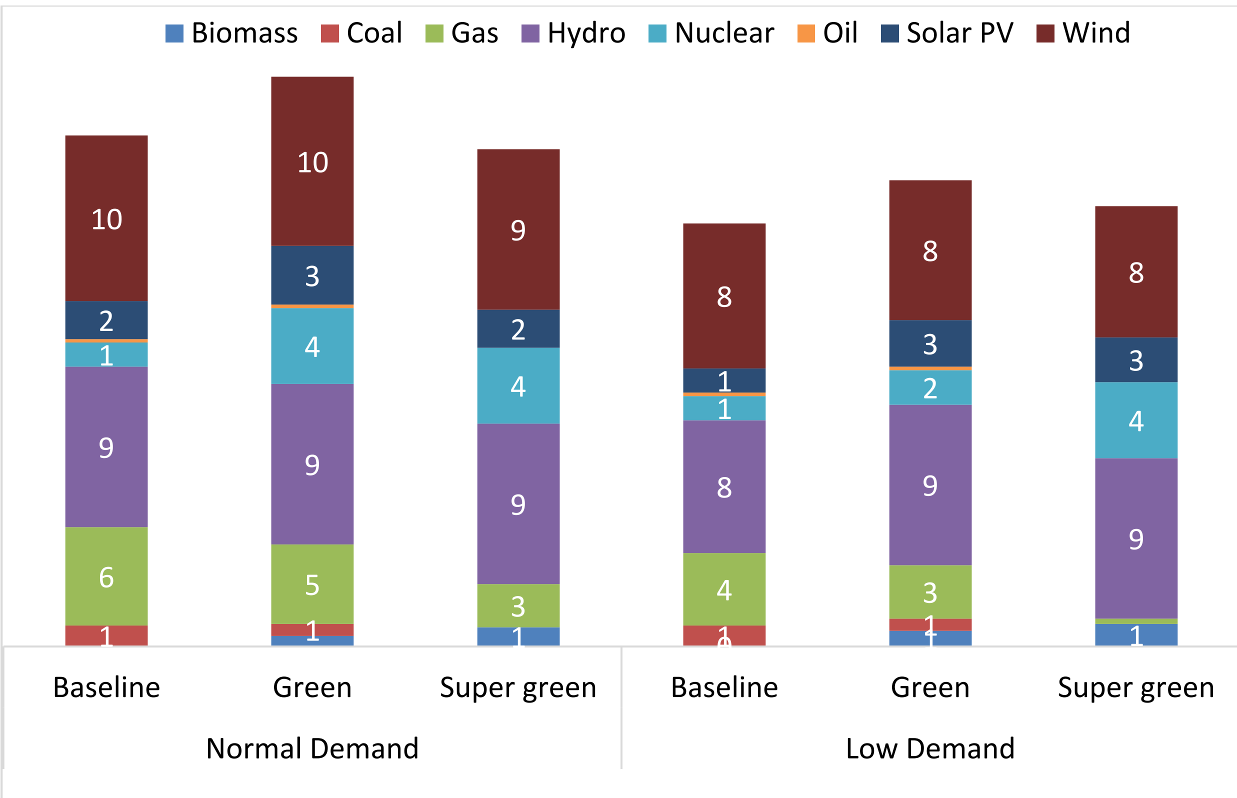
3.2.1 Total Installed Capacity

Figure 4 presents total installed capacity need in Romania by 2050. Romania's installed capacity for power generation is projected to grow from 23 GW in 2015 to 30 GW in 2050 under the baseline. Under the low demand case, the installed capacity would remain almost the flat during the planning horizon (2015-2050) as new capacity requirement would be offset by improvements in energy efficiency in the demand sectors. Total installed capacity under the green and super green scenarios would be higher than that in the baseline due to large share of renewables sources which have lower availability factors.

The electricity supply system would be relatively cleaner in Romania because this sector is covered under the existing EU emission trading regime and it expected to reduce its emissions by 20% from the 2005 level. This existing mandate would push the country to adopt cleaner sources for electricity generation even in the baseline. Therefore, the share of coal rapidly diminish and drops to 4% in 2050 from 30% in 2015.

Hydropower, the largest source of clean energy for the country, accounted for about 32% percent of the installed capacity in 2010, slightly low (28%) in 2015 but rebounds back above 30% by 2050. Wind power, which accounted for 12% of the total installed capacity in 2013 is expected to grow significantly to 32% by 2050. Romania's only two nuclear power plants, Cernavado plant 1 and 2, currently account for about 6% of the country's total installed capacity. There will be no installation of new nuclear capacity under the baseline.[9] Under the low demand baseline case, solar PV installation drops to 1 GW from the 2 GW installed under the normal demand baseline scenario; similarly installed capacity of hydropower drops to 8 GW from 9 GW installed under the normal demand baseline scenario.

Figure 4: Total Installed Capacity for Electricity Generation by 2050 (GW)



Under the green and super green scenarios, the electricity generation capacity mix would be significantly different from that in the baseline. The share of wind and solar PV will increase tremendously by 2050; while wind will occupy 30 to 32% and solar PV will occupy 8 to 10% of

[9] Our analysis like any other long-term electricity generation plans, is based on least cost expansion satisfying resources and environmental constraints. While the results from this analysis could provide important insight for the development of power sector strategy, it is not itself an electricity sector development strategy, which would consider several factors in addition to economic factors. While nuclear is not found economically attractive for the baseline in this analysis, the government could still consider nuclear from other consideration, such as security of supply.

the total electricity generation capacity by 2050. The share of natural gas in the total electricity generation capacity in 2050 would drop to 14% in the green scenario from 19% in the baseline scenario. It would drop further to 9% under the super-green scenario. The share of nuclear power in 2050 would increase to 13% and 15% under the green and super green scenario, respectively from the 6% in 2015 under the baseline scenario.

Table 3: Total Installed Capacity (% and GW)

	Normal demand				**Low demand**			
	2020	**2030**	**2040**	**2050**	2020	2030	2040	2050
Baseline Scenario								
Biomass	0%	0%	0%	0%	0%	0%	0%	0%
Coal	30%	16%	6%	4%	30%	22%	6%	5%
Natural Gas	14%	17%	25%	19%	14%	9%	20%	17%
Hydro	28%	30%	28%	31%	28%	31%	31%	31%
Nuclear	6%	7%	6%	5%	6%	7%	7%	6%
Oil	7%	1%	1%	1%	7%	1%	1%	1%
PV	3%	2%	9%	7%	3%	2%	7%	6%
Wind	13%	28%	25%	32%	13%	28%	28%	34%
Total (GW)	23	21	23	30	23	20	21	25
Green Scenario								
Biomass	0%	0%	0%	2%	0%	0%	0%	3%
Coal	30%	9%	5%	2%	30%	9%	5%	3%
Natural Gas	14%	21%	18%	14%	14%	17%	14%	11%
Hydro	28%	31%	36%	28%	28%	35%	39%	34%
Nuclear	6%	7%	5%	13%	6%	8%	6%	7%
Oil	7%	1%	1%	1%	7%	1%	1%	1%
PV	3%	2%	13%	10%	3%	3%	12%	10%
Wind	13%	28%	22%	30%	13%	27%	23%	30%
Total (GW)	23	20	26	33	23	18	22	27
Super-green scenario								
Biomass	0%	5%	4%	4%	0%	4%	3%	5%
Coal	30%	0%	0%	0%	30%	0%	0%	0%
Natural Gas	14%	8%	5%	9%	14%	8%	1%	1%
Hydro	28%	44%	38%	32%	28%	49%	41%	36%
Nuclear	6%	13%	18%	15%	6%	9%	20%	17%
Oil	7%	0%	0%	0%	7%	0%	0%	0%
PV	3%	14%	19%	8%	3%	8%	16%	10%
Wind	13%	16%	16%	32%	13%	22%	19%	30%
Total (GW)	23	21	25	29	23	19	23	26

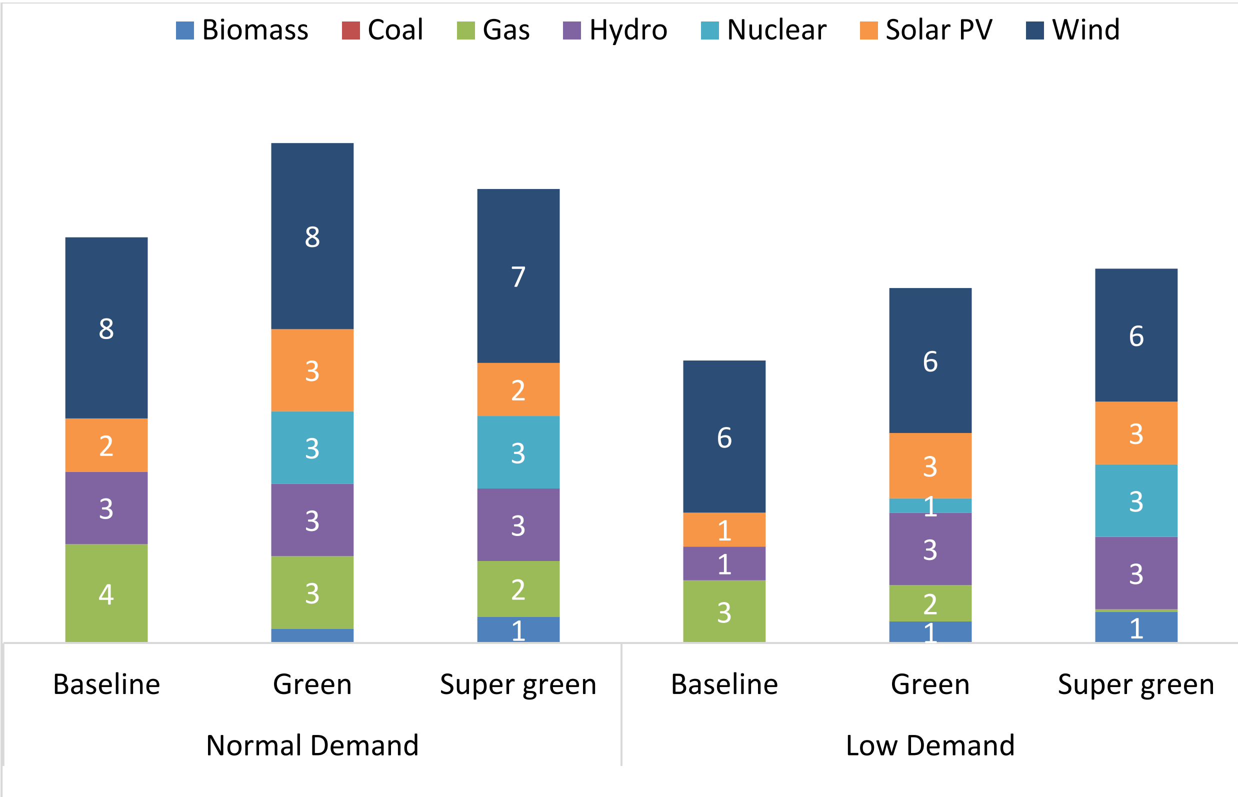
Please note that at present Romania has much higher installed capacity compared to its peak load (20 GW installed capacity vs. 10 GW peak load). Adding more renewable sources for energy generation, particularly the intermittent sources (wind and solar) would further increase the gap between total installed capacity because intermittent sources do not provide commitments to meet peak load. Thus, the higher installed capacity because of higher penetration of intermittent renewable sources to meet climate change mitigation targets could create a situation where fossil fuel based generation sources (e.g., coal, gas) are built to meet the peak load but they will not be utilized unless there exist export markets for electricity generated from fossil fuel sources, which is unlikely in the EU due to climate change mitigation obligations.

3.2.2 New Capacity Addition

Figure 5 presents total new installed capacity added during the 2015-2050 period. Under the baseline, more than 8GW of new wind capacity would be added by 2050. Note that Romania has 12 GW economically exploitable wind capacity of which 3 GW has been already exploited. About 3 GW of new hydropower capacity would be added; this capacity is assumed to operate at very low capacity factors, around 34% thereby incorporating any adverse impacts on catchment areas and run-off due to potential climate change impacts. Another main source of electricity generation is solar PV, which currently accounts for less than 1GW. About 2 GW of new solar PV capacities would be installed by 2050. Nuclear capacity of 3 GW would be added only in the green and super-green scenarios replacing natural gas capacity installed under the baseline scenario.

It is very important to note here that it is not only the realization of clean electricity scenarios that is challenging, realization of baseline scenario, which is developed in line with EU 2020 climate target, itself is challenging. This is because the existing renewable electricity capacity (especially wind and solar) resulted from generous renewable energy support mechanism has already created price pressure on retail level which is deemed unaffordable. Adding further renewables would mean electricity supply costs would further increase if the cost of renewable energy supports are also included. Moreover, Romania has one of the best lignite resources in the region and it does not have an international market; throwing it out of the future electricity supply mix due to climate change policies would cause an economic loss to the country.

Figure 5: New Installed Capacity during the 2015-2050 Period (GW)

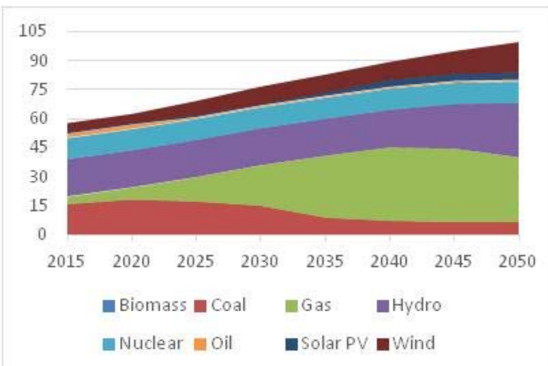


3.2.3 Electricity Generation

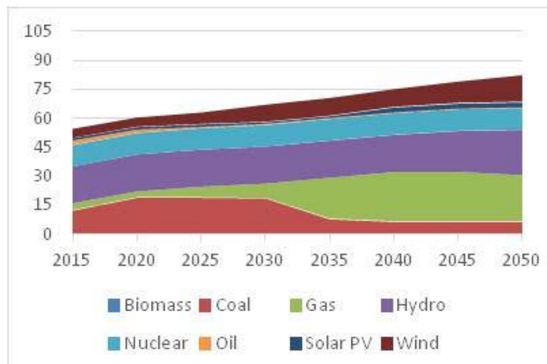
Figure 6 presents the electricity generation mix from various sources under different scenarios. Under the baseline scenario, total electricity generation over the planning horizon almost doubles, from 58 TWh in 2015 to 100 TWh in 2050. Under low demand base case, total electricity generation in 2050 would be 18% less compared to the baseline scenario. As expected, electricity generation mix does not change much between the baseline and low demand baseline cases. However, there are significant changes of electricity mix in green and super green scenarios from that in the baseline scenario. Under the green and super green scenarios, the electricity generation from fossil fuel based sources decreases rapidly. For example, there would be no electricity generation from coal based sources by 2030 under the super green scenario. The generation from gas fired power plant still operating by 2050 would be equipped with CCS so that there would be no GHG emissions released from power generation by that year. Electricity generation from nuclear power generation facilities under the green and super green scenarios would be almost three times as high as that under the baseline scenario. Please note that the main difference between the baseline and super-green scenario is the coal and nuclear based power generation. Due to EU mandate for 2030, Romania would replace coal based generation with renewable energy resources even in the baseline. Under the green and super-green scenarios, nuclear power would serve as the main base load plants. There is no change on hydro, solar and wind based generations between the base and green/super green scenarios. Nuclear, biomass, CCS gas and hydro would be main sources for non-intermittent resources for power generation and their combined capacity would exceed the projected peak load by 2050.

Figure 6. Electricity Generation by plant type (TWh)

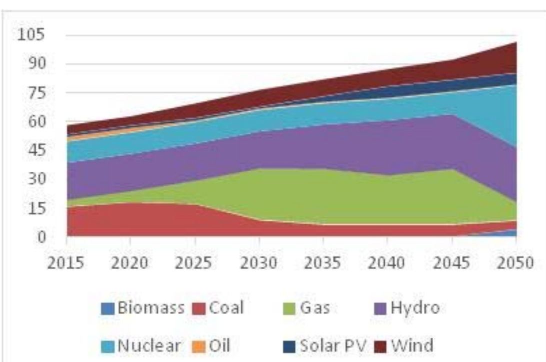
(b) Baseline



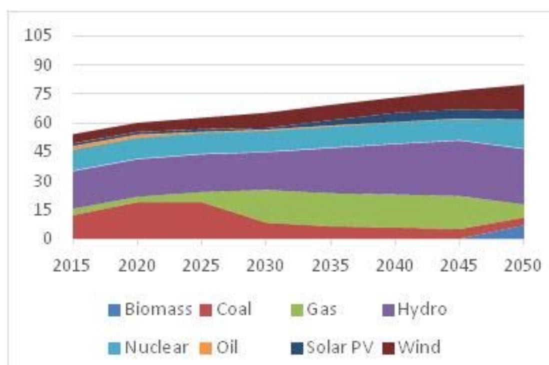
(b) Baseline with low demand



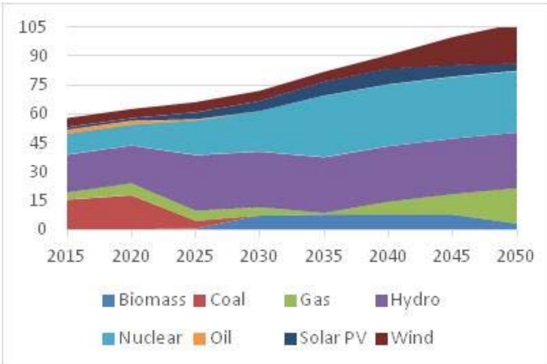
(c) Green



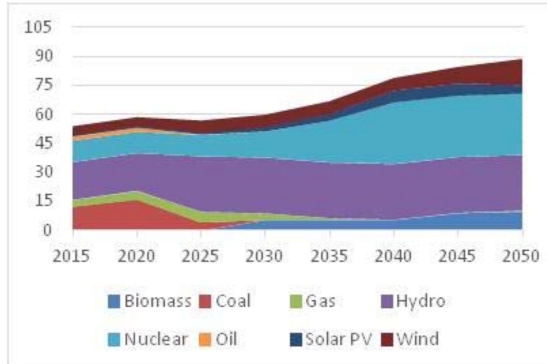
(d) Green with low demand



(e) Super green



(f) Super green with low demand



3.2.4 Heat Supply

Like electricity, heat is another main energy commodity in Romania. Demand for space heating is expected to grow faster along with increased heating areas resulted from increasing demand for larger living spaces. Unlike electricity which is mainly produced from power plants, heat is produced directly and through district heating facilities, normally, combined heat and power (CHP) plants. Direct heating refers to, for example, use of natural gas or biomass for home heating. Heat produced from CHP plants distributed to buildings through pipelines. Total demand for heat (final demand not useful demand) increases by 20-23% in 2050 compared to that in 2015 if energy efficiency measures are not implemented. If energy efficiency measures are implemented final heat demand drops by 10-14% in 2050 from the 2015 level. Natural gas remains as the main source for heat energy, in all years and in all scenarios. This is intuitive as there is no other alternative source to replace it for heating even under the strict climate change mitigation scenarios (e.g., super-green). Due to climate policies, heat coming from CHP plants, which fall under the ETS category, is replaced with heat from direct sources.

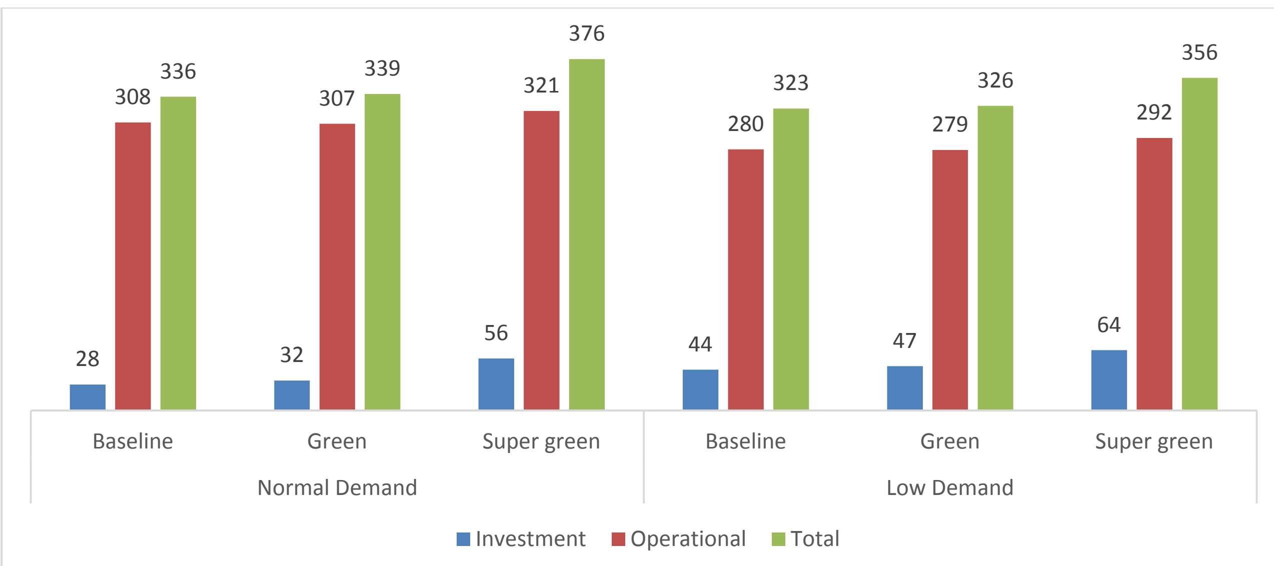
3.3. Total Energy Supply Costs and Investment

Figure 7a presents the total system costs for the energy supply during 2015-2030 period. Total energy supply costs for different time intervals are presented in Table 4 (a). Under the baseline (with normal demand case), Romania would need 28 billion investment (discounted at 5%) for energy supply system expansion on top of costs that incur to purchase energy commodities, such as natural gas and oil & products.[10] The total energy supply costs for the 2015-2050 period would be €336 billion or approximately 10 billion euro per year, on average, over the next 35 years. The total energy supply costs would increase slightly under the green scenario and by 12% under super green scenario.

It is very important to understand that Romania would need substantial replacement of existing coal and lignite fired based power plants by gas and renewable energy based power generation to meet the EU's 2020 emission reduction targets, which require power and other covered sector GHG emissions to be 20% below from the corresponding emissions in 2005. Due to this target, our study finds that no additional coal and lignite fired power plants would be built even in the baseline. The new capacity added in the baseline during the 2015-2050 period includes 4 GW gas, 3 GW hydro, 2 GW solar and 8 GW wind.

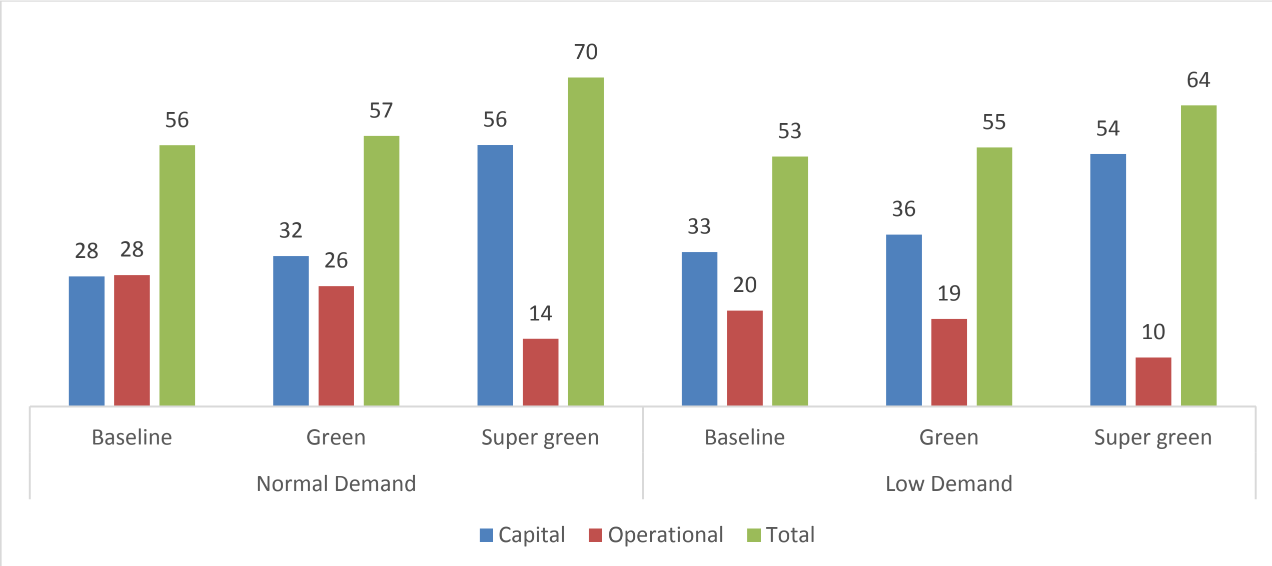
Figure 7. Discounted energy supply costs for 2015-2050 Period (Billion €)

(a) For the energy system as a whole



[10] While the model conducts a detailed simulation for the power sector and combined heat and power and estimates investment need for generating electricity and district heat, it however treats other energy commodities as purchased from the market. Thus, it does not include investment needed for coal/lignite mining, natural gas pipelines. Since the study is for low carbon development and most low carbon options fall under the power sector, it does not underestimate the investment need in low carbon scenarios.

(b) Electricity supply system



The change between the green and baseline scenarios (both under normal demand case) is that the green scenario needs 3 GW new nuclear plants (there was no nuclear in the baseline) and substitution of 1 MW of gas capacity with solar. As the nuclear capacity is added only after 2045, its discounted value is low. Thus, the incremental investment (discounted) for energy supply system expansion under the green scenario is not substantially high as compared to that under the baseline. Therefore, the smaller incremental investment need under the green scenario on top of the baseline scenario should not be surprising. However, the total energy supply cost under the super green scenario is 11% higher compared to that under the green scenario. This is because of early requirement of nuclear power under the former case. If a plant is installed earlier from now, the discounted costs would be higher (i.e., lower impacts of discounting) as compared to a situation where a plant is commissioned in a later date. Moreover, super-green scenario requires 1 GW of biomass based power generation.

Energy efficiency improvement in the demand side (i.e., low demand case) would reduce the total cost of energy supply by 4% from €336 billion in the normal demand case base case to €326 billion in low demand base case. To realize this, about €19 billion of investment would be needed to increase energy efficiency in the demand side.

The power supply system would need €28 billion investment over the next 35 years to meet country's electricity need under the baseline. The investments required for power system expansion in different interval of time are presented in Table 4 (b). The investment would increase to €32 billion under the green scenario. If power sector emissions to be completely eliminated by 2050, investment in the power sector would be twice as high as that in the baseline. This is because, elimination of power sector emissions would require massive replacement of fossil fuel based generation with more capital intensive renewable and nuclear energy based generation. The lower demand due to energy efficiency improvements in the demand side would reduce the total costs of electricity supply, but it would require additional investment in the demand side. Note that the investment required for energy efficiency measures here would be €8.3 billion instead of €19 billion mentioned above because we accounted for energy efficiency improvements only on electricity using end-use services, whereas the €19 billion accounts for all energy efficiency measures including in space heating, cooking.

Table 4: Total energy supply costs and investments for the electricity system expansion

(a) Total energy supply costs (Billion €, undiscounted unless specified otherwise)

	2015-2020	2020-2030	2030-2040	2040-2050	2015-2050 (Discounted)
	Without Energy efficiency in the demand side (or normal demand case)				
Baseline	91	178	231	281	336
Green	91	179	235	287	339
Super green	91	194	274	352	376
	With Energy efficiency in the demand side (low demand case)*				
Baseline	85	163	206	245	304
Green	85	164	209	251	307
Super green	85	176	242	303	337
Energy Efficiency**	3	11	15	19	19

* Each number under all three scenario should be added to corresponding energy efficiency costs to get total energy supply costs including energy efficiency investments

** includes energy efficiency in measures using all types of fuels

(b) Total investment required for electricity system expansion (Billion €, undiscounted unless specified otherwise)

	2015-2020	2020-2030	2030-2040	2040-2050	2015-2050 (Discounted)
	Without Energy efficiency in the demand side (normal demand case)				
Baseline	7.4	14.2	17.5	27.6	27.6
Green	7.4	14.1	22.9	39.3	31.9
Super green	7.4	28.7	48.1	65.4	55.6
	With Energy efficiency in the demand side (low demand case)*				
Baseline	7.4	12.9	15.0	20.9	24.5
Green	7.4	12.5	19.5	31.6	28.2
Super green	7.3	22.5	38.3	51.9	45.3
Energy Efficiency**	1.6	5.3	5.9	6.8	8.3

* Each number under all three scenario should be added to corresponding energy efficiency costs to get total energy supply costs including energy efficiency investments

** Includes energy efficiency in measures using electricity

3.4. CO_2 Emissions

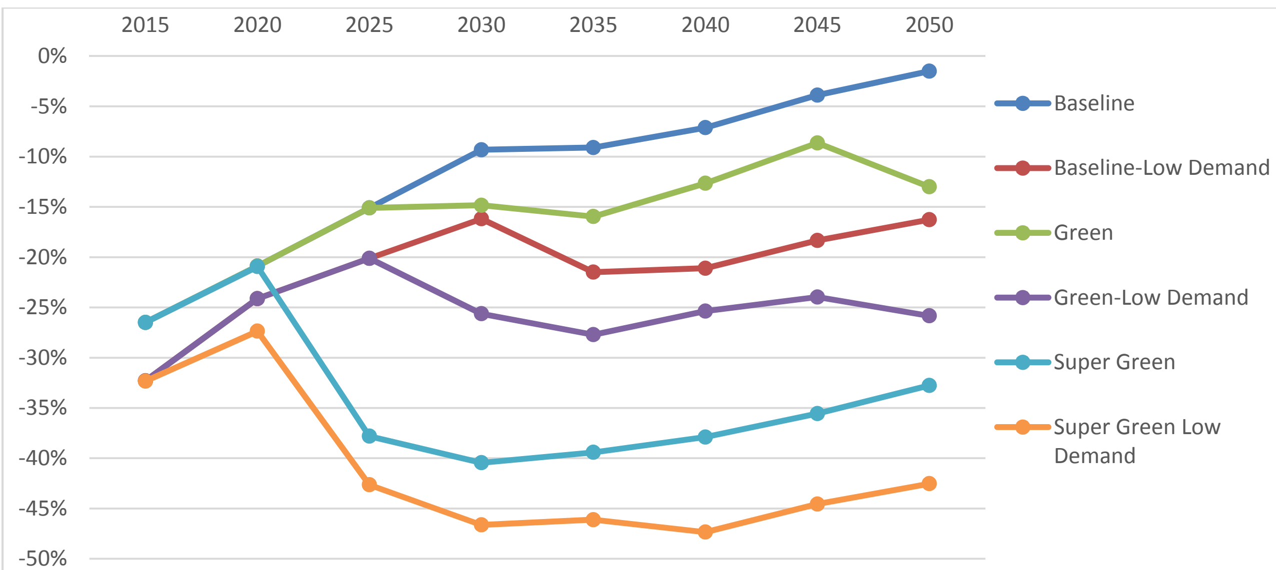
The reductions of CO_2 emissions from the energy sector as whole and power sector specifically are presented in Figure 8(a) and (b). In all scenarios, energy related CO_2 emission in Romania would be lower in years between 2015 and 2050 from the level in 2005. If energy efficiency measures are not implemented, total energy related GHG emissions in 2030 and 2050 under the baseline scenario would be, respectively, 9% and 2% lower from 2005 level. It is very important to note that historically energy related CO_2 emissions in Romania are dropping from the level of 2005. For example, according to emissions data published by IEA (IEA, 2014b), Romania's 2012 emissions are 16% lower compared to 2005 level. If efficiency measures in the demand side are implemented, the baseline emissions in 2030 and 2050 would be 16% below from the 2005 level in both years. Under the green scenario, total energy activity related CO_2 emissions would be 26% below the 2005 level in both years. Under the stringent super green scenario total national CO_2 emissions from energy activities in 2030 and 2050 would be respectively, 47% and 43% below the 2005 level.

The power sector will experience a large reduction of CO_2 in all scenarios. Since it is an ETS sector and mandated to reduce emission even in the baseline, its emissions in the baseline scenario will drop by 20% in 2030 and 36% in 2050 from the 2005 level. If energy efficiency improvements in the demand side are also accounted for (i.e., low demand case), the drop (i.e., emission reduction compared to 2005 level) would be as high as 45% in 2050. Under the green scenario, power sector emissions in 2030 and 2050 would be 34% and 68% smaller as compared to the 2005 level. If energy efficiency improvements in the demand side are accounted for (i.e., low demand case), the corresponding drops would be 45% and 72%, respectively.

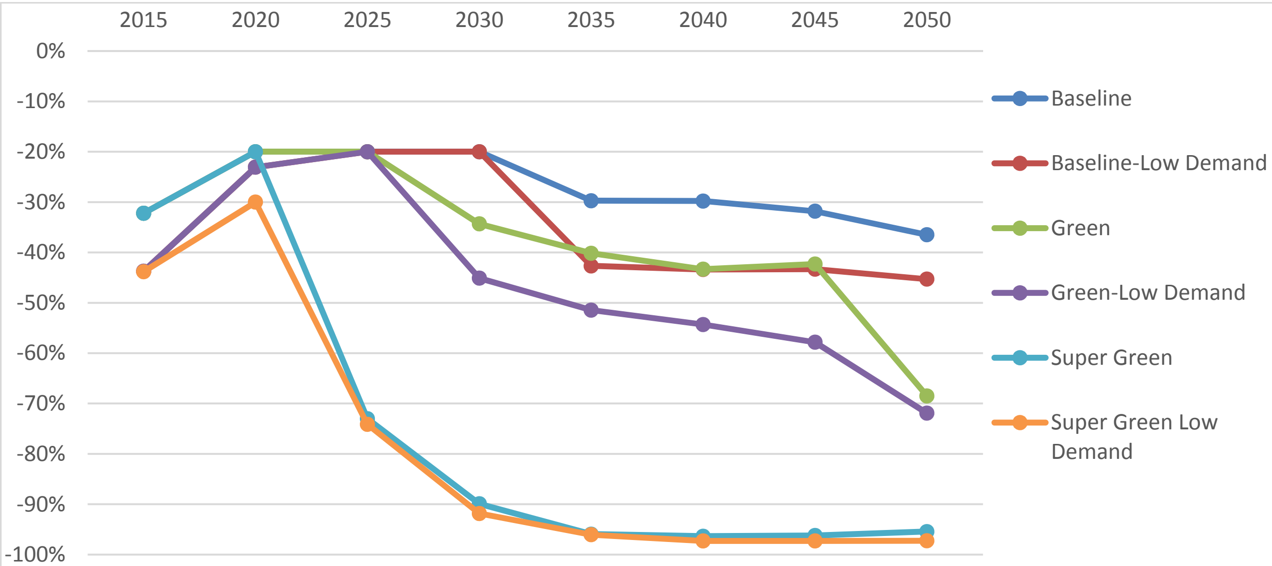
By design, the super green scenario almost eliminates CO_2 emissions from the power sector by 2050 (95% reduction under the super green and 97% reduction under the low demand super green scenarios from the 2005 level). In fact, more than 90% of emission reductions from the 2005 level would be achieved by 2030.

Figure 8. Energy related CO_2 emissions reduction from 2005 level (%)

(a) Energy sector as a whole



(b) Power sector



4. Policy Discussion

Romania can meet the mitigation obligations likely under the EU 2030 Climate and Energy Policy Framework at moderate costs. With an energy sector responsible for almost 60 percent of total GHG emissions, Romania clearly cannot achieve climate change mitigation targets beyond those of the current EU 2020 policy without significant action in the energy sector. The Green scenario compels substantial emissions reduction in the power sector which requires moderate incremental investment as compared with the Baseline. The Green scenario will achieve 45 percent emissions reduction by 2030 (and 72 percent reduction by 2050) as compared with 2005. The investment cost of the Green power sector scenario through 2050 is €37 billion (present value),[11] equal to an annual average 1.1 percent of GDP through 2050.

The prospective requirements of the EU 2050 Roadmap, which requires at least 80 percent reduction in emissions and the virtual elimination of emissions from the power sector, are both expensive and challenging to implement. The Super Green power sector scenario will provide 92 percent emissions reduction between 2005 and 2030 and 97 percent reduction by 2050, achieving an almost complete elimination of emissions from power. This scenario also delivers abatement

[11] At a 5 percent discount rate. The discount rate was selected as a mid-range social discount rate (the typically used social discount rates range from 4 to 6 percent).

on a faster schedule than the Green scenario. The investment cost of the Super Green scenario to 2050 is €54 billion (present value) or an average annual of 1.7 percent of GDP.

Implementation of the same set of aggressive energy efficiency measures is a key part of the Green and the Super Green scenarios, as these measures deliver low cost abatement in the short term, require moderate upfront investment, and have modest implementation barriers. Improving energy efficiency across the board in all economic sectors, but especially in residential and nonresidential sectors, offers the most effective and also viable means for containing the growth of energy demand, limiting investment requirements to meet the growing demand, and reducing GHG emissions. Beyond the climate agenda, improving energy efficiency is also critical for Romania's competitiveness in the European Union. While the energy intensity of Romania's economy has been decreasing for the past two decades, it is still one of the highest in the EU, and greater efficiency will go hand in hand with modernized and more competitive companies and sectors.

A lower carbon path for Romania's energy sector imposes significant costs and complex planning challenges on the sector, in particular on power generation. Achieving emissions reduction targets beyond the EU 2020 targets--the Green (likely EU 2030 targets) and the Super Green (possible EU 2050 targets)–will require Romania to abandon plans for new coal-based power generation capacity and life-extension of existing plants. It will also require significant additional renewable generation capacity and, therefore, a regulatory environment that would promote it.

While this assessment included a set of generally-agreed technologies at costs based on today's best analysis, both technologies and costs will surely evolve, and updated analysis will be needed. The TIMES/MARKAL supply model and the Energy Service Demand Analysis tool constructed for this analysis remain available for further development and application by the government for current and future policy questions related to the energy sector, in particular questions related to low carbon. The Ministry of Energy has already taken on these models to apply to critical questions in support of the country's new energy strategy. The usefulness of such tools and models will only increase into the future as Romania begins to take a more active role in contributing to EU climate and energy policy, as well as implementing it.

At the same time, it should be noted that the energy sector in Romania has the potential to become an engine of economic growth. Romania's endowment of energy resources is significant and diversified well beyond coal, including hydro and other renewable resources, natural gas, and even uranium to fuel its nuclear power industry. Romania has the potential to satisfy its own needs and export electricity and gas into the regional and European energy markets (even without the use of coal), to energize the economy and create jobs and prosperity.

While long-term sector development to 2030 and 2050--the subject of this assessment—is important, the government cannot be distracted from critical near-term sector reforms. Implementation of the energy reform program jointly supported by the European Commission, the International Monetary Fund, and the World Bank should continue. The measures recommended here under the Green and the Super Green scenarios to allow Romania to meet various GHG mitigation obligations require long-term implementation. In the short-term, it is critical that the sector continues with current reform efforts, many of which lay down essential conditions for the success of the long-term green transition. These reforms include completion of the ongoing liberalization of residential electricity and gas prices; adoption and implementation of the Minimum Social Insertion Program (a social safety net which *inter alia* will help secure access of low income households to basic energy services); restructuring of the Hunedoara and Oltenia energy complexes; and adoption and implementation of the Law on Corporate Governance for further improvements in the corporate governance of state-owned energy enterprises. Along with energy security, competitiveness and fiscal benefits, these measures are key for Romania's achievement of emissions reduction targets.

Greening of the energy sector implies substantial costs, which rise significantly over time and as requirements for emissions reduction tighten, but a lower-carbon energy sector needs to be part of Romania's long-term planning. Careful modeling of the power sector provides a detailed assessment of low carbon possibilities. A need for 30 percent more installed power capacity between now and 2050, along with existing mitigation obligations, push even Baseline investment costs to a very high level of €28 billion through 2050[12] or an average annual 0.8 percent of GDP. Lower carbon scenarios economize on supply costs by pushing energy efficiency to contain demand and achieve significant mitigation: in 2030, emissions are 31 percentage points and 94

[12] In present value terms using a 5 percent discount rate.

percentage points below Baseline in the Green and the Super Green scenarios respectively; while by 2050, emissions are 56 percent below the Baseline in the Green scenario and almost completely eliminated in the Super Green. This is achieved with additional costs during 2015-2050 in the Green scenario (costs above Baseline) of about nine billion euros and in the Super Green scenario of about €26 billion. Until 2020, investment needs in electricity supply and demand total about seven billion euros in the Baseline and just over nine billion euros in the green scenarios. These costs jump after 2030, as remaining fossil-based plants are replaced with renewable and nuclear capacity and aggressive energy efficiency actions continue. Financing for these investments, whether power generation or energy efficiency, will be the responsibility of the private sector, although the public sector may need to establish programs of support for energy efficiency, with some financing available from the European Union.

5. Conclusions

The energy sector would play a crucial role in meeting EU mandates on climate change and marching towards low-carbon economic growth in Romania. This study develops three scenarios to explore climate change mitigation and low-carbon growth opportunities in Romania. In the baseline scenario, which is consistent in line with EU 2020 climate mitigation targets, total national GHG emissions in year 2050 would be 2% below 2005 if energy efficiency measures are not included. If energy efficiency measures are included, emissions in 2050 would be 16% below from the 2005 level. If energy efficiency measures are not included, the baseline energy supply costs in Romania would be €336 billion (discounted to 2015 at 5% rate) over the next 35 years (2015-2050 period), €10 billion per year, on average. It would be slightly lower (€323 billion) when energy efficiency improvements in the demand side are included. The demand side energy efficiency improvement would cost €19 billion in total but saves €29 billion through avoidance of capacity expansion in the electricity sector and also reducing fuel costs in all energy supply sectors. Thus, improving energy efficiency across the board in all economic sectors but especially in the residential sector and district heating offers the most effective and also viable means for containing the growth of energy demand.

The baseline scenario requires an addition of 6 GW of wind, 1 GW each of hydro and solar and 3 GW of natural gas based electricity generation capacity by 2050 even if energy efficiency measures are included. This would pose a challenge to a power system which already has 5 GW of wind and 1 GW of solar already operating as of the present. This is because adding more renewable sources for energy generation, particularly the intermittent sources (wind and solar) would further increase the excess electricity generation capacity on top of its peak load since intermittent sources do not provide commitments to meet the peak load. Thus, the higher installed capacity because of higher penetration of intermittent renewable sources to meet climate change mitigation targets could create a situation where fossil fuel based generation sources (e.g., coal, gas) are built to meet the peak load but they will not be utilized unless their exist export markets for electricity generated from fossil fuel sources, which is unlikely in EU due to climate change mitigation obligations.

A green scenario along with energy efficiency improvements in the demand sectors would lead to 26% reduction of energy related CO_2 emissions from the 2005 level by 2030. The discounted total energy supply costs over the next 35 years would be €326 billion (or additional €3 billion on top of the €323 billion under the baseline scenario with energy efficiency measures implemented).[13] The green scenario with low energy demand (i.e., energy efficiency measures implemented), requires additional 2 GW of solar 2 GW of hydro, 1 GW biomass and 1 GW of nuclear power during the 2015-2050 period. The total investment to expand energy supply under the green scenario would be 9% higher from that under the baseline with energy efficiency measures considered under both scenarios. In order to achieve the green scenario, Romania will require to abandon plans for new coal-based power generation capacity and life-extension of existing plants; this would be challenging, as coal based generation accounts for almost 40% of total electricity generation at present.

If Romania aims to eliminate GHG emissions from the power sector, a rather radical approach would be needed. It would require that the entire 16 GW capacity addition during the 2015-2050 period runs with non-fossil sources (biomass, hydro, wind, solar and nuclear). Specifically, it would need 1 GW of new biomass based electricity generation capacity, 3 GW new hydro power capacity, 3 GW new nuclear capacity, 6 GW new wind capacity and 3 GW of new solar capacity. The total energy supply costs including the investment needed in the demand side

[13] It should not be interpreted that the additional €3 billion causes additional 10% emission reduction from the base case in 2050. The investment is for 35 years (2015-2050) and it would cause certain reductions in emissions in all years during the 2015-2050 period. The comparison of cumulative investment with a single year's emission reduction would be misleading and therefore should be avoided.

to improve energy efficiency would be €356 billion over the next 35 years. For the power sector, this scenario needs 63% higher investment from the baseline when both scenarios includes energy efficiency investments. This is an expensive scenario for Romania's energy sector.

This analysis recommends Romania to stay in the low demand green scenario (i.e., green scenario with implementation of energy efficiency measures in the demand side). Yet, the low demand green scenario requires 9 GW of intermittent resources (6 GW wind and 3 GW solar) and realization of this scenario would still be challenging. Note further that if energy efficiency in the demand side is not realized, the requirement of new intermittent capacity would be 11 GW, increasing the challenge further. Realizing energy efficiency measures is itself tough considering the hidden and transaction costs involved with them. Often, energy efficiency measures look very attractive in an economic analysis but their deployment in the real world is slow due to several barriers.

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