

# Life Cycle Assessment of the Romanian Electricity Mix: Impacts, Trends and Challenges

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**Abstract.** Considering the recent pressures in the energy sector at global level, in close relation with the conventional fuel availability, climate change, public interest and the overall debate for more sustainable energy sources, there is an acute need for instruments, capable to identify and measure in a coherent framework how various changes in the energetic systems lead to progress/challenges, in terms of environmental impacts and sustainability. In this context, Life Cycle Assessment (LCA) is a standardized methodology, capable of analysing complex systems, as well as to identify and quantify various environmental impacts of products for their entire life cycles. The main objectives of this study are to perform a life cycle evaluation of the Romanian energy sector for electricity production, in order to identify, quantify and update the associated environmental impacts and to investigate the sustainability of future scenarios. The LCA is focused onto 1 kWh of electricity produced in Romania, considering the indigenous resources mix: coal and gas-fired power plants, hydro-power, wind turbines, nuclear power, solar panels and biomass, as well as imports and exports. The assessment is based on the ReCiPe impact assessment methodology, which enables the use of 18 environmental impact categories. By applying the LCA methodology, the Romanian energy mix environmental impact profiles can be compared for 4 years: 1990 (reference year), 1997, 2010 and 2015. Furthermore, the 2030 and 2050 scenarios were analysed. The results show how the changes in the electricity production mix have positive changes in the environmental profile.

**Keywords:** Life Cycle Assessment · Electricity mix · Carbon footprint · Environmental impacts

## 1 Introduction

The energy sector of a country is considered to play a strategic role in the national development, being closely linked to an improved economic status, a better life quality and the impact on natural resources. According to the European Union, an advanced economy cannot be competitive without a reliable and sustainable energy sector. As a response to economic and societal challenges, in the entire European Union, in 2014,

the total net electricity generation was estimated at 3.03 million GWh. There are several main aspects related to the energy sector that the European policies have struggled to overcome: price volatility of the carbon dependent markets (oil and gas); difficulties in energy transportation (imports/exports); issues related to the nuclear energy; the environmental impact, directed in particular to greenhouse gas (GHG) emissions from fossil fuel combustion [1]; the ageing process of the conventional power plant infrastructure [2].

In the last years, the energy sector received an increased interest from the sustainability point of view. Researchers have focused on analyzing the current situations in various countries and on the development of decision support systems that would allow the formulation of policies and strategies for future developments. The life cycle assessment studies of electricity generation for various countries include: Japan [3], Singapore [4], Belgium and Spain [5], Mexico [6], Nigeria [7], the United Kingdom [8].

More recently, studies have been updated and extended by considering developments and targets in the energy sector and the reduction of greenhouse gas emissions.

For example, Santoyo- Castelazzo and Azapagic [9], have suggested a five step decision support framework to analyze the energy profile in Mexico, by applying the life cycle methodology on a “*cradle to grave*” approach. Their assessment is based on 10 environmental impact indicators, 4 social indicators and 3 economic indicators to evaluate in an unitary manner the existing situation as well as future scenarios based on Mexico energy drivers and climate change targets for 2050.

Stamford and Azapagic [10], have performed a study that give information on future energy scenarios in United Kingdom, for a timeframe as long as 2070. The researchers started from the current situation of the British energy mix, based mostly on fossil fuels (87%) and build up scenarios on the energy mix decarbonisation. The 36 indicators values, from environmental, social and economic categories, provided information on challenges and implications of the energy policies. The main conclusion of the study is that the degree of decarbonisation of the energy mix strongly influences the outcomes and compromises should be addressed, because none of the analyzed scenarios can be considered as a “best case” scenario.

Developing countries such as Mauritius have also been recently analyzed from the point of view of energy sector sustainability [11]. The main objective of the study was to inform the stakeholders in the energy sector on the current impacts and the major environmental impacts associated to the rapid development in the area. The Mauritius current energy mix, based extensively on coal and natural oil (77%) has a significant environmental impact for 10 indicators, while the renewables: bagasse and wind power contribute up to 12% to the environmental impacts. In Mauritius’ case, the main recommendation is that more emphasis should be put on the renewable share, mainly wind farms and solar energy harvesting, while investing in increasing the fossil power plants performances.

Recently, the rapid development of United Arab Emirates (UAE) in terms of electricity production was studied by Treyer and Bauer [12]. The authors assessed the energy sector environmental footprint, based on LCA methodology. Six environmental indicators were used to characterize the actual status of the UAE energy sector and future scenarios. Until 2009, the energy was produced entirely from natural gas and oil, with significant consequences in terms of GHG emissions. The diversification of

energy mix such as: nuclear, renewables and the improvements of existing natural gas plants technologies will diminish the environmental footprint of the energy sector, by comparison with the reference scenario.

In Turkey, a life cycle analysis of the national energy sector was realized by Atilgan and Azapagic [13], mainly focused on renewable energy sources (RES), which account for approximately 27% of the country's energy mix. In 2010, the Turkish RES was based extensively on hydropower plants (93%), while the rest includes wind farms, geothermal and other renewables and waste. The evaluation comprises a set of 11 environmental indicators applied for energy production systems such as: large and small reservoirs, run-of-river, onshore wind and geothermal power. An increased percentage of RES in the energy mix should be approached.

Nanaki et al. [14], have investigated the environmental impact of the energy produced from coal in Greece. The contribution of lignite and fuel oil to Greek energy mix was 64% in 2009. By using the Eco-indicator '99 and '95 methods, the environmental impact of lignite and fuel in the energy mix and also future scenarios that envisage an increased input from RES were assessed.

The occurrence in literature of a combination of Life Cycle and Data Envelopment Analysis (LC+DEA) used in the assessment of energy systems, was investigated by Martin-Gamboa et al. [15]. The LC+DEA allows the modelling of energy scenarios by integrating life-cycle indicators and ranking energy scenarios, based on sustainability criteria.

Coupling multi-criteria decision analysis (MDCA) with LCA was proposed by Santos et al. [16], in order to evaluate the Brazilian power sector. The energy mix in Brazil is currently based on RES with 77% hydro, 7% biomass and 1% wind power. Fifteen criteria from economic, social and environmental categories were selected to investigate 5 suggested scenarios. The most important findings are the following: the RES share is expected to increase in the energy mix and the wind power, currently under-exploited, and it should be considered as a feasible option.

Another methodology found in literature used to analyze a part of the Portuguese energy sector namely hydropower generation is a partial equilibrium bottom-up optimization model (TIMES\_PT). This framework allow the modelling of future energy scenarios up to 2050 and provides information on costs and GHG emissions [17].

Besides the evaluation of national energy systems, sustainability indicators have been suggested for smaller systems like municipalities e.g. Ormoz (Slovenia), a study performed by Kostevsek et al. [18]. The proposed Locally Integrated Energy Sector (LIES) concept considers besides environmental, economic and social indicators, some specific energy indicators. Another investigated system may be a region, like in the case of Martire et al. study, [19] which investigated the alpine area of Lake Como (Italy), by using Sustainability Impact Assessment, or the case of Ding et al. who focused on 31 regions in China, the evaluation being made based on LCA [19]. Furthermore, the versatility of LCA methodology allows the investigation of technologies like Power-to-Gas technologies like in the case of a recent study of Zhang et al. [20].

Romania is one of the European Union (EU) member states in which the latest statistics show increases in electricity generation, in contrast with most of the member states that have recorded a decline in electricity generation.

In 2014, Romania has recorded the largest annual increase in electricity production ar European level, followed by Slovenia and Bulgaria [1]. In this context, the following research questions may be formulated: (a) Which are the main environmental issues/impacts related to this sector in Romania? and (b) How sustainable is the Romanian growing energy sector for electricity production?

This study has as main objective the identification and quantification of the environmental impacts related to the energy production system in Romania, by using the Life Cycle Assessment (LCA) methodology. To the best of our knowledge this is the first study that: applies a life cycle approach to scenario analysis of electricity production in Romania; considers a wider range of environmental aspects, going beyond the traditional link between energy sector and greenhouse gas emissions, in a coherent and unitary manner so as to reflect current and future scenarios for the Romanian energy profile, and discusses the futures energy generation options. The LCA approach uses ReCiPe impact assessment methodology, included in the SimaPro software package.

## 2 Romanian Electricity Production System

The Romanian energy mix (electricity and heat production) is based mostly on indigenous resources. In 2015, the energy production mix had the following profile: 28% coal (lignite), 27% hydropower, 18% nuclear, 13% natural gas, 11% wind power, 2% photovoltaic and 1% biomass. Approximately 41% of the energy production comes from renewable resources, 60% from the mix is considered to be with “zero” GHG emissions, while 75% of the mix has low CO<sub>2</sub> emissions [21].

The Romanian electricity production system is still largely carbon-based, but also hydro- and nuclear sources represent an important part in the energy mix. Also, renewable sources are becoming more and more important in terms of share, as presented in Table 1.

**Table 1.** Romanian electricity mix for 1990, 1997, 2010, 2015

Year	1990	1990	1997	1997	2010	2010	2015	2015
Sources\Units	GWh	%	GWh	%	GWh	%	GWh	%
Hydro	11,411	17.7%	17,509	30.9%	20,603	33.6%	17,381	26.1%
Solar	0	0.0%	0	0.0%	0	0.0%	1982	3.0%
Wind	0	0.0%	0	0.0%	306	0.5%	7063	10.6%
Biofuels	0	0.0%	11	0.0%	110	0.2%	463	0.7%
Biogas	0	0.0%	0	0.0%	1	0.0%	61	0.1%
Nuclear	0	0.0%	5400	9.5%	11623	19.0%	11640	17.5%
Coal	18502	28.8%	16862	29.7%	20681	33.7%	18125	27.2%
Oil	11823	18.4%	6863	12.1%	475	0.8%	203	0.3%
Gas	22573	35.1%	10084	17.8%	7516	12.3%	9738	14.6%

**Table 2.** Energy balance for the years: 1990, 1997, 2010, 2015

Energy balance, GWh	1990	1997	2010	2015
Gross production	64,309	56,729	61,315	66,656
Imports	9,476	777	767	4,492
Exports	0	556	3,041	11,220
Distribution losses	5,929	6,600	7,058	7,161
Energy available for final consumption	54,236	38,714	41,468	43,134

In this evolution, it is important to pinpoint the appearance of the nuclear sources in the mix in 1997 and the rise of the renewables in the last period, all of which have led to changes in the environmental profile of Romanian electricity production systems. The energy available for final consumption is mainly based on internal production, however, in time, the ageing of the infrastructure leads to an increase in distribution losses (Table 2).

## 2.1 Combined Heat and Power Plants

Approximately 80% of the combined heat and power (CHP) plants, have been installed in 1970–1980, operating longer than the usual expected lifespan. In general, the literature considers a technical lifetime for coal power plants to be around 40 years [2]. With few exceptions, the plants performance is reduced to 30% due to the old technologies. The rehabilitated CHP plants (on coal) have a performance around 33%. In 2009, from a total installed power of 4900 MW, 53% come from CHP plants older than 30 years, 30% is produced in installations 20–30 years old, while the remaining 17% comes from plants under 20 years.

Most of the CHP plants lack proper gas treatment installations and have a significant impact in terms of SO<sub>2</sub> and NO<sub>x</sub> emissions (higher than the maximum values set out by EU). In the last 10 years, the CHP plants technologies have been updated, representing 10% of the installed power, with efforts directed towards the fulfilment of environmental requirements [22].

## 2.2 Centralized Heating Systems

The centralized heating systems have low technical performance (heat and steam generation) and register heavy losses in terms of transportation and distribution (between 10–50%). Also the disappearance of industrial steam and hot water industrial consumption has led to unsustainable operating regime, reflected in higher energy production and distribution costs, low quality services and increased bills for average consumers, [22].

### 2.3 Hydroelectric Power Plants

The hydroelectric power plants (HPP) have been in use longer than the usual lifespan and sum up an installed power of 6450 MW (31% of the total installed power). After 2000, the modernization of HPPs has been considered systematically with the scope of achieving approximately 1/3 of their installed power (2400 MW) by 2020, [22].

### 2.4 Nuclear Power Plant in Cernavoda

Since 2007, the Nuclear power plant (NPP) in Cernavoda has 2 operating units with an installed production capacity of 700 MW each and an average contribution to the energy production mix of 20%. The Cernavoda NPP uses the Canadian Deuterium Uranium Technology (CANDU 6), based on natural uranium as fuel and deuterium as moderator and cooling agent [23]. In 10 years, the assumed lifetime of a nuclear power plant, the First Reactor Unit will exceed the usual lifespan [2].

### 2.5 Natural Gas Production

In Romania, there are 2 key players, Romgaz and Petrom, both having 98% of the natural gas production, the remaining 2% belonging to other companies [22] (Romanian Energy Strategy for 2007–2020, revised for 2011–2020). The gas power plants have an expected technical lifetime of 34 years [2].

### 2.6 Wind Power

Romania has a significant potential in energy production from wind power, being classified as the second country within EU member states. According to several authors [24, 25], energy production from wind power has registered a significant increase in 2010 of up to 462 MW as compared with 2009, with just 14 MW.

By the end of 2015, 75 wind farms with 1200 onshore wind turbines were in use in Romania, with a power range varying from 0.08 to 600 MW and an average of 40 MW. These windfarms are distributed mainly in the Dobrogea Plateau (78% of the total power installed) and Barlad Plateau.

### 2.7 Solar Energy and Photovoltaics

As in the case of wind power, Romania exhibits a great potential for further developments in terms of energy production from solar energy. However, the first projects and investments in solar energy harvesting started in 2009–2010. By the end of 2012, statistics show 25 installed projects in solar energy based on photovoltaics, with 8 areas having operational solar parks, summing up an installed power of 51 MW. By the end of 2014, the installed capacity of solar power was 1219 MW. The same report shows records of the following installed projects: 1222 wind; 409 microhydro, 2 biogas and 34 biomass [26, 27].

## 2.8 Romanian Objectives and Targets in the Energy Sector for 2016–2030

As an EU member state, Romania has to fulfil targets related to: energy efficiency, energy production from renewable resources and GHG emissions.

Energy efficiency is estimated based on the primary energy demand reduction. The target for 2020 is set at 20%, a target already exceeded by Romania. The value achieved, estimated at 36%, exceeds the target and is considered to remain constant up to 2030.

In 2015, Romania has achieved a 54% reduction of the GHG emissions, as compared to 1990, exceeding both the 2020 and 2050 targets. This situation was possible due to the transformations (reduction) of the Romanian industry, the former larger energy consumer. It is assumed that 60–63% reduction of GHG emissions (reference year 1990) will be possible by 2030.

The 2020 target, namely 24% of the gross final energy consumption that is supposed to come from renewables was already achieved in 2015. It is expected that this percentage will slightly increase, starting with 2020. Also, it is possible that Romania will introduce a supporting mechanism for the development of energy production from biomass that will increase the contribution of this RES in the energy production mix [21].

## 3 Methodology

The LCA analysis performed in this research has followed the ISO 14040 structure of an LCA study in 4 steps: goal and scope definition, inventory analysis, life cycle impact assessment, and interpretation of results.

### 3.1 Goal and Scope Definition

The life cycle analysis performed in this research approaches the primary energy sources and processes used for the production of electricity in Romania in four different years (1990- as reference year; 1997- the year when the 1<sup>st</sup> reactor of Cernavoda NPP became operational; 2010, 2015- as years after Romania entered EU and renewable energy sources usage increased).

The main drivers for this research endeavor are motivated by the need to identify and quantify the extent of various environmental impacts of electricity production and to analyze how different changes have impacted and how future changes may affect the performance of this system. The analysis takes into consideration multiple conventional sources, as well as renewable resources.

From an LCA point of view, the analysis considers the corresponding shares of primary sources to one kilowatt-hour of electricity. 1990 is used as reference year for comparing changes in the mix, as well as to project a series of scenarios for the future, as 1990 has also been selected as reference year for measuring the GHG emissions reduction efforts at global level (Kyoto protocol). This LCA considers the gross-electricity production and it also accounts for the heat produced by various co-generation systems.

### 3.2 Life Cycle Inventory

Data collection and analysis represents a major challenge for any LCA study, and this is even more important in complex systems, such as the energy sector where there are so many different processes and uncertainty sources. Thus, to allow for a credible analysis, systematic, comprehensive and complete data sources are always required to ensure a low uncertainty of the results.

To achieve this goal for high quality data, a top-to-bottom approach for data collection has been implemented, and so, this analysis is based onto data sourced from the Eurostat database for energy production and the Romanian National registry of GHG emissions for the air emissions. The Eurostat data is based on the data collection methodology described at the following link: [www.wc.europe.eu/eurostat](http://www.wc.europe.eu/eurostat), [1] while the National Registry for GHG emissions considers the IEA Energy Statistics Manual [28], thus ensuring a unitary platform for data collection.

The life cycle inventory of this study considers the inputs (fuels consumption by year and type corresponding to 1 kWh gross electricity, as presented in Table 3) and outputs (polluting streams) (see Table 4) and the overall operational phase of electricity production infrastructure. The analysis does not take into consideration the construction and decommissioning electricity production infrastructure. Although construction and decommissioning of large infrastructure can have important impacts, they were not considered given the large time span of the analysis and the data availability.

Furthermore, the output fluxes of electricity production was sourced from the Ecoinvent 3.0 data base and were updated with quantities relative to 1 kWh electricity corresponding to their source. Data for the specific pollution streams is presented in Table 3 and it mainly concerns the carbon-based fluxes and was sourced from the National GHG inventory (2012 emission).

Data summarized in Table 3 presents the total fuel consumption (and calorific data) for the electricity production, considering the fuel types and the studied years.

**Table 3.** Fuel consumption data for electricity produced in Romania, in various years

Fuel type	Unit	1990	1997	2010	2015
<i>Liquid fuels</i>					
Refinery gas (not liq.)	t 10 <sup>3</sup>	0	59	95	0
Net calorific value	kJ/kg	42435	42435	42435	42435
Gas-diesel Oil	t 10 <sup>3</sup>	0	3	5	0
Net calorific value	kJ/kg	42435	42435	42435	42435
Transport diesel	t 10 <sup>3</sup>	0	3	5	0
Net calorific value	kJ/kg	42485	42485	42485	42485
Residual fuel oil	t 10 <sup>3</sup>	6492	3427	200	1
Net calorific value	kJ/kg	39350	39350	39350	39350
<i>Solid fuels</i>					
Lignite/brown coal,	t 10 <sup>3</sup>	33856	30235	29813	25918
Net calorific value	MJ/t	7507	7513	8297	7805
Sub-bituminuous coal	t 10 <sup>3</sup>	0	1173	379	196

(continued)



**Table 3.** (continued)

Fuel type	Unit	1990	1997	2010	2015
Net calorific value	MJ/t		18932	24585	24586
Bituminous coal	t 10 <sup>3</sup>	3098	0	0	0
Net calorific value	MJ/t	24442	-	-	
<i>Natural gas</i>	Mm <sup>3</sup>	11112036	5305203.9	2822749.5	948.53216
Gross calorific value	kJ/m <sup>3</sup>	37613	37126	36959	36959

**Table 4.** Specific emission factors

Fuel type	Carbon content, t/TJ	CO <sub>2</sub>		CH <sub>4</sub>	CO	NM VOC	N <sub>2</sub> O	SO <sub>2</sub>
		kg/kWh		g/kWh				
		1990–1997	2010–2015					
<i>Liquid fossil</i>				0.011	0.018	0.00288	0.0022	1.656
Gas/diesel oil	20.2	0.266	0.2619					
Residual fuel oil	21.1	0.278	0.286					1.746
Refinery Gas	18.2	0.240	0					
<i>Solid fossil</i>		0	0	0.004	0.407	0.00612	0.0051	6.415
Other bituminous coal	25.8	0.340	0.341					
Sub-bituminous coal	26.2	0.345	0					
Lignite	27.6	0.364	0.347					2.952
Blast furnace gas	66.0	0.871	0					
<i>Gaseous fossil</i>		0	0					
Natural gas (dry)	15.3	0.201	0.201	0.004	0.140	0.0054	0.0004	0.001
<i>Biomass</i>		0	0					
Solid biomass	29.9	0.394	0	0.108			0.0144	
Liquid biomass	20.0	0.263	0					
Gas biomass	30.6	0.403	0					
Other biomass & wastes				0.108	3.5999	0.18	0.0144	0.04

### 3.3 Life Cycle Impact Assessment (LCIA)

The LCIA has been performed using the updated Recipe 1.12 methodology, which considers the impact categories presented in Table 5. For data validation, an additional analysis was performed by using the CML 2000 baseline methodology.

One of the main advantages of the LCA methodology in evaluating the environmental impacts is represented by the possibility of depicting a complex environmental

**Table 5.** ReCiPe 1.12 Impact categories

No	Impact category	Sym.	Unit	Normalization values	
				Europe set	Local set
1	Climate change	CC	kg CO <sub>2</sub> eq	0.0000707	1
2	Ozone depletion	OD	kg CFC-11 eq	45.4	1
3	Terrestrial acidification	TA	kg SO <sub>2</sub> eq	0.0309	1
4	Freshwater eutrophication	FE	kg P eq	2.41	1
5	Marine eutrophication	ME	kg N eq	0.0988	1
6	Human toxicity	HT	kg 1,4-DB eq	0.00286	1
7	Photochemical oxidant formation	POF	kg NMVOC	0.0176	1
8	Particulate matter formation	PMF	kg PM10 eq	0.0671	1
9	Terrestrial ecotoxicity	Ttox	kg 1,4-DB eq	0.121	1
10	Freshwater ecotoxicity	Ftox	kg 1,4-DB eq	0.091	1
11	Marine ecotoxicity	Mtox	kg 1,4-DB eq	0.132	1
12	Ionising radiation	IR	kBq U235 eq	0.000485	1
13	Agricultural land occupation	ALO	m <sup>2</sup> a	0.000221	1
14	Urban land occupation	ULO	m <sup>2</sup> a	0.00246	1
15	Natural land transformation	NLT	m <sup>2</sup>	6.19	1
16	Water depletion	WD	m <sup>3</sup>	0	1
17	Metal depletion	MD	kg Fe eq	0.0014	1
18	Fossil depletion	FD	kg oil eq	0.000643	1

profile which comprises other impact categories beside the traditional global warming potential. In this context, the Recipe methodology is very useful as it uses 18 impact categories which include aspects like climate change, ecosystem related impacts (toxicity, eutrophication, acidification, photochemical oxidation potential), human related impacts (toxicity, land use) and resources-related impacts.

Life cycle impact assessment consists in impact classification (impact identification, which is automatically done by the LCIA method by correlating various environmental impacts with the fluxes in the life cycle inventory), impact characterization (using the life cycle inventory values and method specific characterization factors which enable impact quantification and impact correlation among various contributors). To be able to compare the environmental impacts across different impact categories, an additional normalization step is required to reduce the impacts to the same reference. In Table 5, the normalization values for the Recipe 1.12 method are presented which show the corresponding impact weights for the 18 impact categories for the European weighting set. To better represent the local environmental impacts, a local set of normalization weights has been developed in which all impact categories have the same importance.

## 4 Results and Discussion

### 4.1 Environmental Profiles of the Electricity Mixes

Figure 1 presents annual environmental profiles of the Romanian electricity mixes after the characterization step of the LCIA, by considering the impact categories as designated in Table 5 (the impact categories abbreviations are used subsequently for all figures).

The results in Fig. 1 present a comparison of environmental impacts for the evaluated period (1990, 1997, 2010 and 2015) and show that for 8 of the 18 impact categories, the environmental impacts have decreased. However, to be able to compare impacts across impact categories, one must refer to normalized results. In Fig. 2, normalized results using a weighting set show that only in a few categories the impacts are higher. In the context of this study, the European normalization set (Table 5) is not useful, because the aim is to analyze the evolution of the Romanian electricity production and not to compare it with other European energy systems. Because of this, a

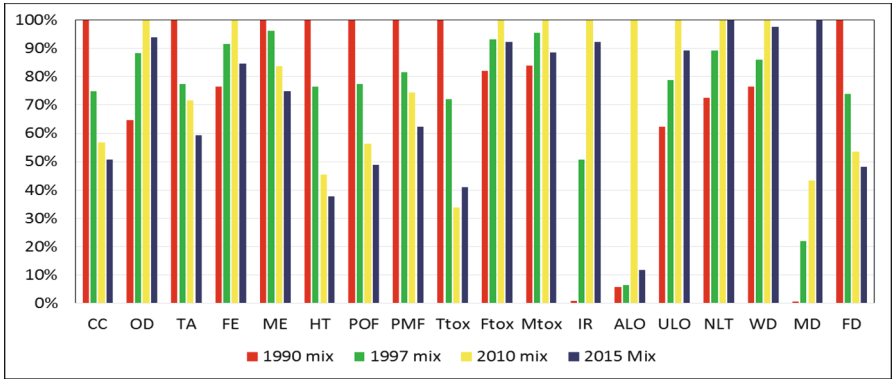


Fig. 1. Romania’s environmental profile (characterization step)

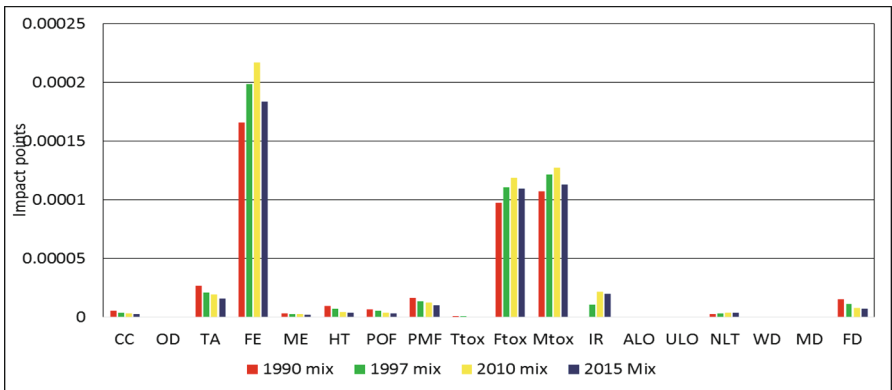


Fig. 2. Comparative environmental profile (weighted normalized results)

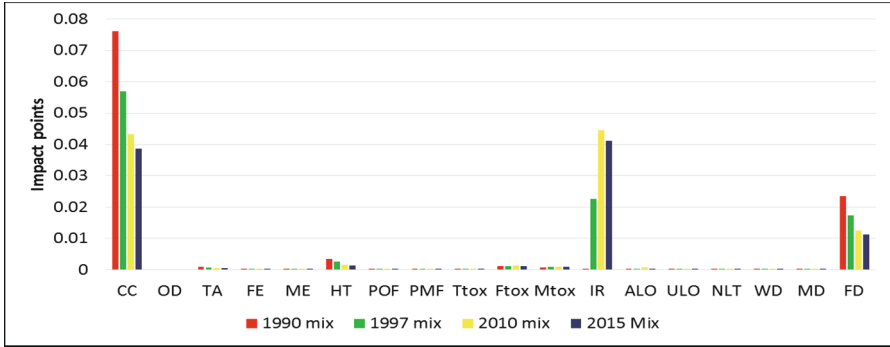


Fig. 3. Comparative environmental profile (non-weighted normalized results)

non-weighted normalization of results was performed and the results are presented in Fig. 3 which point out the impact categories with the highest impacts: Climate change, Ionizing radiation, Fossil depletion, Human toxicity, Freshwater and Marine Eco-toxicity, which reflect the structure of the electricity mixes, and the corresponding entries in the life cycle inventories.

If we refer to the yearly environmental profiles, the contributors to each impact category may be observed in Figs. 4, 5, 6 and 7. These results point-out the vast contribution of fossil-based fuels to most of the impact categories, except the Ionizing radiation (IR), where the nuclear electricity production has the largest contribution and the Agricultural land occupation where the bio-based fuels generate higher impacts in 2010 and 2015.

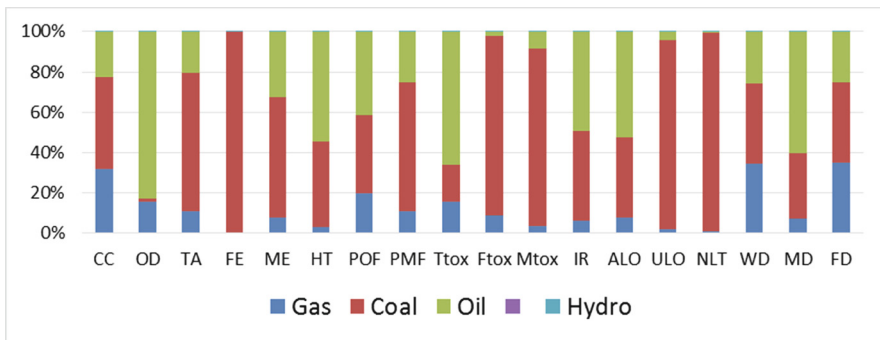


Fig. 4. 1990 environmental profile

These results showcase how the structure of the Romanian electricity mix influence its environmental profiles, and indicate a few impact categories that need a more in-depth analysis.

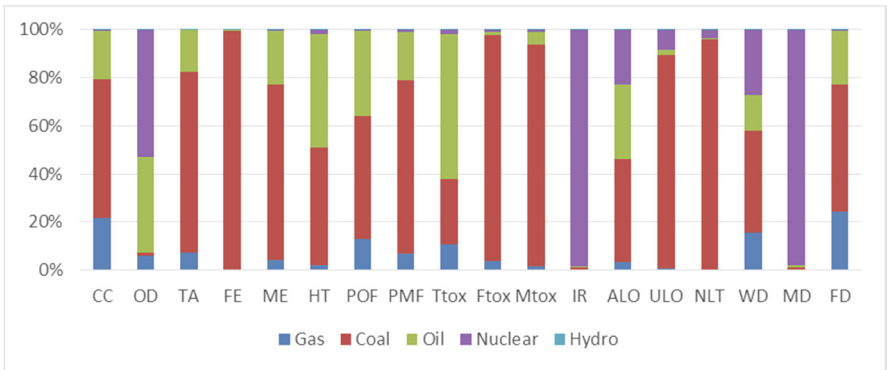


Fig. 5. 1997 environmental profile

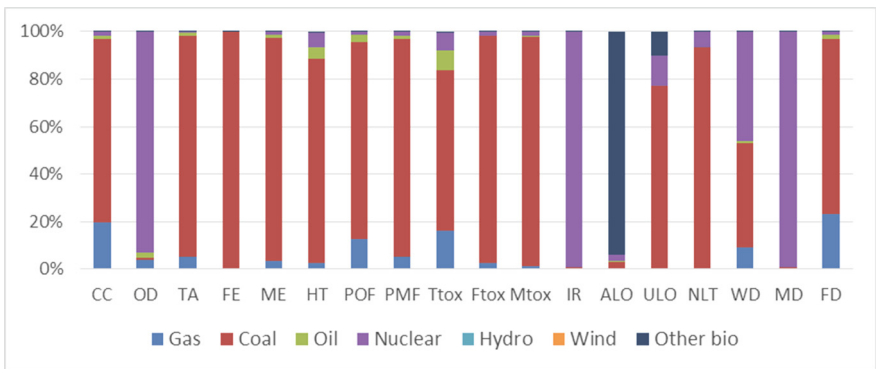


Fig. 6. 2010 environmental profile

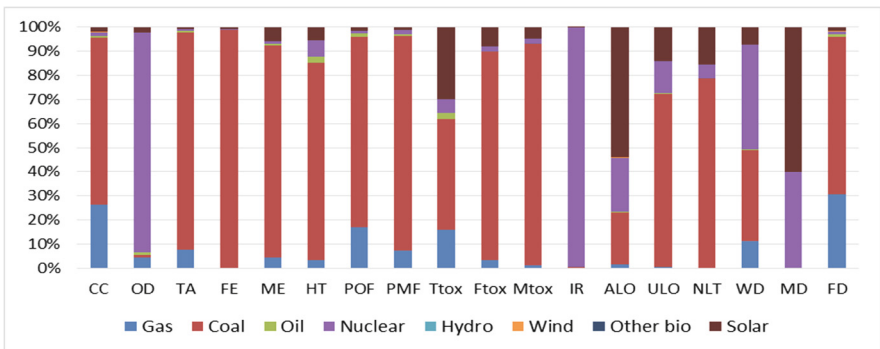


Fig. 7. 2015 environmental profile

### 4.2 Climate Change Impacts

As presented in Fig. 8, the Climate changes impacts, have constantly decreased from 1990 to 2015 due to changes in the quantities of fossil-fuels used in the electricity production (see Table 1). If 1990 is used as a base to compare GHG emissions, until 2015 a 45% reduction was recorded for the Romanian electricity mix. This was possible due to the changes in the electricity mix (in 1996 the first nuclear reactor was started and in 2007, another one started to operate).

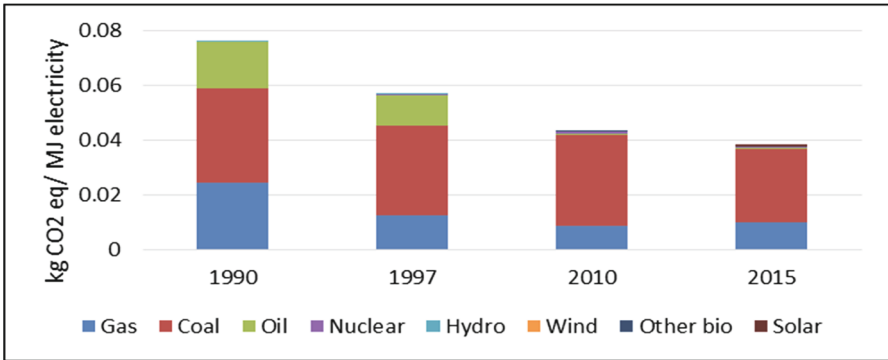


Fig. 8. Evolution of climate change impacts

Coal (solid fuels) make about half of the emitted GHG emissions which, in conjunction with the relative constant proportion of the coal in the mix induces a high dependence of the carbon footprint to the solid fuel use. Although, the targets set by the Kyoto protocol for Romania have already been met and overcome (20% reduction assumed, 45% realized), an additional decrease of the GHG emissions seems only possible by further decreasing the fossil fuels and coal in particular.

### 4.3 Future Scenarios

The previous analysis of the Romanian electricity mix in this study has enabled the identification of its characteristics in terms of major impacts, contributors, and has pointed out some aspects to be further analyzed.

Two future scenarios have been considered in order to analyze the future environmental impacts of the Romanian electricity mix, as presented in Table 6, with reference to 2015.

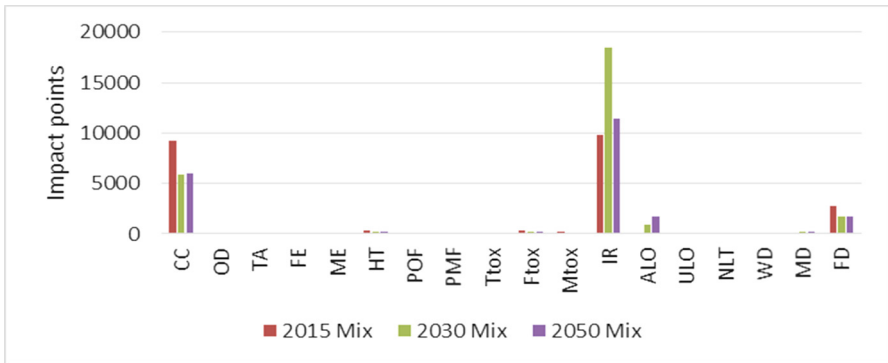
The 2030 scenario considers a light increase in electricity production (to 73 TWh) and some optimistic changes in the electricity mix (13% and 7% decrease of coal and respectively gas use, a 13% increase of nuclear electricity and a 11% increase of the renewable energy sources), in accordance with the Romanian Energy Strategy, 2016–2030, with an outlook to 2050.

**Table 6.** Electricity mix scenarios

Energy source %	2015	2030	2050
Hydro	26	24	24
Solar	3	7	10
Wind	11	16	20
Biofuels	1	1	2
Nuclear	17	30	20
Coal	27	14	16
Gas	15	8	8
Gross production, TWh	66.56	73	67.89

The data for the 2050 scenario was derived from a provision document which considers the primary energy production (not electricity) for the 2030–2050 period which considers changes related to the decommissioning of some of the nuclear reactors, and an increase in the renewables.

The impact profiles are presented in Fig. 9, where it may be observed that the impact structure is similar with the 1990–2015 period. Changes of the impact values are due to changes in the production mix, being more visible in the climate change and ionizing radiation impact categories. A tradeoff between the reduction of GHG emissions between 2015 (reference year) and 2030 scenario is compensated by an increase in the Ionization Radiation category due to the increase of the nuclear electricity production.

**Fig. 9.** Future scenarios impacts

## 5 Conclusions

The main objective of this study was the identification and calculation of the overall environmental impacts associated to electricity in Romania by means of Life Cycle Assessment (LCA). This was performed by developing an LCA study according to the

ISO 14040 methodology. A top-down approach for data collection was used as data was collected from Eurostat for energy production mix structures and the national inventory for GHG emissions.

The results have demonstrated the utility of LCA to depict complex environmental impacts, evolutions and trends.

In the Romanian context, this analysis has pointed out how the changes in the electricity production mix have had positive changes in the environmental profile (expressed mainly as a 45% decrease of the GHG emissions for the 1990–2015 period) and how future changes may affect this evolution.

This analysis has also pointed out some aspects that need a more in-depth analysis, especially to include the infrastructure-related processes in the LCA analysis, considering the dynamic future evolution of the Romanian electricity production system (new renewable sources e.g. wind farms and solar farms, future construction and decommissioning of the nuclear reactors at Cernavoda, the dynamics of the hydro system, etc.). Furthermore, the dependence of the environmental profile structure and dimension to the carbon-based energy source needs to be further investigated, in correlation with changes of the other electricity production options.

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