INFLUENCE OF RENEWABLE ENERGY SOURCES ON CLIMATE CHANGE MITIGATION IN SERBIA

by

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Global discussion on climate change and strengthening environmental protection has been launched, especially in the last three decades. As climate change is a result of greenhouse gas emissions, different mechanisms were introduced in order to reduce this impact, surely the most significant was set by the Kyoto Protocol. The Republic of Serbia considers a proper policy on environmental protection as one of its priorities. As the switch from traditional to renewable energy sources carries valuable improvements in environmental protection and economic efficacy, the Government encourages the use of renewable energy sources for the production of energy. This paper provides analysis of the potential of renewable energy sources in Serbia, carbon potential and their possible role in mitigation of climate changes. Results presented in the paper can be useful for the improvement of the strategic planning on the national level with the final aim to contribute to the increase in importance of use of renewable energy sources in that planning.

Key words: *climate changes, renewable energy sources, carbon potential*

Introduction

The use of different forms of energy was crucial in human development through the ages. Energy was obtained from different sources available in human's close surroundings (coal and oil), which very often lead to great pressure on ecosystems. Their usage and exploitation, enhanced with human activities in the second half of 20th century, caused multiple deleterious effects on the environment through significant pollution of soil, water and air. The increased emissions of carbon dioxide, methane, nitrous oxide and other so-called greenhouse gases (GHG) in the atmosphere result in a greenhouse effect, which was identified as the main cause of climate change on our planet. The greenhouse effect is a process by which thermal radiation from a planetary surface is absorbed by atmospheric greenhouse gases, and is re-radiated in all directions. Since part of this re-radiation is back towards the surface and the lower atmosphere, it results in an elevation of the average surface temperature above what it would be in the absence of the gases. This results in the rise of global average temperatures and climate change in large expanses of our planet. Besides meteorological effects, global warming also causes changes of biological activity that may result in major changes in the human habitat. Also, as

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fossil fuels and their sources are exhaustible, it has become necessary to examine other sources of energy that would fulfill two criteria:

– the emission of hazardous materials into the atmosphere is reduced during energy production, and
– access to the energy source is relatively simple and possible at regular intervals.

These criteria are met by so-called "renewable energy", based on solar radiation.

Renewable or "green" energy can be defined as the energy that is obtained from natural resources that are replenished constantly such as sunlight, wind, rain, tides, geothermal heat, and biomass. This energy also includes waste energy that is obtained from different waste products (biomass waste, heat waste generated in the course of industrial production, and energy derived from the processing of communal waste), and biofuels and hydrogen derived from renewable resources. Renewable energy is sustainable, which means that energy production, distribution and use give future generations the same opportunity to access energy services as those enjoyed by the current generation. Also, its production and consumption does not put the environment at risk. Opposite to fact that energy sources are concentrated in a limited number of countries, renewable energy is mainly produced from local sources that are immediately available to the consumer, which also ensures energy-independence at local and national levels.

Pollution, the increase of energy and resource prices as well as global climate change in the last three decades initiated global discussion about climate change and the strengthening of environmental protection, and the conclusion is that collective global action is the key to reducing climate change. One of the United Nations Millennium Development Goals is to ensure environmental sustainability through the increased protection of the environment and reverse loss of environmental resources by applying energy and material efficient technologies and services. The Rio Declaration on Environment and Development [1], often called Rio Declaration, was approved in United Nations Conference on Environment and Development (UNCED), informally known as the Earth Summit, which was held in Rio de Janeiro in 1992. It consists of 27 principles intended to guide future sustainable development around the world, which implies the preservation and revitalization of the environment and its resources for the coming generations. One of basic postulates of sustainable development is the use of renewable energy sources (RES) which was elaborated in detail in Action Plan Agenda 21 adopted in the same conference.

Aside from the idea of sustainable development, the concept of applying RES has been supported by UN Framework Convention on Climate Change (UNFCCC) [2] adopted in the same Rio Conference, which entered into force in March 1994. The treaty prepared provisions for the Kyoto Protocol [3] in 1997 and the Marrakech Accords to the Kyoto Protocol in 2001, which defined the mechanisms for mitigation of greenhouse gas actions. Parties to the Kyoto Protocol (191 up to now) are obliged to contribute to the reduction of emissions of greenhouse gases at a global level and compared to emission levels in 1990. Bearing in mind the different economic development of the countries and their historical emissions, the UNFCCC draw a distinction between industrialized countries, listed in Annex I of the Kyoto Protocol, and non-Annex I countries. The Annex I countries committed themselves to a reduction of four greenhouse gases (carbon dioxide, methane, nitrous oxide, sulphur hexafluoride) and two groups of gases (hydrofluorocarbons and perfluorocarbons) produced by them, by 5.2% on average for the period 2008-2012, compared to 1990's level.

Also, under the Kyoto Protocol, a set of so called "flexible mechanisms" was established which supports Annex I countries to meet their GHG emission reductions. These are: market-based mechanism International Emission Trading (IET), and two project-based mechanisms: the Joint Implementation (JI) and Clean Development Mechanism (CDM). IET allows

Government-to-Government trading of Assigned Amount Units (AAU) between developed (Annex I) countries. JI enables the generation of Emission Reduction Units (ERU-represents 1 metric tonne of CO_2 equivalent reduced), which allows Annex I countries to implement emission reduction projects in other Annex I countries. In this way, the investor country gets emission certificates units realized by the project. CDM generates Certified Emission Reductions (CER) in countries without the emission reduction commitment (non-Annex I countries), which can be used in Annex I countries as a contribution to achieving their national reduction targets under the Kyoto Protocol. At the same time CDM needs to fulfill sustainable development criteria of non-Annex I countries, or contribute to those countries achievement of economic, social and environmental goals, through technology transfer and job creation.

Implementation of the Kyoto protocol in the Republic of Serbia

Republic of Serbia (at that time a part of Federal Republic of Yugoslavia) is a Party of UNFCCC from June 2001 although signed in 1997, while Kyoto Protocol entered into force in January 2008 (after ratifying in the Assembly in October 2007) [4], making it the last country in Europe to do so. The Republic of Serbia has status of non-Annex I Party to the Protocol, which means that it has no GHG emissions reduction commitments, but is obligated to contribute to global efforts on greenhouse gases emission reduction. The Republic of Serbia successfully submitted Initial (first) National Communication [5] to the Secretariat of the UNFCCC (GEF/UNDP project) in November 2010, in accordance with obligation which is prescribed in articles 4 and 12 of the Convention. Inventory of GHG, as a part of the Initial National Communication, was prepared for the reference years 1990 and 1998 according to International Methodology. Currently the Second National Communication is under development, and it will include inventory for reference year 2000. In addition, the Law on Air Protection adopted in 2009 requires GHG emission monitoring to be established and performed and the respective national inventory to be prepared. This inventory should be an integral part of the registry of emissions into the atmosphere of Serbia. The same Law predicted elaboration of the Framework Climate Change Strategy, with a corresponding Action Plan. Also, Republic of Serbia is actively participating in climate activities under the Regional Environmental Network for Accession (RENA), and GHG emission abatement action plan is developed until 2020 – including identifying a cluster of Nationally Appropriate Mitigation Actions (NAMA), and potential areas for carbon finance interventions. In this way, climate change is integrated into a broader development planning process of the country.

As the Republic of Serbia is a non-Annex I country, it is eligible only for CDM of three flexibility mechanisms. To become eligible for CDM projects implementation, it was necessary to establish a Designated National Authority (DNA), and it has been operational in Serbia since November 2008 [6]. This authority is responsible for evaluation and approval of CDM projects at a national level. CDM Executive Board (CDM EB) is responsible for registration of CDM projects at an international level. After National Strategy for Incorporation of the Republic of Serbia into Clean Development Mechanism under the Kyoto Protocol for waste, agriculture, and forestry sector has been approved by the Government in February 2010 [7] and corresponding Decree on Criteria and Procedures on Approval of CDM Projects and Programs was adopted, the institutional framework for hosting CDM projects in Serbia was ready. Up to August 2012, 8 projects were proposed for approval to Serbian DNA, all in energy field. In February 2012, the "Wind Farm Cibuk 1" was registered as the first project of the Clean Development Mechanism of Kyoto Protocol in Serbia approved by CDM EB. The project involves the construction of wind turbines with total capacity of 171 MW in the municipality of Kovin. Beside this one, 3 more projects were registered as well: Wind Farm Plandiste, Wind Farm Kosava and Reduction of Methane Leakages in the Gas Distribution Networks operated by the Serbiagas Company. Additional 4 projects are being considered by DNA Serbia: Wind Farm Kladovo, Alibunar Biogas Plant Construction Project, Recovery and Electricity Production at the Bubanj Landfill site, Nis, and Small Hydropower Programme of Activities in Albania and Serbia.

Carbon reduction potential in Serbia

Energy sector

Serbia is one of South-East European countries with a very unfavorable energy potential. Oil and natural gas indigenous resources are small, and exploitation reserves are estimated at 20 Mtoe. Due to coal exploitation reserves which are estimated at 2741 Mtoe, among which 2616 Mtoe is lignite, Serbia has relative energy self-sufficiency [8]. Also, total hydro potential in Serbia is estimated at 2.15 Mtoe (25,000 GWh) per year, whereof around 1.46 Mtoe (17,000 GWh) per year have been identified as technically and economically feasible and around 0.86 Mtoe (10,000 GWh) is already utilized.

Energy sector (production of electricity plus district heating) has an important economic role as the largest economic sector in Serbia, which makes more than 10% of GDP. At the moment, electricity makes 28% of total energy consumption, with total installed generation capacity of 7,124 MW (2011 year), excluding 1,235 MW installed in thermal power plants in Kosovo [9]. The aggregate capacity of six thermal power plants (TPP) with 18 blocks is 3,936 MW (55.25% of installed capacity), while 2.835 MW (39.8% of installed capacity) is in nine hydroelectric power plants (HPP) with 50 hydro units (31 units in run-of-river HPP with capacity of 1850 MW, 17 units in reservoir HPP with capacity of 371 MW and 2 units in pumped storage HPP with capacity of 614 MW) [10]. A small part of 353 MW (4.95% of installed capacity) is installed in combined heat and power plants (co-generation) which use natural gas and oil as fuel. Apart from this, approximately 461 MW_e is installed in industrial energy plants of more than 30 companies. However, significant portion of these production capacities is currently out of operation. The total share of generated electricity from TPP is much higher than their actual share in the installed capacities, as around 73.5% of electricity generation is obtained from local lignite-fired thermal power plants, approximately 25.5% is produced in large hydropower plants, and the rest of 1.0% is obtained from combined heat and power plants (year 2011) [11], but this can vary depending on hydrology.

Serbia's municipal district heating systems operate in 55 cities and towns with the installed capacity of around 6,800 MJ/s (thereof 3,000 MJ/s in Belgrade, which is about 44%), and total heat production of 7,000 GWh [12]. Approximately 17% of Serbian households are connected to the district heating system. The district heating systems are fuelled by natural gas (65%), heavy and light fuel oil (18%), electricity (2%), and coal (15%).

The current carbon intensity (emission of greenhouse gases per unit GDP) and environmental impact of the energy sector in Serbia is relatively high, mainly as a result of the use of domestic low calorific pit-mined lignite which is burned using old equipment without abatement technology, and has low efficiency of energy production and energy use. Lignite combustion generates 90% of energy related SO_2 and NO_x emissions, 65% of CO_2 emissions and roughly 67 kt of particulate emissions [13]. GHG emissions of Serbian energy sector are estimated at 31 million t CO_2 eq. (year 2010, without Kosovo), which is about 45% of Serbia's total CO_2 emissions. It is expected that the emissions of greenhouse gases will increase by about 10-13% by the year 2020 comparing to 2010, as a result of increased demand for electricity. In

2006, Serbia used 5 times the amount of energy to produce one unit of GDP compared to the EU average [14], also Serbian carbon intensity per GDP is 6.8 times the world's average and 10.8 times the average of the Organisation for Economic Cooperation and Development (OECD) [15]. As energy utilization is inefficient, Serbia ranks among the 20 most energy intensive and among the 10 most carbon intensive countries in the world in terms of GDP [16]. On the other hand, due to out-of-date energy production and distribution facilities, there is a great potential for energy efficiency and reduction of operational losses and emissions of greenhouse gases, which makes the energy sector the important sector in the future climate change regime. Mitigation potential through modernization and capacity increase of existing TPP and construction of new ones using advanced ultra super-critical technology instead of conventionally used sub-critical and closing some old TPP which operate with low efficiency is above 3 Mt CO_2 eq. [17]. Additional 1 Mt CO_2 eq. can be achieved through increasing the capacity of combined heat and power plants, and 800,000 t CO_2 eq. through the modernization of existing district heating systems. With additional measures in building sector like thermal insulation of building walls, replacement of the existing lighting systems with more efficient ones, as well as the windows in the households and public buildings, total mitigation potential in energy and building sector is estimated at 12.5 Mt CO_2 eq./year [18].

Renewable energy sector

Hydroelectric potential

As it was mentioned earlier, out of 17,000 GWh (1.46 Mtoe) per year of total technically exploitable hydro potential in the Republic of Serbia, about 10,000 GWh has been activated so far, *i. e.* somewhat around 59%, almost all in big hydropower plants. In currently unexploited hydroelectric potential, about 1900 GWh/year (over 25%) of technical potential refers to small hydro plants (less than 10 MW) [8], on about 900 potential locations on rivers in Serbia including even small rivers, with about 600 MW of possible installed power. Out of 69 existing small hydropower plants in Serbia, 31 are currently operational with total installed capacity of 34.65 MW and annual production of 175.4 GWh/year (15,000 toe) [19]. This is 9.2% of its technically usable potential. Little progress in development of small hydropower plants is predicted for future, as the revitalization of 17 old and construction of 18 new plants is planned, with total capacity of 80 MW.

When RES and climate change are considered in the same context, the analysis is usually focused on the impacts RES might have on mitigation of climate change. But future climate changes might impact energy generation from RES. The biggest influence is expected in hydroelectric potential. Due to projected reduced precipitation, production of electricity in HPP in the nearby region is expected to decrease by 10-35% in the summer period 2080-2100 years comparing to the average production in the reference period 1961-1990 [20].

Geothermal energy

Serbia is a country with the largest potential for geothermal power generation in the region, and with the largest number of sites. There are data on 160 geothermal springs, mainly on the territory of Vojvodina, Posavina, Macva and Central Serbia, with temperature ranging from 15 °C to 96 °C, which could be used for both electricity and heat production. More than 50 locations have potential greater than 1 MW. The estimates of total potential of geothermal energy in Serbia are approximately 800 MW_t which can produce around 0.2 Mtoe [21]. This is comparable to the potential of small watercourses, but far less than biomass energy potential. The use of geothermal energy is low compared to its potential. The total installed energy use is 83 MW_t, out of which 36 MW_t are in balneology, and 47 MW_t for other types of uses like agriculture, and space heating, with additional 6 MW_t of thermal water heat pumps. Geothermal energy saves approximately 5000 t of crude petroleum per year (0.00492 Mtoe in 2009, 0.0053 Mtoe in 2010).

Biomass

Agriculture is considered to be an important sector of the Serbian economy accounting for about 20% of total employment and 8.3% of GDP. Total area of the Republic of Serbia amounts to 7.8 million ha and agriculture land occupies the area of 5.1 million ha, out of which 1.55 million ha is grassland, 3.35 million ha is arable land cultivated with various crops and about 0.2 million ha is left fallow every year [22]. Regarding forestry, it is estimated that the wood stock occupies about 362.5 million m^3 of more than 2.25 million ha of total forest area in Serbia and net annual increment of forest biomass is 9.079 million m^3 [23]. Agricultural residues and waste residues in the forestry sector are a source of considerable biomass quantities that can be used for energy production.

Among the different types of biomass energy feedstock available in Serbia, agricultural residues include field crop residues and arboricultural residues. Biomass residues from forestry include bark, twigs, tree stumps, and leftover cuttings from logging operations. Unfortunately, due to poor forest management and lack of high quality roads, most of the wood residue from logging operations is simply left to rot and the wood residues are not utilized for any productive purpose. Also, residues from wood processing in saw mills are often left unutilized too, as well as almost all agricultural residues.

Unfortunately, the traditional use of biomass as source of energy which has existed in Serbia for a long time is mainly limited on wood as a fuel for direct combustion, which in the majority of cases is characterized by a very low rate of utilization and is not ecologically justifiable. It is estimated that about 1.23 Mtoe of energy is produced using renewable biomass in 2009 [24, 25], mainly for heating and cooking purposes in households and buildings in rural and suburban areas and not for electricity generation. This amount is 4.4 times higher than the value of energy from fuelwood which is contained in the energy balance of Serbia for 2009 (0.276 Mtoe) [26]. The main reason for such a large difference between the values contained in energy balance and actual value of consumed energy from wood fuels in Serbia is a result of the lack of data on overall consumption of wood fuels. Namely, official statistics calculates energy value of fuelwood only from officially registered amounts out of which mostly in state forests. However, the largest part of fuelwood amounts produced in private forests as well as fuelwood amounts outside forests are not recorded, thus they could not be included in Serbian energy balance.

Serbia has around 1.97 Mtoe of technically feasible unused potential based on agricultural and wood biomass, which makes 51.4% of all unused renewable energy sources in Serbia. Agricultural biomass holds the greatest potential with 1.67 Mtoe [7], followed by biomass from wood residues in the forestry sector of 0.3 Mtoe [25]. It is obvious that there is considerable potential of agricultural and wood based biomass in Serbia, and that high contribution to environment can be provided by using biomass instead of other types of fuels due to much lower quantity of CO_2 emitted in course of their combustion. That is not the case with other types of fuel and especially not with fuel oil and coal. In this context, CDM can be used to leverage financing for the construction of biomass power plants using agricultural and forestry residue.

Another significant potential source of energy can be animal manure (livestock residues). Animal manure, including poultry litter, can be used for heat and electricity generation, as they can generate biogas rich in methane (CH_4). The current practice in Serbia is that it is directly disposed of in water basins, where it is treated by aerobic digestion. As methane emissions from its decomposition are negligible, environmental friendly fertilizer is produced in this way and it is very often spread directly over agricultural land or used for other purposes of local farmers. Instead of this, the treatment of manure in anaerobic digesters can generate large volumes of methane, which can be further used for both heat and/or electricity generation. Also, these anaerobic digesters guarantee a relatively stable supply of biogas for energy applications. Estimation based on the number of animals has shown that production of biogas in this way may be up to 42,240 toe in great and medium farms only [27], while the installed capacity of power plant should be up to 80 MW_e. Carbon saving potential, taking into consideration only CH_4 emission reduction from pig residues management sector, may be estimated at 800 kt CO_2 eq annually [18]. In this respect the revenues from the sale of carbon certificates can be an incentive for introducing more advanced and environmentally friendly measures.

In addition, biomass energy from municipal solid waste (MSW) has potential in Serbia. According to the EU legislation (Directive 2009/28/EC) energy produced from the biodegradable fraction of MSW is considered as renewable source. The theoretical potential of MSW component which is biological origin is estimated at 0.22 Mtoe [28].

Solar energy

Total potential of solar energy in Serbia amounts to 7,450 GWh (or 0.64 Mtoe) [29], based on average yearly insolation of about 1400 kWh/m^2 (which is significantly higher than in many European countries, the average for Europe is about 1000 kWh/m^2), and average daily value of about 3.8 kWh/m^2 [30] with the planned estimation that every housing unit install approximately 4 m^2, which would represent in total 10.6 million m^2. Although solar thermal units are used for water and space heating in domestic and tourist sector in Serbia, systematic inventory of its potential applications is unavailable. Because of small installed photovoltaic (PV) capacity, solar power energy generation in 2012 was estimated at 0.3 GWh, which is considered negligible comparing to its potential.

Wind energy

Wind power potential in Serbia is significant, mainly in the Eastern parts of Serbia, Pannonian plain and some mountain regions. The area with suitable winds covers 471 km^2, and an area of 224 km^2 is identified as the area where average wind speed is above 6 m/s for 50% of time during the year [31]. Although further studies and investigations are required, some estimates based on the data collected by the Serbian Hydro-Meteorological Office indicate that approximately 1,300 MW capacity at sites with average wind speed of 5 m/s or greater could be installed in Serbia, with the potential of 2300 GWh/year (about 0.2 Mtoe).

Waste sector

Regarding the waste sector, the highest GHG emission reduction potential is in the municipal waste sector (MWS). Landfills are a primary waste disposal method in the Republic of Serbia. Municipal waste, including hazardous waste generated in households, is usually disposed directly to landfills, without further management or treatment. Currently, Serbia has 164 officially registered municipal waste landfills, whose capacity has already been reached in most municipalities [32]. Most of them do not meet the minimum prescribed requirements for sanitary landfills, as they do not have bottom sealing to prevent the pollution of soil and aquifers. Also, leachate produced from landfills is neither collected nor treated. The problem of landfill gas is resolved only in some landfills with out-of-date extraction units. In addition to the registered landfills, at this moment there are more than 3250 (year 2010) illegal dumpsites (4600 in 2009 year) of various sizes all over the country, which receive about 40% of MSW generated in Serbia. The Serbian waste sector is facing the challenge of establishing 26 regional sanitary landfills.

Carbon potential depends on the possibility of recovering methane from the landfill body. Landfill gas production and recovery rate can be calculated based on the date, on the quality of municipal solid waste from all existing landfills and/or dumpsites, both the operating ones and the closed ones. Although it is very difficult to estimate landfill gas production as methane production varies according to numerous factors on the dumpsite, on average, it is possible to assume that 200 Nm^3 of landfill gas is formed per ton of communal waste for about 20 years. For the total yearly amount of 2.2 million tons (in the entire Serbia) and landfill filling times of 20 years, about 8,800 million Nm^3 of landfill gas would be generated [31]. If only about 10% of the gas was collected, 880 million Nm^3 of landfill gas would be available, *i. e.* an average yearly amount of 44 million Nm^3, *i. e.* 5,500 Nm^3/h. This amount of gas would enable yearly production of approximately 88 GWh of electric power and 100 GWh of heating energy in combined gas engines, which corresponds to 16,165 toe. In addition, approximately 2,750 Nm^3/h of methane, *i. e.* 15.8 kt of methane per year would not be emitted into the atmosphere, which corresponds to carbon potential of 332 kt CO_2 eq. per year. Taking into account all other gasses, it is estimated that carbon potential in waste sector in Serbia is about 410 kt CO_2 eq. per year [33].

Land use, land-use change, and forestry (LULUCF)

LULUCF is defined as greenhouse gas inventory sector that covers emissions and removals of greenhouse gases resulting from direct human-induced land use, land-use change and forestry activities (related to soils, trees, plants in general, biomass and timber). This means in principle all human activities that take place on agricultural land, forested land, wetland and peat land which result directly in emissions or removals of greenhouse gases, such as draining of peat land, felling of forest, ploughing up grassland for growing crops, forestation, reforestation and deforestation, as well as forest management, cropland management, grazing land management and re-vegetation. As it is often difficult to estimate reductions of greenhouse gases achieved or to estimate emissions resulting from other changes to land use, LULUCF activities are subject to specific rules under the Kyoto Protocol. Globally, forests represent a significant carbon stock. They store 44% of carbon in the biomass, 6% in dead wood and 50% in soils (top 30 cm). The total content of 638 Gt of carbon in the forests worldwide is more than the amount of carbon in the entire atmosphere [34]. This standing carbon is combined with a gross terrestrial uptake, which was estimated at 2.4 Gt of carbon a year, a good deal of which is sequestration by forests.

In Serbia, 65% of the territory is considered to be agricultural land, forestland occupies 28.8% of the territory out of which most of it is degraded forest, while other land types comprise the remaining 6.2%. Additionally, private forest areas are very fragmented and it is difficult to manage such small and fragmented forests on a sustainable basis. Activities such as the enlargement of forest area by afforestation and the increase of the annual biomass by improving the forest structure can lead to the generation of carbon certificates. Plans exist for significant land use change (afforestation/reforestation) of some 1.3 million ha of vacant and abandoned agricultural land in the long term, but currently less than 2000 ha are being planted annually [7]. Through the improvement of forestry sector, it is possible to achieve the estimated emission reduction of 600,000 t of CO_2 and the production of 400,000 m^3 of wood per year [35].

Current use of renewable energy sources

The share of renewable energy sources in total primary energy production in Serbia amounting to 10.441 Mtoe in 2009 [26], including large hydropower plants, was 2.193 Mtoe (with 1.23 Mtoe estimation for biomass instead of 0.276 Mtoe), which makes about 21%. The estimation of technically feasible unused potential of RES, and the production of energy in the year 2009 are given in tab. 1. The renewable energy sector in Serbia is considered to have technically feasible unused potential of about 3.83 Mtoe per year. Similar assessment for share of renewable energy sources and total RES potential (used and unused) in Serbia can be found in [25] and [36]. The biggest potential in renewable energy generation is in biomass and hydropower. Solar energy can also play a significant role due to the high intensity and durability of solar radiation, as well as geothermal and wind potential.

Carbon potential for any electricity generation technology would be difference between quantity of possibly emitted CO_2 into atmosphere from conventional energy sources and the technology for the same energy quantity. To calculate how much CO_2 would be saved if the same amount of electricity would be produced from RES instead of conventional energy sources in the same trend of energy production, a complete picture of the emissions caused by electricity generation technologies should be provided, and all stages of their life cycles must be considered. These include their construction and maintenance; the extraction, processing, and transport of their fuels (if applicable); and their ultimate decommissioning and disposal. By combustion of all technically feasible unused potential of biomass and transfer into electricity, around 7,391,446 tones CO_2 (estimated average greenhouse gas emissions expressed as CO_2 equivalent for individual energy generation technologies or average carbon footprint for biomass during burning is 285 kg/MWh [37]) would be emitted into atmosphere for energy quantity of 2.23 Mtoe (25934.9 GWh). If, instead of biomass, conventional energy sources would be used for the same electricity quantity, according to the value of carbon emission factor (CEF) of Serbian national power grid which is CEF = 945 kgCO_2/MWh [38], the quantity of emitted CO_2 into atmosphere would be 24,508,480 tonnes or almost 3.316 times more. At the base of estimated CO_2 equivalent emissions for other individual RES energy generation technologies [39], theirs carbon potential, *i. e.* reduction in CO_2 emission when they are applied for production of same energy quantity instead of conventional energy sources is possible to calculate in the same way. Calculated values of carbon potential for all RES based on theirs estimated technical potential and specific CO_2 emission factor (CEF) for Serbia is given in tab. 1.

Table 1. Technically feasible unused potential of renewable energy sources, average CO_2 equivalent emissions for individual energy generation technologies (carbon footprint), carbon potential based on this technical potential and specific CO_2 emission factor (CEF) for Serbia, and production of energy from RES in the year 2009

		Unused potentials [Mtoe]	Carbon footprint [kg per MWh]	Carbon potential [kt CO_2 eq. per year]	Production in 2009 [Mtoe]
Biomass		2.23	285	17,117	1.23
Hydropower	Large	0.40	41	4,205	0.943
	Small	0.16	41	1,682	0.015
Solar		0.64	90	6,364	–
Geothermal		0.20	170	1,802	0.00492
Wind		0.20	25	2,140	–
	Total	3.83		33,31	2.193

Table 2. Technically feasible unused potential of renewable energy sources, minimum and maximum CO_2 equivalent emissions for individual energy generation technologies (carbon footprint), and maximum and minimum carbon potential based on this technical potential and specific CO_2 emission factor (CEF) for Serbia

		Unused potentials [Mtoe]	Min. carbon footprint [kg per MWh]	Max. carbon potential [kt CO_2 eq. per year]	Max. carbon footprint [kg per MWh]	Min. carbon potential [kt CO_2 eq. per year]
Biomass		2.23	60	22,952	365	15,042
Hydropower	Large	0.40	1	4,391	237	823
	Small	0.16	1	1,756	237	1,317
Solar		0.64	12	6,944	286	4,905
Geothermal		0.20	170	1,802	735	488
Wind		0.20	4	2,188	128	1,900
	Total	3.83	–	40,033	–	24,475

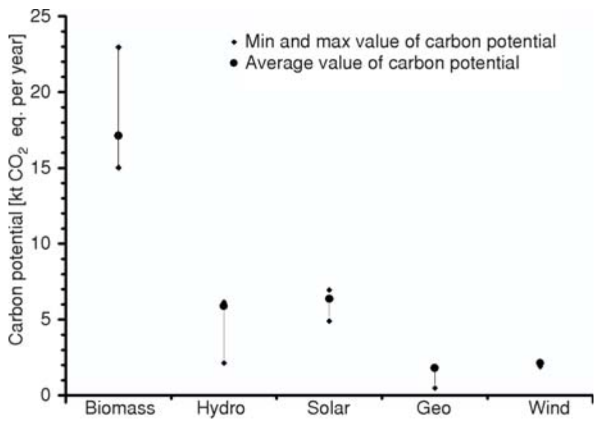

Figure 1. Minimum, average, and maximum estimated values of carbon potential for all RES

Different values of carbon potential for the same values of unused potentials of RES is possible to calculate if instead of average carbon footprint value minimum and maximum estimated values of footprint data are applied [39]. These values are given in tab. 2, together with maximum and minimum carbon potential based on this technical potential and specific CO_2 emission factor (CEF) for Serbia. Also, average carbon potential as well as minimum and maximum estimated values of carbon potential for all RES in Serbia are given in fig. 1.

Table 3. The difference in consumption of energy from renewable sources in gross final energy consumption in 2020 year, compared with the consumption of energy from renewable sources in gross final energy consumption in 2009 year, and its influence on used carbon potential

		The difference in consumption of energy in 2020 year, compared with 2009 year [ktoe]	Used carbon potential [kt CO2 eq. per year]
Biomass		216.4	717.27
Hydropower	Large	95	45.3
	Small	51	24.3
Solar		11	21.74
Geothermal		86	25
Wind		6	6.3
	Total	465.4	839.91

According to the Energy Community Treaty with the EU [40], the Republic of Serbia has accepted the obligation to increase the use of renewable energy sources and to implement measures for improvement of energy efficiency. Because of this, National Renewable Energy Action Plan (NREAP) up to 2020 [41] analysed how Serbia can reach the goal that the share of renewable energy in gross final energy consumption would amount to 27%. This scenario involves the implementation of measures for improvement of energy efficiency together with the use of renewable energy sources, which is compared with referent case when measures of improvement of energy efficiency and the use of renewable sources have not been considered. This paper also analyzed the impact of the scenario in NREAP, which contains the measures for improvement of energy efficiency, and in this way has influence on the total carbon potential. In this analysis, energy production from renewable energy sources in 2009 was chosen for the base. Results of this analysis are given in tab. 3.

Results from tab. 3 show that the considered scenario contributes to reducing of overall carbon potential for 839.9 kt CO_2 eq per year. If it is assumed that the production of energy from renewable energy sources in 2020 year will be unchanged until 2030, this would reduce greenhouse gas emissions emission in period 2020-2030 for 8.4 Mt CO_2 eq.

Although renewable energy sources can play a significant role in satisfying the energy need in Serbia, at this moment apart from large HPP and wood used for heating, current use of other renewables is very low, only 1.5% of total electricity production.

The only investments in RES over the last years were in small hydropower plants, several isolated attempts of generating energy from waste, wind, geothermal and other sources, and one large business venture in first generation bio-fuels (Victoria Oil), which was abandoned after 1 year of operation. The new small hydropower plants which were recently built are: two in Crna Trava with capacity $P = 450$ kW and 640 kW, Vlasotince with $P = 700$ kW, Uzice with $P = 400$ kW, Kursumlija with $P = 350$ kW, and Aleksinac with $P = 250$ kW [42]. Revitalization of hydro power plant Ovcar Banja (7.8 MW) is underway and Meduvrsje 7.6 MW is next planned for revitalization [10]. Regarding wind energy, there is only one wind turbine in operation (Tutin, $P = 500$ kW capacity), but it is expected that the first 102 MW installed in Plandiste 1 wind farm (40 wind generators) will become operational until the end of 2014. As for the solar energy, two big solar power plants exist: in Merdare with 2 MWp maximum power and in Leskovac with 260 kWp maximum power, and a few small ones: in Prokuplje with $P = 73.6$ kW, in Belgrade with $P = 5.1$ kW, in Varvarin with $P = 5.1$ kW, and in Kula with $P = 5.1$ kW. Last 3 photovoltaic plants were installed on 3 secondary school roofs. They are the first solar power plants connected to the grid in Serbia. After a year and a half of exploitation, electricity production in each school has been in the range from 5800 to 6500 kWh per year a [43]. Biomass boilers were installed in several agricultural companies, and in some saw mills.

For average carbon footprint values, a preliminary analysis estimates the carbon abatement potential of the country is more than 46 Mt CO_2 eq. per year (tab. 4). Considering the current market carbon certificate price between 5 and 1 EUR/t of CO_2 eq. in 2012 [44], the resulting potential investment to mitigate greenhouse gas emissions can be expected to range between 46 and 230 million EUR per year. Also, even if minimum value of carbon

Table 4. Estimation of the carbon abatement potential (CAP) in Serbia

Total estimated potential	CAP [kt CO_2 per year]
Energy sector	12,500
Renewable energy	33,310
Waste sector	410
LULUCF	600
Total	46,820

potential of 24,475 kt CO_2 per year is taken into consideration, the share of renewable energy in total carbon abatement potential is significantly higher in comparison with all other sectors.

Conclusion

Renewable energy sources are directly related to the energy sector, but closely corresponding with some other sectors (agriculture, tourism, forestry, *etc*.). The total technically feasible unused energy potential of renewable energy sources in Serbia is estimated at more than 3.83 million toe. Although Serbia obviously has significant potential, it produces poor results in applying renewable energy sources. The main problem is low motivation of energy consumers because of relatively high investment costs in renewable energy technologies, and long administrative procedures. Especially low electricity price (at this moment around 5 Euro cents per kWh) presents a constraint for the development of renewable energy generation. The necessary economic programme that would support the use of green energy is also lacking.

As the energy sector is a major polluter and the energy produced is not used efficiently and energy intensity is very high, increased use of renewable energy sources and rational use of energy, *i. e*., increase in energy efficiency would have the greatest role in climate change mitigation activities in Serbia. The analyses showed that the production of energy from RES is one of the most successful ways for Serbia to comply with Kyoto protocol requests and achieve the adequate stage of sustainable development. Because of that, the Government of the Republic of Serbia has been putting in place policies and measures to reduce GHG emissions, whose important part are energy efficiency measures and the use of RES through price support scheme (feed-in tariff system) for electricity production from renewables with the purpose to promote investments in renewable energy projects in Serbia. Apart from feed-in tariff support scheme, there are also other investment incentives.

Although the Kyoto Protocol entered into force in the Republic of Serbia relatively late compared to other Balkan countries, the country revealed interesting CDM project potential. Apart from RES, Serbia also has potential in energy sources like landfill gas, sewage treatment plant gas, biogas and biofuels, and LULUCF. As Serbia has large, unexploited, carbon potential, revenues from carbon certificates may present an alternative incentive for the use of renewables. The implementation of CDM projects in Serbia could significantly contribute to the modernisation of the country's existing economic structure, as revenues from the sale of carbon certificates may have significant impact on the financial sustainability of projects and can lead to the inflow of international investments together with the transfer of clean technologies.

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