

1 Article

2 Current situation and future perspectives of the 3 Romanian renewable energy

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11

12 **Abstract:** In 2015, Romania was the first country in Europe that achieved EU targets regarding the
13 share of renewables in the generation mix, far ahead of the 2020 deadline. Starting with the energy
14 structure in Romania, the paper: (1) analyses the evolution of the main indicators in the renewable
15 energy sector, (2) discloses the perspectives of renewable energy in Romania synthesizing the main
16 trends of development in the field and (3) analyses the challenges facing with the development of
17 renewable energy in Romania.

18 Based on analyzing the exploratory data, the paper makes a preliminary prediction of the
19 development of the sector for the future decades and proposes targeted countermeasures and
20 suggestions. Romania still has unexploited potential concerning renewable energy sources.
21 Because Romania registered a continuous economic growth, the demand for electricity is steadily
22 growing, and this trend is expected to continue. Also, Romania could introduce a support
23 mechanism for developing the potential of unexploited potential.

24 The results of the present study may be useful for further research regarding public policies for the
25 development of renewable energy. Also, it can represent a useful analysis in order to identify the
26 future trends of renewable energy in Romania.

27 **Keywords:** renewable energy; future perspectives; renewable energy sources; Romania energy
28 structure; exploratory study

29

30 1. Introduction

31 The economic development of a state depends to a large extent on its ability to create and
32 maintain a constant access to energy resources. Contemporary society is in a continuous
33 transformation. Both the current needs and the resources necessary for their satisfaction change
34 rapidly, causing important mutations in everyday life. Energy production sectors are exempted
35 from continuous transformations. Every day the need for energy is growing.

36 Energy security is the ability of a nation to deliver the energy resources needed to ensure its
37 welfare and implies secure supply and stable prices. Decision about ensuring energy security are
38 always taken in long term, because it implies the implementation of large projects, needing
39 enormous investments. Energy sources can be divided into three main categories: fossil fuels,
40 nuclear resources, and renewable energy sources [1]. Renewable energy sources can provide energy
41 free of air pollutants and greenhouse gasses by emitting zero or nearly zero percent of these gasses
42 [2].

43 European Court of Auditors (ECA) reveals in a report which are the main types of renewable
44 energy sources, relevant technologies and specific applications (**Figure 1**). They sustain that using

45 more renewable energy is crucial if the EU wants to reduce its greenhouse gas emissions to comply
 46 with the 2015 Paris Agreement on Climate Change [3].
 47

Solar energy	Wind energy	Marine energy	Hydropower	Geothermal energy	Bioenergy
					
Source: Sun	Source: Wind	Source: Waves, tides	Source: Water	Source: Earth	Source: Biomass, waste
Technologies: Photovoltaics, Solar thermal	Technologies: Wind turbines	Technologies: Dams, tidal barrages	Technologies: Hydropower plant	Technologies: Geothermal and heat pumps	Technologies: Biomass combustion, biogas plants, biofuels
Applications: Electricity, Heating and Cooling	Applications: Electricity	Applications: Electricity	Applications: Electricity	Applications: Electricity, Heating and Cooling	Applications: Electricity, Heating and Cooling, Transport

48
 49

Figure 1. Renewable energy sources, technologies and applications; source: ECA,2018

50

51 Globally, the energy sector has a significant impact on the environment, air pollution, water,
 52 soil pollution and on GHG emissions or climate change. Between 2009 and 2013, the share of
 53 renewable energy sources (RES) in the EU's energy generation mix increased from 9 to 16% and it is
 54 expected to grow up to 20% by 2020 [4]. Over the last decade, significant progress has been made in
 55 the energy sector in Romania to limit the environmental impact. However, considerable efforts are
 56 still needed for the energy sector to contribute to Romania's transition to an economy based on the
 57 principles of sustainable development.

58 Judicious value, energy resources contribute significantly to: (1) economic and social
 59 development, (2) improving the standard of living of the population and (3) managing strategic
 60 challenges / surprises. Overall, energy supply is essential, given that any gap in energy supply can
 61 have significant negative consequences both socio-economic and public. Romania fulfills the first
 62 condition of energy security, holding important energy resources that can support integrated cycles
 63 in certain industrial branches.

64 Romania has rich and varied renewable energy resources: biomass, hydropower, geothermal
 65 potential, respectively wind, solar and photovoltaic energy. They are distributed throughout the
 66 country and can be exploited on a wider scale as soon as the performance-price ratio of technologies
 67 improves. This level will only be achieved by maturing new generations of equipment and related
 68 facilities. Romania has advanced the use of a significant part of the wind and photovoltaic energy
 69 potential.

70 With a share of 24.7% in 2015, Romania has already achieved its 2020 target (24%) for renewable
 71 energy, due in particular to the size of its hydropower sector, which is responsible for about one
 72 third of the installed power generation capacity, but also the evolution of wind energy (9.4% of the
 73 energy generated in 2014) and the use of biomass for heating (16.6% of final energy consumption)
 74 [5].

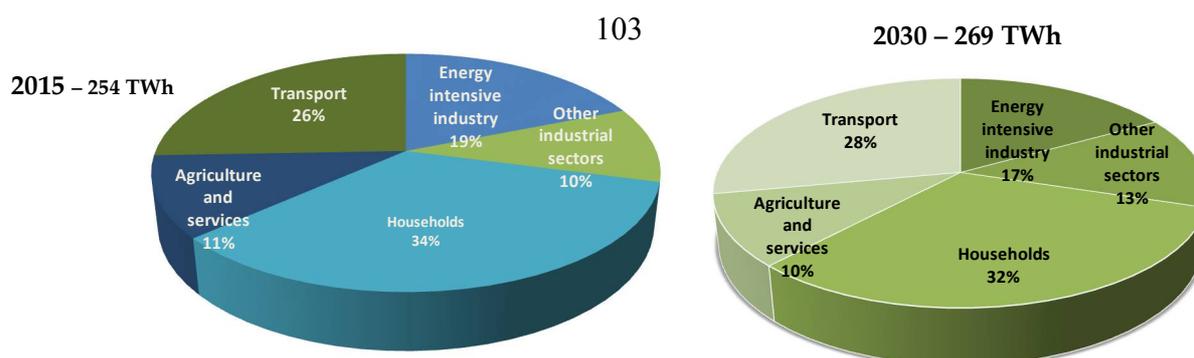
75 The objectives of the article are: (1) to outline the energy structure in Romania; (2) to present the
 76 evolution of the main renewable energy indicators in Romania; (3) to discuss the perspectives of
 77 renewable energy in Romania when Romania intends to participate in achieving the European
 78 targets for reducing the CO₂ emissions; (4) to indicate the challenges facing with the development
 79 of renewable energy in Romania; (5) to predict the development of renewable energy in Romania
 80 and propose targeted countermeasures and suggestions.

81 The aim of the paper is to present an overview of the different types of renewable energy
 82 resources, their current and future states, their share in different economic sectors and their benefits.

83 This study contributes to the existing body of knowledge in several ways. First, this paper is
 84 one of the first contributions to existing literature, which shapes, in one review article, an overview
 85 of Romania energy sector, the impact and the development of renewable energy in Romania and
 86 outlines the future perspectives of this important economic sector. Secondly, this study is the first
 87 attempt to investigate the overall renewable energy in Romania after the publication of Energy
 88 Strategy of Romania 2016-2030 with the perspective of 2050, in the context of achieving the European
 89 Union Climate change targets and UN Sustainable Development Goals.

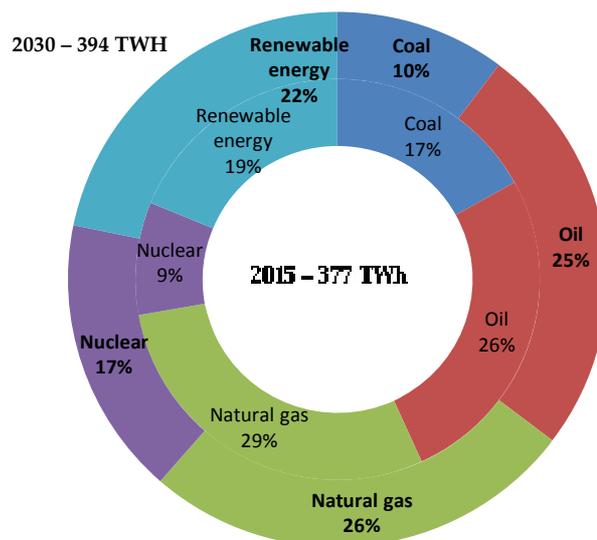
90 2. Energy structure in Romania

91 Romania has become an extremely exciting country in terms of investment over the last
 92 period. This is also due to the economic growth registered by this country over the last period. The
 93 Romanian economy grew by 7% in 2017, compared to 2016, the largest increase since 2008. In 2008,
 94 the Romanian economy grew by 7.1%, in real terms, compared to 2007. In 2016, the Romanian
 95 economy grew by 4.8% and in 2015, the Romanian economy advanced by 3.9%. Though, it can be
 96 observed that Romania's gross energy consumption declined significantly after 1990, reaching 377
 97 TWh in 2015, equivalent to about 19 MWh per capita, and the final energy consumption was 254
 98 TWh. The modeling results estimate gross energy consumption in 2030 to 394 TWh (4% increase)
 99 and final energy demand to 269 TWh (6% increase). Consumption of energy resources as raw
 100 material is set to increase by 35% (6 TWh), while energy consumption and losses will decrease by 4
 101 TWh.
 102



110 **Figure 2.** Final energy demand by sectors in 2015 and 2030

111
 112 The analysis of final energy consumption in 2015 (total 254 TWh) by type of energy
 113 consumption brings to the fore the heating and cooling needs, estimated at 97 TWh (39%) - of which
 114 76 TWh in households and 21 TWh in the services sector (**Figure 2**). The consumption in industrial
 115 processes (48 TWh) and in passenger transport (48 TWh) are the next ranked in descending order.
 116 The rest of the industrial energy consumption is 27 TWh of final energy, and the freight transport
 117 consumes the equivalent of 17 TWh. Electronic and household appliances, used by households and
 118 in services, consumes 13 TWh (of which 10 TWh household consumption). Finally, the specific
 119 consumption of the agricultural sector is 4 TWh.
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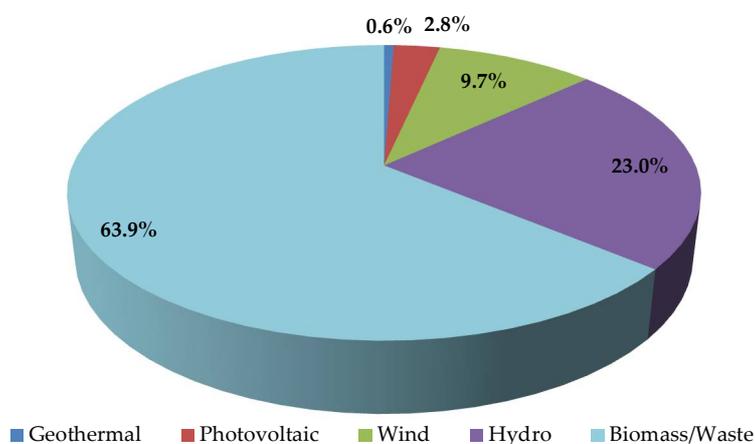


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Figure 3. Structure of primary energy mix in 2015 and 2030

123 Natural gas, the main energy resource in Romania, had a share of 29% (111 TWh) in the primary
 124 energy mix in 2015, followed by crude oil, with a share of 27% (101 TWh) (**Figure 3**). 65 TWh of coal
 125 (of which 55 TWh of lignite) and 46 TWh as biomass were consumed. Nuclear power corresponds to
 126 35 TWh in the primary energy mix and 26 TWh comes from RES to produce electricity (hydro, wind
 127 and photovoltaic). The difference between gross energy consumption and the primary energy mix is
 128 given by the net export of electricity, which cannot be allocated by type of resource.



129

130

Figure 4. Structure of renewable energy mix in 2015

131 As can be observed in **Figure 4**, biomass is the most important contributor in the renewable
 132 energy mix in 2015, with a share of 63.9%. Almost one third of renewable energy is provided by
 133 hydropower, a sector which can be extended in the future, due to the fact that there are unfinished
 134 investments in this sector that were started before 1989.

135 The latest Eurostat data (2016) shows that the final energy price in Romania is considerably
 136 below the European average for both natural gas and electricity. On electricity, Romania had the
 137 sixth lowest EU average household price of 132 €/MWh, Bulgaria (96 €/MWh), Lithuania, the Czech
 138 Republic, Estonia and Croatia (131 €/MWh). For industrial consumption, Romania had the third
 139 lowest electricity price of 80 €/MWh, after Bulgaria and the Czech Republic (78 €/MWh), followed by
 140 Croatia (93 €/MWh) and Estonia (96 €/MWh).

141

142

143 3. Main renewable energy indicators evolution

144 One of the most important indicators in the field of renewable energy is Renewable Energy
 145 Country Attractiveness Index (RECAI). The RECAI ranks 40 countries on the attractiveness of their
 146 renewable energy investment and deployment opportunities [6]. In the same time, RECAI has
 147 established itself as an industry standard and is widely regarded as providing leading market
 148 commentary, analysis and insights on the global renewable energy sector [7]. Analyzing this
 149 indicator (**Table 1**), it can be observed that Romania has an average attractiveness in terms of
 150 renewable energy.

151

Table 1. Romania scores in RECAI rankings

Indicator name	Value
All renewables	46
Wind index	51
Onshore index	55
Offshore index	38
Solar index	33
Solar PV	45
Solar CSP	0
Biomass	44
Geothermal	41
Infrastructure	45

152

Source: Own representation

153 To have an overview of the renewable energy sector in Romania, we consider that a detailed
 154 breakdown of the evolution of the main indicators is necessary. In terms of renewable energy, it has
 155 been selected for this research a series of indicators such as:

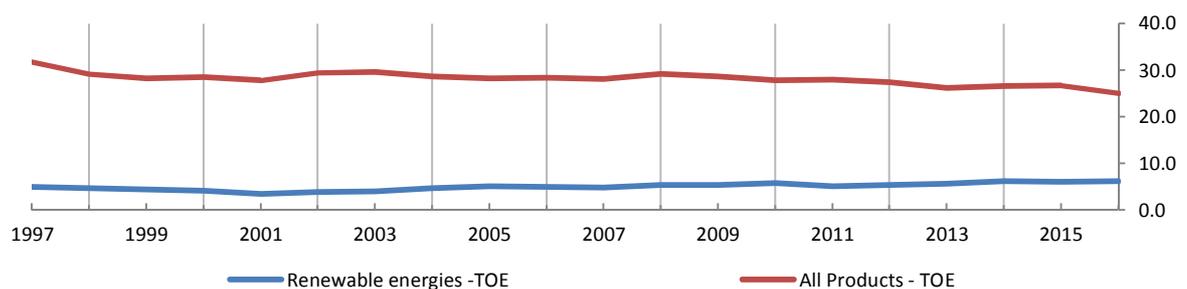
- 156 1. Renewable energies – primary production;
- 157 2. Share of renewables in electricity production;
- 158 3. Renewable electricity output;
- 159 4. Renewable electricity share of total electricity output;
- 160 5. Renewable energy consumption;

161

162 3.1 Renewable energies – primary production

163 According to Eurostat, in renewable energy primary production is included all type of green
 164 energy: wind, hydro, photovoltaic, bioenergy and geothermal. At EU level, renewable energy
 165 primary production is constantly increasing with an average of 5%. Biggest increase can be noted in
 166 2012 and 2011 was the only year when this indicator decreases.

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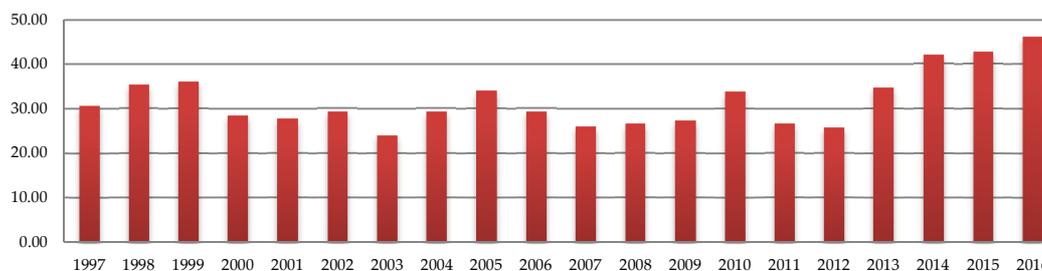
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Figure 5. Energy primary production renewable energy vs. all products

170 As can be seen in **Figure 5**, renewable energy primary production is increasing in case of
 171 Romania. Due to the fact, in Romania was possible to achieve the EU targets in terms of share of
 172 renewable since 2015. At the level of primary production from all products a constant decline
 173 starting with 2012 can be mentioned.

174 3.2 Share of renewables in electricity production

175 The share of renewable energy sources (**Figure 6**) within the global power generation mix has
 176 been growing quickly since the end of the 2000's [8].



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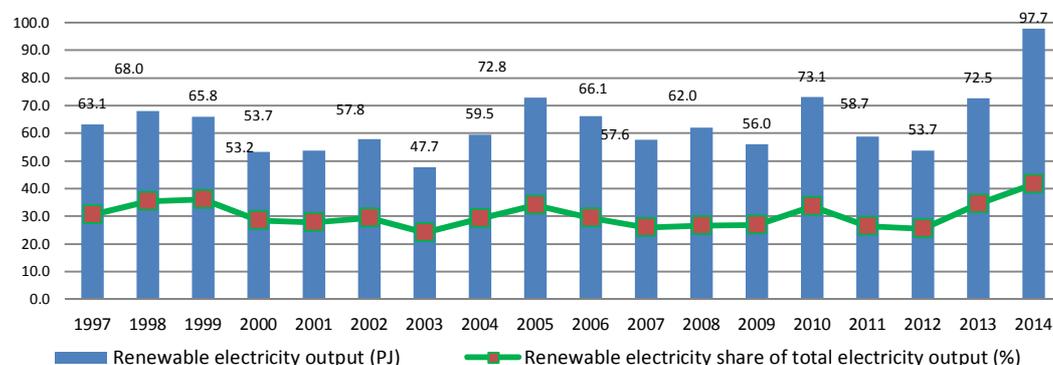
178 **Figure 6.** Share of renewables in electricity production (%)

179 Worldwide, the share of renewable energy registered a 1.6%/year increase between 2000 and
 180 2016. European Union recorded a 4.6%/year increase, which overtakes the increase, 3.4% year,
 181 reached by the Europe as continent.

182 Romania didn't exceed the EU average, having a 3.1%/year increase between 2000 and 2016.
 183 Analyzing the share of renewables in electricity production between 2015 and 2016, for Romania, it
 184 can be observed a 7.8% increase. This value is over the worldwide level, 4.5% and over the European
 185 Union level 1.7% that indicates a significant involvement in renewable energy. At Romania's level,
 186 the fast expansion that took place at EU level between 2006 and 2014 continues, even though at
 187 Union level the penetration of RES in the European Union power mix has been increasing more
 188 slowly since then.

189 3.3 Renewable electricity output and Renewable electricity share of total electricity

190 Renewable electricity is the quantity of electricity generated by renewable power plants in total
 191 electricity generated by all types of plants. In the renewable power plants consists power plants
 192 using renewable resources, including wind, solar PV, solar thermal, hydro, marine, geothermal,
 193 solid biofuels, renewable municipal waste, liquid biofuels and biogas. Electricity production from
 194 hydro pumped storage is excluded [9]. Renewable electricity share of total electricity output (%)
 195 represents electricity generated by power plants using renewable resources as a share of total
 196 electricity output [9].



197

198 **Figure 7.** Renewable electricity output evolution (TJ) vs renewable electricity share of total
 199 electricity output evolution (%)

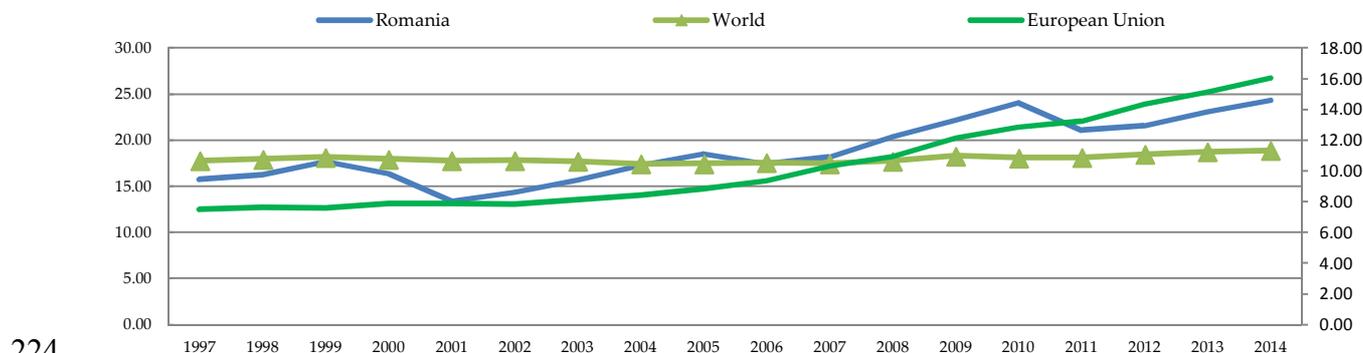
200 Romania has increased its renewable energy output by 55% in the studied period, 1997-2014.
 201 The minimum output was in 2003, with a value of 47.7 PJ caused by political tensions, economic
 202 stagnation and the aging or high wear of production capacities (**Figure 7**). From the perspective of
 203 renewable electricity share in total electricity output can be highlighted a fluctuating trend. The
 204 lowest point was also in 2003, 24%, when renewable electricity share was affected by the same
 205 causes as renewable energy output. At the level of 2014, renewable electricity share was 41.6% of
 206 total electricity output with an ascending perspective for this indicator.

207 3.4 Renewable energy consumption

208 Renewable energy consumption is the share of renewable energy in total final energy
 209 consumption. The first study, belonging to Kraft and Kraft [10], which investigates the relationship
 210 between energy consumption and economic growth, started a segment that has been extensively
 211 researched. Apergis and Payne indicate that energy consumption is positively associated with
 212 economic growth [11]. Contrariwise, in an empirical research for 27 European countries, empirical
 213 results do not confirm causality between renewable energy consumption and GDP [12].

214 Energy consumption was a special issue researched during time. A significant number of
 215 articles investigate the causal nexuses between CO₂ emissions, economic growth and energy
 216 consumption [12-15]. Bhattacharya et al. investigate the effects of renewable energy consumption on
 217 the economic growth of major renewable energy consuming countries in the world [13]. In the
 218 same time, Saidi et al. investigate the impact of economic growth and CO₂ emissions on energy
 219 consumption for a global panel of 58 countries [15].

220 Renewable energy consumption is the ratio between the gross inland consumption of energy
 221 from renewable sources and the total (primary) gross inland energy consumption calculated for a
 222 calendar year [16]. The share of energy consumption from renewable energy provides a broad
 223 indication of progress towards reducing the environmental impact of energy consumption.



224

225 **Figure 8.** Renewable energy consumption (% of total final energy consumption)

226 As presented in **Figure 8**, Romania recorded a fluctuating trend in terms of renewable energy
 227 consumption. In the period 1997-2003, Romania was situated below the worldwide average. Starting
 228 with the year 2007, Romania beat year after year the world average. Year 2007 had a special
 229 signification for this country; it was the year of Romania accession to the EU. For all the studied
 230 period, 1997-2014, Romania renewable energy consumption was above the EU average.

231 Even if, in 2011, this indicator experienced a slight decrease (from 24.1% in 2010 to 21.1% in
 232 2011) due to the global crisis, after 2012 its trajectory is continually improving. In 2014 the maximum
 233 value of renewable energy consumption was reached, for the studied period.

234 4. The renewable energy sources and current situation in Romania

235 In the European Union, renewables account for 80% of new capacity and wind power becomes
 236 the leading source of electricity soon after 2030, due to strong growth both onshore and offshore [17].
 237 Renewable energy sources are steadily becoming a greater part of the global energy mix [18]. World

238 energy consumption rises 28% between 2015 and 2040 [19]. Renewables capture two-thirds of global
239 investment in power plants to 2040 as they become, for many countries, the least-cost source of new
240 generation [20].

241 The development of electricity production from renewable sources led to a decrease in GHG
242 emissions from the electricity generation process. The amount of greenhouse-gas emissions resulting
243 from the production of electricity decreased from 438 g/kWh in 2011 to 326g/kWh in 2015. The
244 influence of renewable energy in domestic electricity was significant, mainly due to the replacement
245 of polluting fossil-fuel electricity.

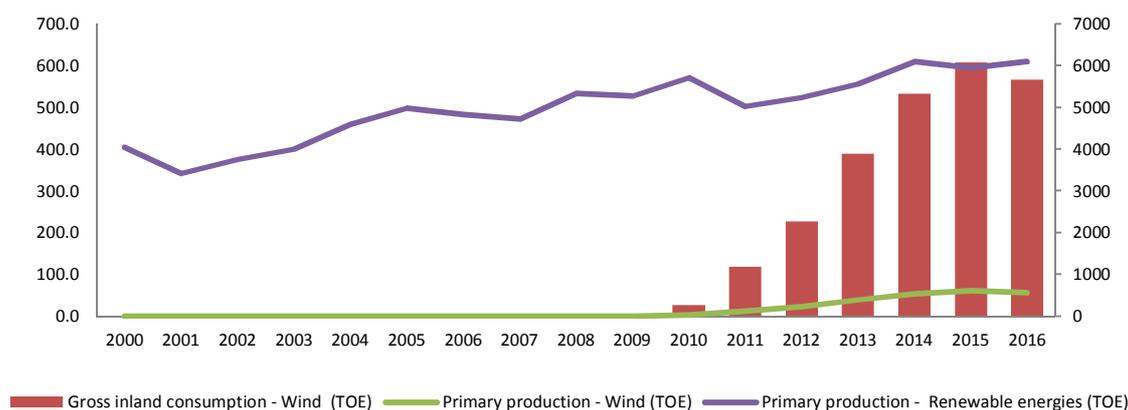
246 Currently, the annual production of energy from renewable resources in Romania is
247 approximately 6,550 ktoe (kilotons of oil equivalent). A technical potential of 8,000 ktoe remains
248 unexploited, with biomass and biogas representing 47%, solar energy 19%, wind energy 19%,
249 hydropower energy 14% and geothermal energy 2%.

250 4.1 Wind

251 The share of wind power in the EU's total installed power capacity has increased from 6% in
252 2005 to 18% in 2017. Having overtaken coal in 2016 as the second largest form of power generation
253 capacity in the EU, wind power is now closely catching up with gas [17].

254 Wind energy generated by wind power remains advantageous, as Romania has the highest
255 potential in South East Europe in the field of wind energy, and southeast Dobrogea is ranked second
256 in the continent. Wind turbines use a perpetual, renewable energy that is never consumed, and start
257 from a wind speed of only 3.5 m / second. In Dobrogea the speed is 7 m/s at a height of 100 meters.

258 As can be observed in **Figure 9**, starting with 2007, Romania begun to produce wind-based
259 energy. The primary production recorded a light increase every year. If in 2007 primary production
260 was only 0.3 TOE, in 2016 the primary production reached 566 TOE. Biggest increase was registered
261 in 2010 and it consists in an enlarging capacity with 3188% compared with 2009. The average
262 increase of primary production in wind energy was 431% between 2007 and 2016. This trend was in
263 accordance with the increase at the level of all renewable energy sources. In 2016, a light decrease of
264 7% in wind primary production can be highlighted. Simultaneously, wind gross inland production
265 followed the same trend.
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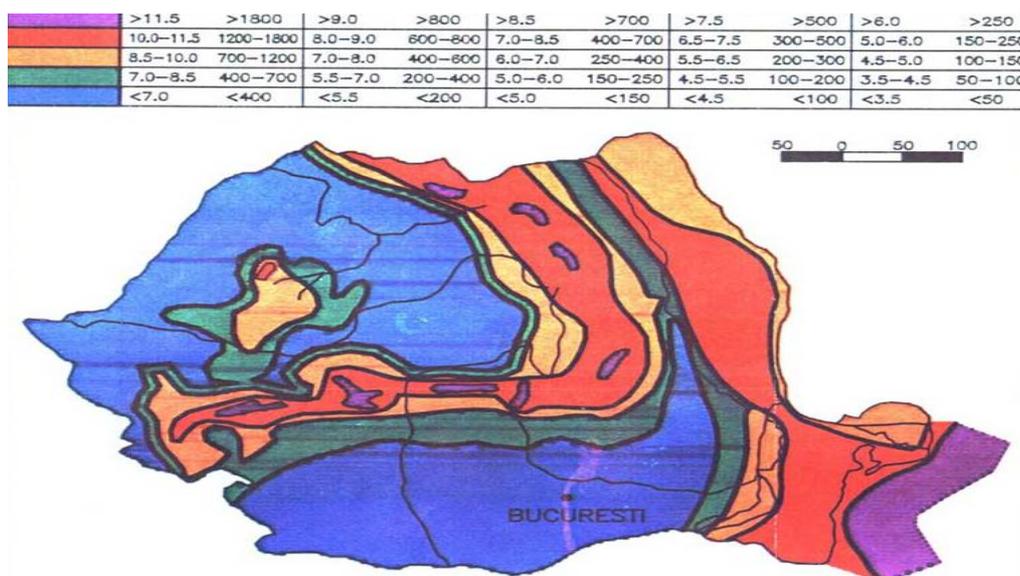
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Figure 9. Main wind indicators evolution between 2000 and 2016

269 In Romania, five wind zones were identified, depending on the environmental and
270 topo-geographical conditions, considering the level of energy potential of such resources at an
271 average height of 50 meters and over (**Figure 10**).

272

273



274

Figure 10. Romanian wind resources

275 The results of the recorded measurements show that Romania is in a temperate continental
 276 climate, with a high energy potential, especially in the littoral and coastal areas (mild climate), as
 277 well as in alpine areas with plateaus and mountain valleys (severe climate). It is estimated that the
 278 annual wind energy potential in Romania is around 23 TWh.

279 In 2015, a total of about 27.3 GW of new power generation capacity were connected in the EU
 280 and 18.2 GW were decommissioned, resulting in 9.1 GW of new net capacity. Renewable energy
 281 sources (RES) accounted for 20.6 GW or 75.6% of all new power generation capacity [21].

282 Romania's wind potential is the highest in Southeast Europe [22]. The wind energy in Romania
 283 witnessed considerable development over the five-year period. 75 wind farms with a power range
 284 from 0.008 to 600 MW and an average of 40MW were built [22].

285 In Romania were installed 923 MW, at the level of 2012, which represents an increase of 94% of
 286 the total wind power capacity in our country. Cumulative wind power capacity of Romania has
 287 reached 1905 MW at the end of 2012, surpassing the estimates of ANRE and the National Action Plan
 288 for Renewable Energy [23]. Simultaneously, Tocan has analyzed the main investments in wind
 289 energy in Romania [23]. Representative investments are presented in **Table 2**.

290

Table 2. Major investments in Romanian wind energy production

Company	Country of origin	Capacity (MW)	Total investments (euro)	Place of investment
Cez	Czech Republic	600	1.1 billion	Fantanele-Cogealac
Enel Green Power	Italy	180	330 million	Tulcea & Caras Severin County
GDF SUEZ	France	48	80 million	Braila County
Verbund	Austria	100	320 million	Tulcea County
Lukerg	Russia&Italy	84	135 million	Tulcea County
EDP Renewables	Portugal	270	200 million	Ialomita County

291 As can be observed in the previous table, the main investor in wind energy in Romania is Cez.
 292 On the second and third place, both for installed capacity and total of investments are ranked Enel
 293 Green Power and EDP Renewables.

294 Dobrogea region became, in 2014, the largest wind farm in Central and Eastern Europe, with
 295 hundreds of 2.5 MW wind turbines installed all over the Constanta County, in sites as: Cogealac,

296 Fantanele, Pestera, Independenta, Chirnogeni, Silistea, Targusor and Crucea localities and
297 surrounding areas.

298 In April 2016 Romania's electricity production accounted 23% of total energy production
299 coming from wind energy. According to the state-based transportation company, Transelectrica,
300 wind was the second most important power source, after hydropower. In april 2016, the wind
301 energy production amounted to 1,941 MW whereas the hydropower reached 2,192 MW,
302 representing 26% of the total [24].

303 After 2017, one of the biggest projects in the field is represented by NERO Renewables project
304 who intends to build in Romania three wind farms with 362 turbines and a total installed capacity of
305 about 1 GW, with 400 MW above the capacity of the Fântânele-Cogealac onshore park, currently the
306 largest of its kind in Europe [25]. Given that the Netherlands expects to miss the target of a 14% share
307 of renewable energy in total energy production for 2020 and Romania has already reached its 2020
308 target, NERO proposes to the Dutch Government to "adopt" the project in Romania. Thus, through
309 the European mechanism "joint projects" for cooperation in the renewable energy sector, the
310 Netherlands will be able to co-finance the wind farms developed by NERO in Romania, and the
311 energy produced by them will be included in the renewable energy production of the Netherlands.
312 At the end of 2017, Romania has 3209 MW installed wind power capacity. This mean that 12.2% of
313 the average annual electricity demand is covered by wind [17].

314 Wind energy investments in 2017 were less geographically concentrated than in 2016. Wind
315 energy investments accounted for 52% of the new clean energy finance in 2017, compared to 86% in
316 2016. Germany was the biggest investor in 2017 with a total financing activity of €6.7 bn for the
317 construction of new onshore and offshore wind farms.

318 4.2 Photovoltaic

319 According to Romania Photovoltaic Market Outlook 2014 – 2025, Romania was one of the most
320 promising emerging markets for photovoltaic energy investments in 2013 amongst SEE countries
321 [26].

322 Romania's solar potential is widespread throughout the country. Romania benefits from about
323 210 sunny days per year. The southeastern region of Romania, the west, the center and the east of the
324 country are the best places to place a solar park. Solar energy is quoted by many market specialists
325 with good chances to turn into the new boom in the green energy segment.

326 It is very difficult to assess the number of photovoltaic (PV) parks existing in Romania because
327 no institution centralizes this information and does not have a cumulative record. At 2016,
328 consulting and comparing information from various sources, not all official, we found that 962
329 photovoltaic power stations or photovoltaic parks with a combined installed capacity of 4,871.66
330 MW were built up to last year. 212 of them produce less than 1 MW and 112 have a production
331 below 2 MW (Table 3).

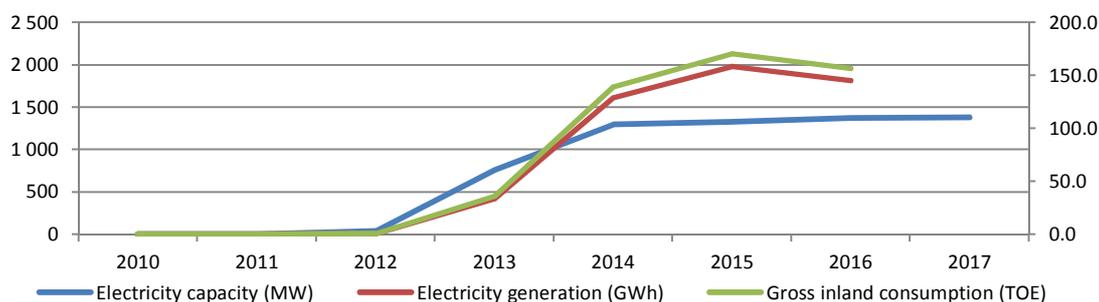
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Table 3. No. of PV farms and installed capacity in Romania, 2016

Region	Number of PV farms	Installed capacity (MW)
North-East	26	28.15
South-East	91	149.51
South Muntenia	302	827.95
South-West Oltenia	134	393.47
West	96	148.85
North-West	178	430.22
Center	110	568.93
Bucharest-Ilfov	25	17.58

334

335 Most PV parks are built in Ialomita county- 59, and the largest installed capacity is in Brasov
 336 county - 287.5 MW.
 337



338

339 **Figure 11.** Main photovoltaic indicators evolution between 2010 and 2016

340 During the 1970's and 1980's Romania was an early player in the solar power industry,
 341 installing around 800.000 m2 of early-technology solar cells, which placed the country third
 342 worldwide as far as the total surface of photovoltaic panels was concerned. Although the support
 343 scheme was one of the main investment drivers lately, the solar sector has lagged. In 2011 the
 344 production of electricity using solar PV was insignificant in Romania, while in April 2012 only two
 345 PV plants were operational, each amounting to 1 MW. The solar installed capacity recorded an
 346 increase from 500 kW in 2008 to 1.3 GW in 2016 (**Figure 11**).

347 The most important increase of the electricity capacity can be underlined between 2013 and
 348 2014, when the capacity has grown from 761 MW to 1293 MW. In 2013, the Romanian incentive
 349 structure subsidize up to a total of six green certificates per megawatt-hour of electricity produced.
 350 Demand significantly exceeded expectations, and in response, the Romanian Energy Regulatory
 351 Authority (ANRE) recommended a reduction in green certificates from six to three in March 2013.

352 The result of this incentive was a 3,667 percent increase in solar installations over the 30
 353 megawatts installed in 2012. Romania's rise is a byproduct of the longstanding forces governing PV
 354 demand, which shifted development from region to region based on rapid changes to incentives.
 355 With an attractive incentive program, acceptable insolation and geographic accessibility for vendors
 356 and EPCs, Romania met all the criteria for a strong PV market. But, similar to other markets, a rapid
 357 phase-out of incentives caused a significant drop in installations.

358 4.3 Hydropower

359 Hydropower is one of the main contributors to the total electricity generation in Romania, with
 360 a contribution of around 30% of the total power delivered to the grid. In 2010 hydro power plants
 361 had a total installed capacity of over 6400 MW and produced 19.8 TWh electricity [27].

362 Compared to 2008, in 2016 the hydropower installed capacity slightly increase from 6.38 GW to
 363 6.71 GW. Also, in the same period, can be remarked a drop of the hydropower production, from 1.46
 364 Mtoe/year in 2008 to 1.25 Mtoe/year in 2016. The biggest company in hydropower sector is a
 365 state-owned company named Hidroelectrica. In 2017, this company produced 14.04 TWh in 208
 366 hydropower plants with 6444 MW installed power. At the level of 2017, Hidroelectrica posted EUR
 367 260 million gross profit in the first nine months of this year, when its turnover stood at EUR 525
 368 million [28]. At the level of 2016, the values of the produced energy and of the power installed in the
 369 hydropower facilities in operation in Romania are represented in **Table 4**.

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Table 4 - Hydropower facilities in operation, 2016

Type of facility	Number of plants	Installed power (MW)	Energy produced (GWh/year)
Large hydropower	107	6104.5	16630.00
Pump	5	91.5	n/a
Small hydropower	418	573.2	1458.00
Total		6769.7	18088.00

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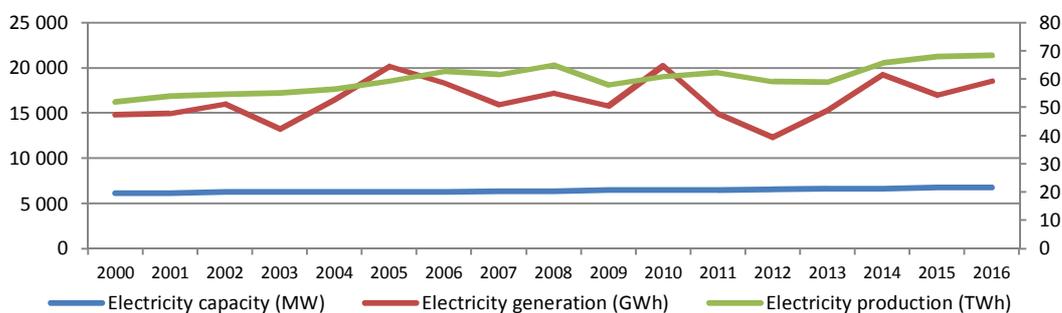
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In Romania, hydropower capacity has grown from year to year. If in 2000 the electricity capacity was 6120 MW, in 2016 it reached 6734 MW. This means a 10% increase in capacity in 15 years (**Figure 12**).



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Figure 12. Main hydropower indicators evolution between 2000 and 2016

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At the level of 2005, a slight decrease in electricity capacity was recorded, - 7MW. In 2014 it can be remarked the biggest increase in electricity capacity of 117 MW added for the analyzed period.

World Energy Trilemma 2016 considers that emerging economies have the potential to double energy production by 2050, including low-power hydro power plants [29]. In the same report is highlighted that hydropower contributes more than 16% of total energy needs and supplies 76% of total energy produced from renewable sources. In Romania, in 2016, the exploitable potential reached 69-75% of its capacity. An important share of the remaining exploitable potential, representing 6-8 TWh / year, can be valued in the future. This represents a new installed capacity of approx. 1700-2700 MW (**Figure 13**).



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Figure 13. Romanian hydropower potential

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To extend the hydropower network in Romania, the national authorities could speed the completion of various plants at various stages of execution. There are 14 large hydropower plants and 8 small hydropower plants with an installed capacity of 416 MW and an annual energy output of 1329.40 MWh / year, which were started before 1989.

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4.4 Bioenergy

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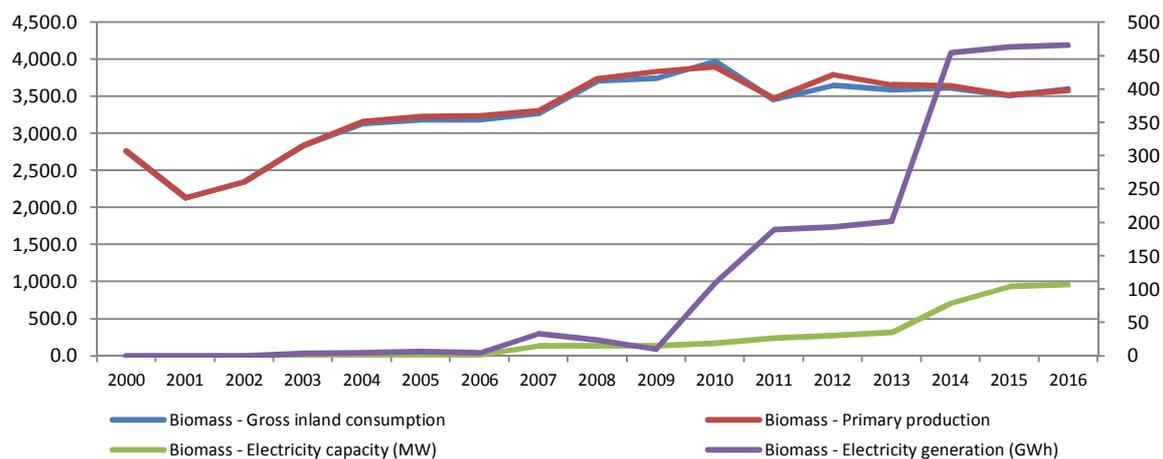
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Romania is the state of Europe best suited for bio-economy with a localization coefficient of 3.9. This means that the share of people working in the Romanian bio-economy is almost four times the

402 share of those working in the bio-economy of the rest of the European Union. In fact, this
 403 "concentration" in the bio-economy is mainly due to a very large concentration of the labor market in
 404 agriculture in Romania. One of the most important aspect that bio-economy refers to is bioenergy. In
 405 the category of bioenergy can be included: (1) Solid biomass including waste; (2) Biogas and (3)
 406 Liquid Biofuels.

407 Biomass is and will remain the main type of RES in Romania. The main form of energy biomass
 408 produced in Romania is firewood (95%), being an important generator of GHG. Data on solid
 409 biomass production presents a high degree of uncertainty (about 20%) compared to a central
 410 estimate of 42 TWh in 2015, uncertainty also reflected in heating consumption and energy balances
 411 of Romania. Household firewood consumption is estimated at 36 TWh; with the mention that the
 412 predominant biomass is used in the production of heat, respectively heat and electricity in
 413 cogeneration. The modeling results show a 20% decrease in firewood consumption by 2030, which
 414 will lead to a slight decrease in production to 39 TWh.

415 We are closer to the truth considering biomass as a bridge between fossil resources and truly
 416 non-polluting resources - so, at best; the use of biomass can mean a period of transition, long
 417 enough, towards a truly non-polluting energy system. For now, the European Commission's report
 418 only succeeds in highlighting the benefits of biomass over the use of fossil resources, but at the same
 419 time highlights the possible large-scale risks that inefficient use of biomass can bring. So, it would
 420 require a reassessment of the importance biomass has to have in the plans of the EU countries.



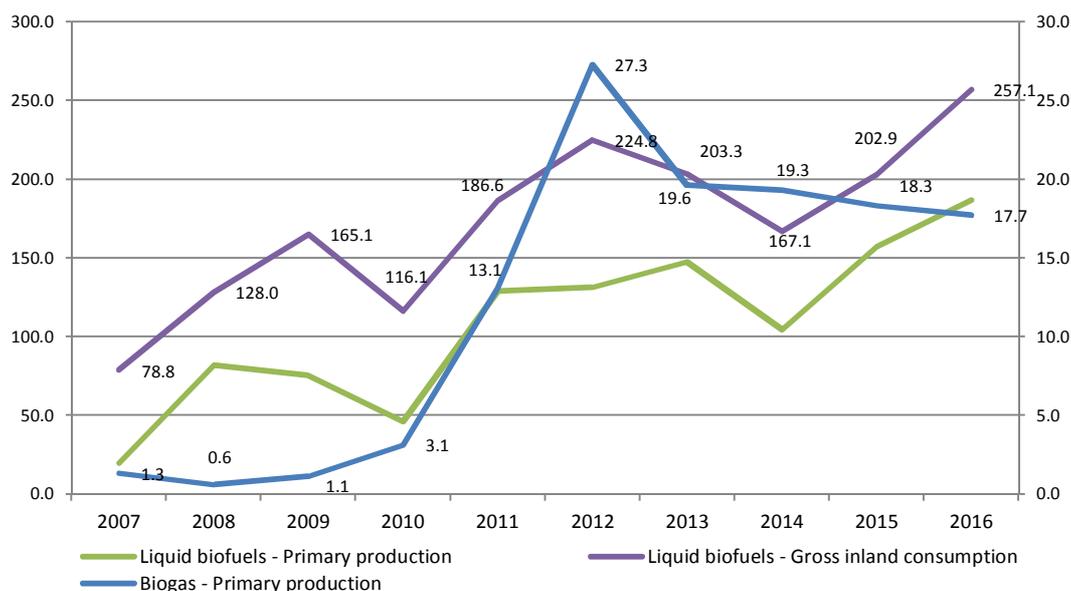
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Figure 14. Main indicators evolution for biomass, 2000-2016

423 Starting with 2009, it can be observed a continuous growth both for electricity capacity and
 424 electricity generation (**Figure 14**). The biggest growth of this indicator can be highlighted between
 425 2013 and 2014, 126%. This increase is due to several major investments in the field of biomass of
 426 which a significant one inaugurated is Genesis BIOPARTNER. It is a Romanian holding company
 427 formed in partnership with Baupartner Romania and Vireo Energy from Sweden with a capacity of
 428 1MW/h electric and 1,2MW/h heat and process 49 tons daily amount of organic substrate. The
 429 project involved an investment of approximately 5 million EUR [30]. Another major investment in
 430 the field, 11 million euro, was made, starting 2012, by KDF Energy.

431 In terms of biomass electricity generation, the most important increase can be observed between
 432 2009 and 2010. If in 2009 the value of this indicator was 10 GWh, in 2010 it reached 110GWh. Another
 433 significant increase was between 2013 and 2014, from 202 GWh to 454 GWh.



434

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Figure 15. Main indicators evolution for biofuels and biogas, 2007-2016

436

Starting with 2010, from the perspective of primary production and gross inland consumption, it can be seen a negative correlation (Figure 15). A bigger value of gross inland consumption is due to imports in the field of liquid biofuels, because major companies in fuel distribution are foreign entities. For the analyzed period, the total amount of biogas production was consumed by the domestic market. Since 2014, biogas primary production is decreased from 19.3 to 17.7 Mtoe in 2016.

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The Bio-Based Industries Consortium (BIC) report has identified the main local biomass sources that could be used as sustainable raw materials for bio-industries as well as key actors in relevant sectors and industry-based development opportunities based on these activities [31].

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According to the same report, agriculture and forestry, together with other industries such as food processing, wood industry, paper and pulp industry, can produce large quantities of waste and other unused or less used materials, being available as raw material for biomass processing industries [31].

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In 2012, Transelectrica reported that there are about 35 MW using agricultural or forestry waste to produce light, which means that the field has already attracted investments of 70 million euro.

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In 2017, a new state aid scheme to support investments in 'less exploited' renewable resources, such as biogas, biomass and geothermal energy, has been approved in Romania. The new support scheme from the Romanian government has a total budget of over EUR 100,000 (\$107,000). 85% of the budget comes from the European fund for regional development and 15% from the state's funds.

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5. Perspectives of renewable energy development

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The renewable energy sources to be stimulated in Romania for the period 2030-2050 are: wind energy, hydropower, geothermal energy, biomass and solar energy. As previous research underlined, Romania has the potential for green energy production as follows: 65% for biomass, 17% for wind energy, 12% for solar energy, 4% for small hydropower plants and 2% for geothermal energy [32].

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Moreover, the European Parliament voted for a project that requires 35% of Europe's energy consumption in 2030 to be renewable. Each Member State will have a target from which it will be able to deviate by a maximum of 10%, under certain conditions, including Romania. In 2030, each EU Member State will have to ensure that 12% of the energy consumed in the transport sector comes from renewable sources.

465 According to a map compiled by the National Meteorological Administration, this potential is
466 allocated zonal as follows:

- 467 1. Danube Delta – Photovoltaic;
- 468 2. Dobrogea – wind and photovoltaic;
- 469 3. Moldova – small hydropower, wind and biomass;
- 470 4. Carpathians Mountains – biomass and small hydropower;
- 471 5. Transylvania - small hydropower;
- 472 6. Western Plain – geothermal;
- 473 7. Subcarpathian - biomass and small hydropower;
- 474 8. Romanian plain – biomass, geothermal and photovoltaic.

475 In order to encourage companies and householders to develop such systems, the Romanian
476 government has created support tools such as the green certificates market, investment financing
477 solutions or incentive regulatory framework.

478 Policies continue to support renewable electricity worldwide, increasingly through competitive
479 auctions rather than feed-in tariffs, and the transformation of the power sector is amplified by
480 millions of households, communities and businesses investing directly in distributed solar PV.

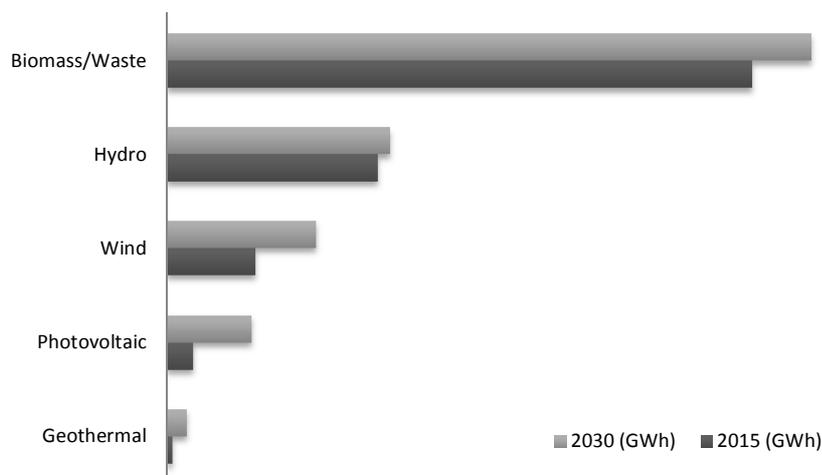
481 The electricity produced in Romania, between 2011 and 2015, increased by approximately 4.5%,
482 and the reduction in greenhouse-gas emissions from the electricity production process decreased by
483 5.8 million tons. This decrease reflects the change-over in the electricity production process, from
484 fossil fuels, particularly coal, to electricity generated from renewable sources, in particular, wind
485 power.

486 For 2030, the estimations show a more significant increase only for energy consumption in the
487 machine, machinery and equipment industry, respectively in freight transport. Heating
488 consumption is likely to decrease slightly by increasing energy efficiency.

489 In the medium and long term, an increase in mobility is expected, eliminating exhaust fumes,
490 especially in the urban environment. For the electric vehicle to contribute substantially to reducing
491 air pollution, the energy transition to renewable energy sources and other low-emission electricity
492 technologies, or sustainable technologies for storing significant amounts of electricity, will have to be
493 completed.

494 For the year 2030, an optimal scenario shows a decrease in natural gas to 106 TWh (27%), the
495 maintenance of crude oil consumption (26%) and the reduction of coal's contribution. Instead, the
496 contribution of nuclear energy is doubled and energy from biomass (including biogas) increases to
497 51 TWh. Renewable energy capacities in electricity generation grows to 37 TWh (**Figure 16**).

498



499

500 **Figure 16.** Renewable energy mix evolution between 2015 and 2030

501 For Romania, frequent changes to the Green Certificates support scheme in recent years,
502 aggregated with the country-specific risk of an emerging economy, place the cost of RES capital at

503 one of the highest levels in the EU. Therefore, there is a risk that Romania's equitable participation in
504 meeting the EU's common targets for RES in 2030 will be costly.

505 Access to the current green certificates support scheme closed at the end of 2016, so new
506 investments in wind, photovoltaic, micro-hydropower or biomass capacities are unlikely in the
507 period 2017-2020, except those receiving co-financing from European Structural Funds.

508 In an Optimistic Scenario, after 2020, Romania is succeeding in attracting investment in new
509 RES-based capacities by reducing capital costs without the need for new support schemes. This
510 development enhances competitiveness in attracting investment in related industries. Under low
511 capital cost and without a support scheme, a gradual increase of 1,500 MW wind power and 1,400
512 MW of photovoltaic capacity over the 2020-2030 period is projected. In total, the increase in
513 RES-based capacity between 2017 and 2030 will be lower than in 2011-2016.

514 Biomass occupies a central place in the electricity mix, but the development potential is still
515 high, especially through efficiency and the introduction of new technologies such as bio refineries
516 and biogas production capacities. Judicious management of the forest fund is a basic condition for
517 the energetic use of wood. Geothermal and solar resources are only marginally exploited in
518 Romania, with substantial potential for increasing the use of these resources in the future decades.

519 Biomass is the main form of RES in Romania's energy mix and will retain this role in the long
520 run. After 2030, the analysis of the potential for biomass development at European level indicates the
521 possibility of a considerable increase of the surface area used in Romania effectively in annual and
522 perennial lignocelluloses cultures. Total biomass production in Romania could increase from 47
523 TWh in 2015 to 184 TWh in 2050, of which 119 TWh lignocelluloses biomass cultures. Thus, biomass
524 could become Romania's main energy product, as much of it could be for exports, after
525 transformation into finished energy products with high added value. The problem of waste
526 management will be solved by transforming into energy products, biogas production and
527 energy-producing oils, but the resulting volume is lower than the potential of lignocelluloses plants.

528 45 TWh increase in RES is allocated almost equal wind, solar and geothermal. Hydropower is
529 not expected to increase substantially, but growth is not excluded if new investments are made in
530 hydroelectric power plants on the main water courses - the greatest potential being still on the
531 Danube.

532 There is also a need for strategies to ensure energy security. Thus, by 2030, Romania should
533 streamline the capacity and the way of electricity production. Modern and flexible technologies are
534 required to deliver optimal energy and reduce carbon emissions. The digitization of the entire sector,
535 especially in terms of transport and distribution of energy should be considered.

536 The production of biofuels and biogas has a high potential. In 2015, the production was 1500
537 GWh for biofuels and 450 GWh for biogas. For 2030, the modeling results indicate an increase of
538 4100 GWh of biofuels, amid the development of the agricultural sector and, to a lesser extent, the
539 upgrading of sewage treatment plants. These values can help to reach the national required target
540 for 2020 of 10% RES share in the transport sector.

541 Waste energy production may increase in Romania, but the focus should be on selective
542 collection, recycling and recycling of raw materials rather than incineration.

543 In the short term, the following measures are proposed to ensure the development of the energy
544 sector: strategic stocks and enough capacity reserves; ensuring the calibration of the National Energy
545 System; balancing, backup and storage systems; protection of critical infrastructure from
546 cyber-attacks or terrorism.

547 Long-term domestic measures refer to: increasing the capacity of energy governance -
548 legislation, regulations and administrative act; maintaining a diversified and balanced energy mix as
549 well as a high level of demand-side coverage with internal resources; maintaining an integrated
550 nuclear cycle and providing expertise in the nuclear field; completing investment in transport and
551 distribution networks in order to increase their efficiency and achieve the transition to smart grids;
552 reducing energy poverty, including by increasing energy efficiency for vulnerable consumers.

553 From the GHG reduction perspective, Romania can propose a series of targets that can be
554 achieved by 2050 with the improvements and adjustments presented below (Table 5).

555

Table 5. Decarbonization targets for 2020, 2030 and 2050

Indicator	Unit	2015	2020	2030	2050
GHG reduction	% compared to 1990	54	55	62	75
GHG reduction – non ETS (Emission Trading System)	% compared to 2005	8	0	2	30
Share of RES	%	26.3	24	27	47
Share of RES – energy	%	43.7	44	55	78
Share of RES - transportation	%	4.6	10	13	60
Energy intensity	TOE/mil € ₂₀₁₃	319	300	170	50

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558 Based on actual perspectives of development for energy sector, the GHG reduction compared to
 559 1990 will be only 75%. The European target for this indicator is 80%, but Romania can have
 560 reasonable contribution. It is expected that Romania reach the 10% target for share or RES in
 561 transportation till 2020. If by 2020, the increase in RES-Transportation share will be supported by the
 562 biofuel mix in petrol and diesel until the 10% target is reached; in 2020-2030, the share of
 563 RES-Transportation will grow especially because of the increase in the share of electric mobility, on
 564 the railway and road segments.

565 For Romania, is not excluded an 80% GHG reduction till 2050, but it is possible only by
 566 maturing new technologies, with cost savings. The energy sector contributes essentially to the
 567 development of Romania through its profound influence on the competitiveness of the economy, the
 568 quality of life and the environment. To sustain long-term consumer expectations, the Romanian
 569 energy sector needs to become more robust economically, technologically advanced and less
 570 polluting. There can be highlighted five major themes that should be developed till 2030, such as: (1)
 571 storage and energy mix; (2) infrastructure; (3) the role of biomass in households heating; (4)
 increasing buildings energy efficiency or (5) mitigating energy poverty.

572 6. Conclusions

573 Several factors are making Romania emerge as an attractive and alternative location for
 574 renewable energy investors who are increasingly concerned about lower returns from more
 575 established markets in the Western European countries.

576 It can be observed that electricity demand in Romania declined starting with the 1990s and
 577 several older thermal power stations have been decommissioned. In the last years, due to the fact
 578 that Romania registered a continuous economic growth, the economy expands, and the demand is
 579 steadily growing. This trend is expected to continue in future decades. Therefore, Romania was able
 580 to meet its target of covering 24% of its final energy consumption from renewable sources much in
 581 advance (2013) of the 2020 deadline.

582 A 7% primary energy demand is estimated between 2030 and 2050, from 394 to 365 TWh. The
 583 share of fossil fuels in the primary energy mix also drops, from 61% to 47%, being replaced by RES,
 584 increasing from 22% to 35%.

585 Romania cannot assume an ambitious RES target for 2030, the target proposed to the European
 586 Commission is 27%. A faster increase in the share of RES is possible, but it could compromise the
 587 objective of raising the quality of life in rural areas.

588 Romania could introduce a support mechanism for developing the potential of biomass in
 589 modern and efficient forms, but further development of photovoltaic and solar photovoltaic parks
 590 will continue only when the cost of these technologies makes them competitive without support
 591 schemes. This is expected to take place in the next decade, so new photovoltaic and photovoltaic
 592 capacities will be built in Romania even in the absence of a support scheme after 2020. The modeling
 593 results confirm a gradual but more sustained increase in capacity wind and photovoltaic for the
 594 entire 2020-2030 period.

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607

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