Positive and Negative Impacts of Renewable Energy Sources

Review

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Abstract *– In this paper, positive and negative impacts of renewable energy sources are presented. Impacts of solar power, biomass power, fuel cells, hydro power, wind power and geothermal power are described. Ecological, social and political impacts of different renewable energy sources are described. Impacts of power plants using different renewable energy sources on the power grid are also described.*

Keywords *– ecology, impact, power grid, renewable energy sources.*

1. INTRODUCTION

Unlike conventional energy sources which require millions of years for formation, renewable energy sources (RES) are sources that constantly renew throughout the human lifespan. Nowadays, RES is a term used for electricity or heat generated from solar, hydro, wind, geothermal, biomass or biogas energy.

The main advantages of RES are inexhaustibility, and an impact on the environment. The main disadvantage of RES are low energy density and the technology in development. In fact, the technology of exploitation of RES has become popular only in the last few years, in contrast to conventional power plants that develop from the beginning of electricity production.

In Section 2, environmental impacts, sociopolitical impacts and impacts on the grid of photovoltaic systems, solar thermal power plants and solar thermal systems are described. Section 3 deals with environmental impacts, sociopolitical impacts and impacts on the grid of biomass power plants. In Section 4, impacts of fuel cells on the environment, the grid and social and political activities are shown. Section 5 deals with impacts of hydro power on the environment, the grid and social and political activities. In Section 6, environmental impacts, sociopolitical impacts and impacts on the grid of wind power plants are described. Section 7 deals with environmental impacts, sociopolitical impacts and impacts on the grid of geothermal power plants. The conclusion gives a summary of impacts of different renewable energy sources on the environment. The status of different renewable energy sources in Croatia is also presented.

2. SOLAR ENERGY

Solar energy is most commonly exploited in three ways [1]:

- Photovoltaic systems – for electricity generation;
- Solar thermal power plants – to obtain electricity and heat;
- Solar thermal systems – for thermal energy.

2.1. PHOTOVOLTAIC SYSTEMS

A photovoltaic (PV) system generates electricity directly from solar energy radiation. Photovoltaic systems (PV cells) are based on semiconductor materials such as silicon in a variety of designs and semiconductor compounds such as GaAs or CdTe, which are less widespread.

PV systems do not emit greenhouse gases in electricity generation. Building-integrated PV systems have a minimal impact on the environment and landscape. Larger PV plants are often built on free land or agricultural land. In that case, their impact on land is expressed in terms of flora and fauna, respectively. Maintenance of land covered with PV modules involves complete or partial removal of plant life which is drastically disrupted. There are also indirect impacts on wildlife (habitat change, food, etc.). PV modules require periodic maintenance by washing the absorptive surfaces, thus polluting the water. Manufacturing of PV modules requires large amounts of energy. Impacts of power plants producing energy needed for manufacture of PV modules are also listed as negative impacts of PV plants. Also, emissions during transport are listed under negative impacts [2] [3].

Positive effects of these types of power plants are far more significant than the negative ones. In PV electricity generation, there are no CO_2 and greenhouse gas emissions. During power plant operation, there is neither emission of particles that cause respiratory problems in humans and animals nor emission of heavy metals such as lead (Pb) nor noise [2][3].

Sociopolitical impacts: PV systems are constructed often in all developed countries, especially on the roofs of buildings. This opens up jobs in PV system fabrication and installation, encouraging thereby regional development and reducing the demand for electricity from conventional sources. PV systems have become standard in areas where there is no access to the electricity network (cottages, etc.). PV systems can be easily incorporated into smart grid models. A big problem with those systems are the investment costs, which are relatively high. The reason for a slow rate of development in the Republic of Croatia are the quotas that limit power supply connection to only 5 MW per year. The reason for this is the lack of money in the state budget for the promotion of RES. Fig. 1 shows locations of PV systems installed by 2014.

The impact on the grid: PV systems are connected to the distribution network. One of the advantages of these systems is the short-circuit current that is slightly higher than the nominal, which reduces investments in safety equipment.

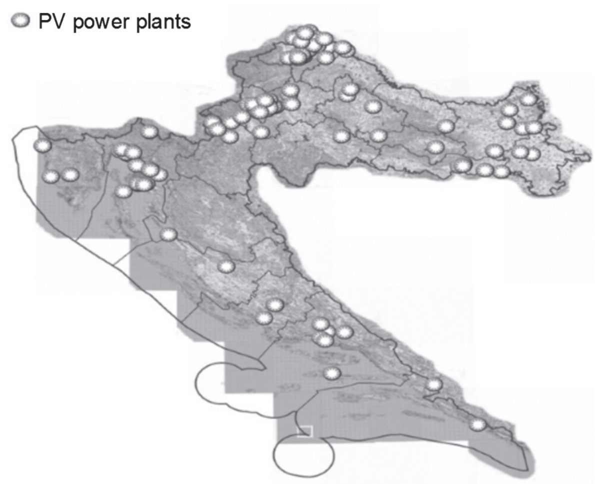

Fig. 1. PV power plants in Croatia built by 2014 [4]

When measuring power quality (EN50160) by connecting a PV plant, in most cases noticeable harmonic distortion can be seen, but within limits. This is due to power electronics in the inverter and nonlinear loads in the household. Also, at THD, voltage is not ideal; there is little distortion. PV power plants have a negligible impact on the voltage asymmetry, but it still exists [5] [6].

2.2. SOLAR THERMAL POWER PLANTS

There are three basic designs of solar thermal power plants, i.e.:

- Solar thermal power plants with parabolic collectors,
- Solar thermal power plants with a central tower,
- Solar thermal power plants with parabolic dishes.

In all three versions, water is heated (evaporated), and the rest of the plant is based on classic steam power plants [1].

Environmental impacts: Solar thermal power plants occupy a large area and the impacts on land and wildlife are similar to those of PV systems. These power plants are built for high power and they greatly reduce CO_2 emissions which can be seen in Fig. 2. In a hybrid version, CO_2 emissions are increased.

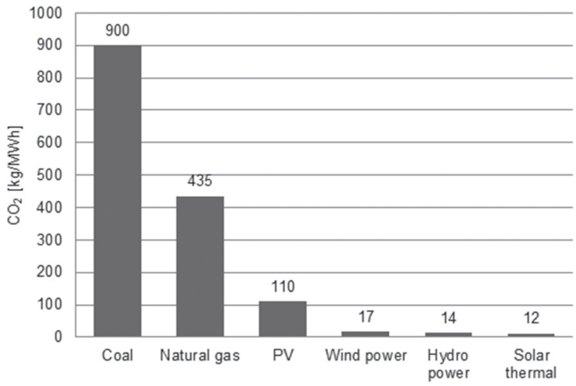

Fig. 2. Specific emissions of carbon dioxide (CO_2) for different power plants [1]

Unlike PV systems, large volume of water is required for cooling or as a working fluid, or for washing reflective surfaces which affects water quality. The reflected rays of sun can cause sunburn to the birds flying near the towers. They are built in desert areas, which further reduces the impact on wildlife.

Sociopolitical impacts: This type of power plants can supply electricity to smaller cities; therefore, they can be the basis of regional development. They provide much greater employment opportunities due to greater complexity of the plant in relation to PV systems. Also, they may be partially equal to conventional power plants of medium size, and hybrid versions can be completely equal.

Currently, there are no solar thermal power plants in Croatia.

Impacts on the grid: Solar thermal power plants have the same working principle as steam power plants; therefore, they are completely equal to conventional power plants in terms of the quality of electrical energy. Time-of-day dependence can be eliminated by a hybrid version of the plant, where natural gas is mostly used for heating water at night and cloudy days during the year. These power plants are built more often in desert areas, which requires an additional transmission grid to populated areas [7].

2.3. SOLAR THERMAL SYSTEMS

A solar thermal system is a system that uses solar energy to produce energy for heating or for hot water. Environmental impacts: Water is heated exclusively by solar energy; there is no need for fuels and combustion, which makes these systems environmentally friendly. Problems occur due to higher needs for hot water where the collectors are placed on the land. The time of day is also a major problem with these systems. Insulated containers are needed for storing water in bad weather conditions. There are hybrid versions with gas or electricity, where the problem of the lack of radiation is eliminated.

Sociopolitical impacts: Solar thermal systems provide employment opportunities during the construction of the system and later in maintenance. In Croatia, solar thermal systems are mostly installed in parallel with PV systems in order to acquire greater privileged electricity prices. In warm months during the year, these systems may completely reduce the cost of heating domestic hot water. The problem is the initial investment, which is quite high in comparison with the standard of the Republic of Croatia.

The potential for solar thermal systems in Croatia is very good (1.2–1.6 MWh/m^2, a year). According to [8], energy production from solar thermal systems is 183 TJ/year. According to the Energy Strategy of the Republic of Croatia, the target is installation of 0.225 m^2 of solar collectors per capita by 2020.

3. ENERGY OF BIOMAS

Biomass is the most complex form of RES because it covers a wide raw material base; the location of biomass energy usage can be separated from the location of biomass production. Biomass energy can be exploited in three different ways, i.e.:

- Biomass power plants;
- Biogas power plants;
- Biofuels (biodiesel and bioethanol) [9].

3.1. ENVIRONMENTAL IMPACT

Biomass power plants are based on the same principle as conventional power plants, what is different is the type of fuel. It uses various remains of forestry, agriculture and livestock, which are directly burned or gasified. Unlike other RES, these plants have direct emissions of greenhouse gases and particulate matters, but they take into account continuous renewal of fuel, the amount of produced CO_2 is equivalent to consumption in the process of photosynthesis. Large land areas are needed to grow biomass in any of the forms which has a direct impact on the eco-world in those areas (herbicides, pesticides, fertilizers) [10]. For the production of biofuels (biodiesel and bioethanol), a large area of cultivable land is needed. For the production of biodiesel waste, edible oils are also used. Greenhouse gas emissions are reduced depending on the concentration of biofuels in classic fuels.

3.2. SOCIOPOLITICAL IMPACTS

Biomass energy provides great opportunities for the development of rural areas and employment in those areas. Of all RES, this type has the highest employment potential in production and preparation of biomass, power plant construction, management and maintenance of power plants. The same holds for biofuels. The disadvantages are the noise of machines and jobs in the plants, often unpleasant smell, and the fact that these plants are unacceptable for urban centers.

3.3. IMPACT ON THE GRID

As already stated, these plants are based on conventional ones, but built for lower power because of bad characteristics of the fuel; therefore, the impact on the network is the same as in conventional power plants. They offer the possibility to build smart grids. Plants are usually connected to the distribution network, depending on plant power. Voltage profile is improved and transmission costs are reduced in rural areas.

According to the Energy Strategy of the Republic of Croatia, the potential of biomass energy is as follows: forestry 71 PJ, agriculture 23 PJ and biofuels 9 PJ. The goals of the Energy Strategy of the Republic of Croatia referring to biomass energy by 2020 are: 85 MW in biomass power plants (30 PJ), 340 000 t/year of biofuels (9 PJ) and 2.6 PJ in biogas. Fig. 3 shows locations of biogas, landfill gas and biomass power plants installed by 2014.

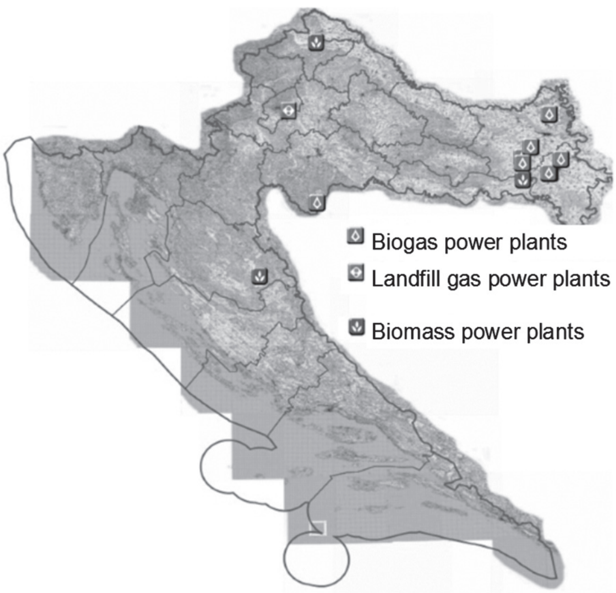

Fig. 3. Biomass power plants in Croatia built by 2014 [4]

4. FUEL CELLS

A fuel cell converts chemical energy of a fuel into electricity directly, with no intermediate combustion cycle. Since there is no intermediate 'heat to work' conversion, the efficiency of fuel cells is not limited by the second law of thermodynamics, unlike conventional 'fuel → heat → work → electricity' systems. The efficiency of conversion from chemical energy to electricity by a fuel cell may theoretically be 100% [11]. The impact on the grid will be skipped due to the lack of information and an unexplored area.

4.1. ENVIRONMENTAL IMPACT

From an environmental point of view, fuel cells are very acceptable because during their work there is no emission of harmful gases and particles. A by-product of fuel cell operation is water that is produced by a chemical process. They produce electricity and heat simultaneously and this is the CHP, the system has operating efficiency up to 90%, waste heat is kept to a minimum, and thus the impact on the eco habitat in water used for cooling.

The biggest problem is the production of hydrogen which requires large amounts of electricity produced by fossil fuel power plants. Therefore, negative impacts of fuel cells are often attributed to effects of conventional power plants necessary for the production of hydrogen. A concept has emerged lately about producing hydrogen at night using excess electricity produced by wind turbines (possibly other RES) to completely eliminate negative effects.

4.2. SOCIOPOLITICAL IMPACTS

The main reason for the slow implementation are high costs of plant construction and energy production. Plant construction and operation open up job positions in almost all technical activities. Fuel cells have recently become more interesting in the automotive industry, even more than in electricity generation. Almost all major car brands have their own models of fuel cell cars and will soon move to serial production.

The impact on people is almost negligible; the noise is reduced to a minimum because there are no strong vibrations. They are visually similar to conventional plants [12].

5. HYDROPOWER

Hydropower represents all kinetic and potential energy of water suitable for electricity generation. Hydropower implies river flows, wave energy and tidal energy. Hydropower (in terms of large hydropower plants) is the only renewable energy source with power generation costs competitive to fossil fuels.

5.1. HYDROPOWER PLANTS

Hydroelectric power plants are plants used for electricity production from water power. This means that it uses the conversion of potential and kinetic energy of water into electricity.

5.2. SMALL HYDROPOWER PLANTS

Small hydropower plants are plants up to 10 MW, and they typically deliver electricity directly to the grid. These plants require special construction of individual components, such as the water supply pipe for the engine and the generator.

According to the type of a network, they are divided into those with:

- a centralized network;
- an isolated network (off-grid networks);
- some factories for their own production.

Environmental impacts: Ecological impacts of hydropower plants are big because, in addition to flooding of the habitat of some animals, they change natural watercourses and movement paths of wildlife around the plant and thus alter the ecosystem.

A problem occurs with dams; they prevent free movement of fish, and the solution is the construction of fish passages. Another problem is the minimum amount of water that is always needed in the bed during dry periods. Since there is no burning in these plants, no use of fossil fuels, except during construction, they are considered a clean energy source [13].

Sociopolitical influences: One of the biggest sociopolitical problems in relation to hydropower is displacement of people from flooded areas. What is positive in the construction of hydroelectric power plants in most cases is that it becomes a significant source of income for the local community. Access roads built because of the plant and local availability of energy greatly contribute to the economic development of the community.

Impacts on the grid: Attention should be paid to the voltage at the point of connection, as well as to the power flows in the low-voltage and medium-voltage branches which the plant is connected to. In addition to the parallel working mode, there is island mode operation of the plant, where it is necessary to take account of default regulations during commissioning. Short-circuit currents should be taken into account, too, because small hydropower plants increase short-circuit current levels, and their impact on short-circuit currents will be higher if a short circuit occurs closer to the plant.

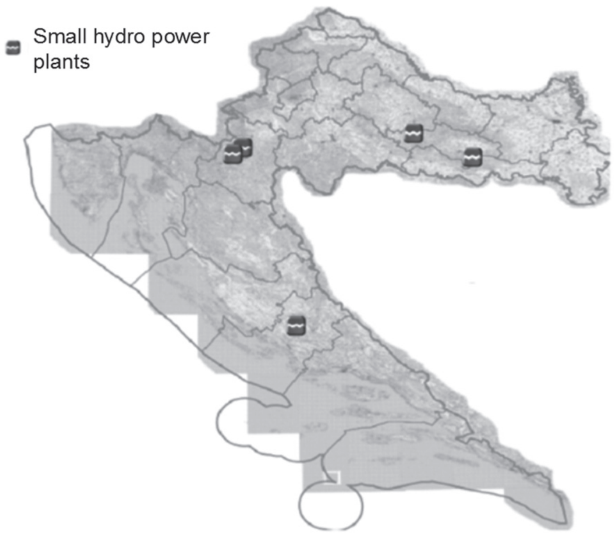

Fig. 4. Hydroelectric power plants in Croatia built by 2014 [4]

Fig. 4 shows locations of small hydroelectric power plants in Croatia built by 2014. Total technical potential of hydropower in Croatia is 12.45 TWh/year. Current use is 6.13 TWh/year. There are 67 potential locations for small hydropower plants (<5 MW) with the total capacity of 177 MW (568 GWh) [8].

5.3. WAVE ENERGY

Wave energy is the kinetic energy created by the movement of water masses caused by wind. Wave energy is mostly used in a float chamber in which it creates a change in pressure due to the action of the waves, the waves rise in the floating chamber and create overpressure in the chamber. The high pressure and the flow of air and water which enters the chamber are used to drive a turbine.

Environmental impacts: Wave energy converters remove energy from waves. This means that both nearshore bottom mounted devices and offshore floating devices will calm the sea. This will be broadly beneficial since it will protect the coast from waves. Wave converters will cause some disruption to the marine environment during construction but this should be short lived. Once in place, they should have little impact. There may be a visual impact and oscillating water column converters may generate noise from their air turbines. Floating devices are likely to be a hazard to shipping and sites will need to be selected that cause minimum disruption [14].

Sociopolitical influences: Energy produced using waves is used in regions along the sea and is a new and environmentally friendly energy source. The energy is better due to the proximity of the plant, and the independent production decreases dependence on imported energy.

Aesthetically, these plants do not violate the attractiveness of a location, the plants are at greater distances from the beach and the coast, and most of the plant is under water. The cables from the power plants are under water and buried in the ground, and the beaches are breached by horizontal drilling, so that the outer appearance is not altered in any period of plant operation. Also, it provides a certain number of jobs during plant construction and its operation [15].

Impacts on the grid: Before commissioning the plant, it is necessary to prove that it meets all necessary criteria referring to the quality of energy and stability. There is an issue of ongoing availability of energy from these plants because the waves that produce energy depend on the wind, and it can lead to a complete failure of the power plant. Due to variability in production, there is also a flicker problem.

Because of all these problems, numerous tests have been carried out and the conclusion is that every problem can be solved by using a good regulation [16].

5.4. TIDAL ENERGY

Tidal energy is the use of energy created by raising and lowering sea levels due to the influence of the Moon.

Environmental impacts: These plants have no emissions and contribution to acid rains. The construction of these power plants, reservoirs and dams can have harmful effects on local aquatic life, and on the appearance and structure of the coast. Research conducted in this area shows that the impact on aquatic life is minimal and that the impact on local ocean currents is not noticeable. The biggest impact is recorded on the appearance of the site.

In addition, there are problems of noise and disturbance in relation to the movement of fish. Swirling rotor blades represent a potential threat to small animals, and during repairs they greatly hinder local aquatic species [17].

Sociopolitical influences: The construction of these plants has no effect on humans. They only spoil the countryside, but they open up many other opportunities for the local population. Such power plant provides a certain number of jobs during the periods of its construction and operation. The energy in the plant becomes better and "cleaner", the population is encouraged to develop the area, and the need for engineers working at the plant improves the education of the local population, as well as the social status of the area itself. These plants are not common because they are not cost-effective. Compared to plants on rivers, these are much more expensive, but the power plants that have already been built showed the advantage of using water with higher density because it reduced the flow velocity needed to produce energy [18].

Impact on the grid: These plants are usually used to repair voltage states in the network due to the use of AC/DC/AC technology voltage and current levels are maintained very well. The voltage drop by the customers is reduced because these plants are closer to the user, but as high overloads may occur, it is necessary to limit their production. In addition, there are problems with flickers that are sent to the network, as well as an increase in short-circuit current in the event of a network failure [19].

6. WIND ENERGY

Wind is the movement of air in response to pressure differences within the atmosphere. Pressure differences exert a force which causes air masses to move from a region of high pressure to the one of low pressure. Such pressure differences are caused primarily by differential heating effects of the sun on the surface of the earth [14]. Wind energy is the kinetic energy of the movement of air dependent on the mass of air and the square of the wind speed.

6.1. ENVIRONMENTAL IMPACTS

Harmful effects of these plants on humans, animals and the landscape are discussed very often, but all these problems are solved by choosing a good location. The area which is occupied by one unit is 30 m^2 and the land between them may still be used for agriculture or livestock breeding.

The noise produced by the generators is a problem, but there are certain legal norms on the amount of noise they can produce in certain areas, and they are placed only there where they do not exceed the set standards.

One of the biggest ecological issues is an impact of wind turbines on bird populations. Birds can be injured or killed when they fly through blades of wind turbines. Current evidence on this issue shows that they offer only a small threat. According to [14], this could be considered more serious if a colony of an endangered species lived in the vicinity of a proposed wind farm, but birds do seem to learn to take account of wind farms.

6.2. SOCIOPOLITICAL INFLUENCES

These power plants do not lead to the emigration of people, because these plants are regularly built outside populated areas; the animals get used to them and return them to their habitat. Wind power may affect the employment of local people.

According to the Global Wind Energy Council [20], 15,000 new jobs were created in Brazil in 2012 by wind industry. In the EU, in 2011, around 240,000 people (i.e., a 30% increase from 2007 to 2010) were employed in the wind power industry. Furthermore, 520,000 people are expected to be employed by the wind power sector in the EU by 2020. By 2030, the figure will be 794,079, with 62 % of jobs in the offshore sector. 670,000 people were employed worldwide by the wind power industry in 2011. The EU exported 5.7 billion Euro worth of wind industry products and services in 2011.

6.3. IMPACTS ON THE GRID

Wind power plants affect system stability in many ways, and because of that, they are connected to the distribution network. Constant flickers due to changes in wind speed affect the quality of the voltage and frequency in the network, and both units are strictly regulated with minimal changes. Additionally, they produce electromagnetic disturbances that affect communication and signal transmission interferences.

Wind power plants can also influence power system reliability, available transmission capacity and power system operation in general. Some research into the influence of wind power plants on reliability indices of the transmission network, available transmission capacity and power system operation was conducted in [21], [22] and [23], respectively.

Fig. 5 shows wind farms in Croatia built by 2014.

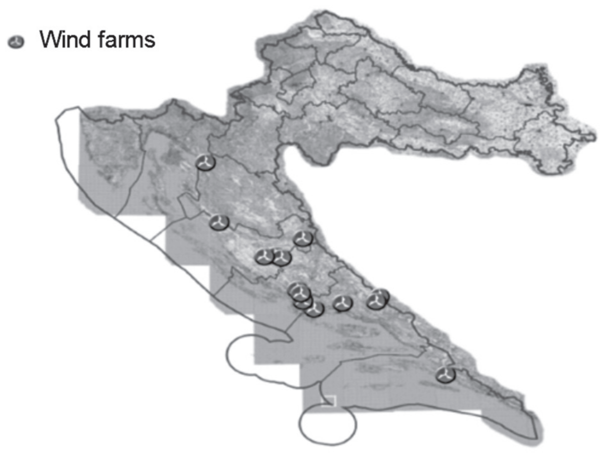

Fig. 5. Wind farms in Croatia built by 2014 [4]

7. GEOTHERMAL ENERGY

A geothermal resource can be simply defined as a reservoir inside the earth from which heat can be extracted economically (cost-wise less expensive than or comparable with other conventional sources of energy such as hydroelectric power or fossil fuels) and utilized for generating electric power or any other suitable industrial, agricultural or domestic application in the near future. A geothermal reservoir can contain heat both in the solid rock as well as in the fluids that fill the fractures and pore spaces within the rock [14].

7.1. ENVIRONMENTAL IMPACTS

Geothermal power plants use fluids drawn from the deep earth. These fluids can carry a mixture of gases, notably carbon dioxide (CO_2), hydrogen sulfide (H_2S), methane (CH_4) and ammonia (NH_3). These pollutants contribute to global warming, acid rain, and noxious smells if released. Existing geothermal electric plants emit an average of 122 kg of CO_2 per megawatt-hour (MWh) of electricity, a small fraction of the emission intensity of conventional fossil fuel plants. Plants that experience high levels of acids and volatile chemicals are usually equipped with emission-control systems to reduce the exhaust. Geothermal plants could theoretically inject these gases back into the earth, as a form of carbon capture and storage [24].

7.2. SOCIOPOLITICAL INFLUENCES

Geothermal power plants improve the standard of living. Because of the need for workers, they improve the education of local people, and because of the working power plant, health and sanitary issues are taken care of.

But, there are also negative impacts, as well as possible impacts on drinking water, there are cultural heritage impacts, impacts on the landscape, the soil and rocks, and there are disturbances caused by noise [25].

7.3. IMPACTS ON THE ELECTRICITY NETWORK

These plants have very good basic strength, capacitance and energy. This means that they produce consistent and well-compensated energy. Unfortunately, the compensated part cannot be used typically because it is needed for the purpose of restoring fluid into the ground.

The continental part (northern) of Croatia has good geothermal energy potential. The temperature gradient is above the European average and it is equal to 0.049^{0}C. The southern part of Croatia has very small potential with the temperature gradient below the European average. The total geothermal potential of existing wells is equal to 812 MW_t of thermal power and 45.8 MW_e of electric power. Currently, installed geothermal power capacity is 36.66 MW (space heating) [8].

8. CONCLUSION

Today's power plants that use renewable energy sources are considered more an addition to electricity production. Because of their growing trend, it is very likely that in the next few years they will become the primary source of energy due to their ecological dominance, regional development and the construction of smart grids that are definitely the future of electric power. Table 1 gives an overview of specific environmental impacts of renewable energy sources in relation to conventional sources.

Table 1. Summary of environmental impacts [26]

Category of impact	Relationship to conventional sources	Comment
Exposure to harmful chemicals		
Emissions of Hg, Cd and other toxic elements	Reduced emissions	Emissions reduced a few hundred times
Emissions of particles	Reduced emissions	Much less emissions
Exposure to harmful gases		
CO2 emissions	Reduced emissions	A big advantage
Acid rains– SO, NO_x	Reduced emissions	Reduced more than 25 times
Other greenhouse gases	Reduced greenhouse gases	Big advantage – global warming
Other		
Spouts of fossil fuels	Total or partial elimination of oil spills	Heavy fuel oil and other petroleum products spills
Water quality	Better water quality	Reduced water pollution
Soil erosion	Smaller loss of land	In most cases, there is no penetration deep into the earth

Croatia has very good potential in renewables, especially in solar power, wind power, small hydropower and biomass. Solar potential and cost-benefit analysis of PV systems in some parts of Croatia are described in [27] and [28]. Solar energy is used only in PV systems and solar thermal systems but that use is still far away from available potential. There is no solar thermal power plant project in the Republic of Croatia. The reason for a slow rate of development in the Republic of Croatia are the quotas that limit power supply connection to only 5 MW per year. The reason for this is the lack of money in the state budget for the promotion of RES.

The southern part of Croatia has very good potential in wind power. Wind power is a leading renewable energy source (excluding large hydropower plants) in electricity generation in Croatia. In 2014, installed wind power capacity in Croatia was 353.17 MW. Great interest has been expressed in investments in wind power. According to the Ministry of Economy [4], there is interest in additional 2,277.56 MW of wind power. But there is a limit of 360 MW for wind power plants due to technical constraints of the transmission system. Improvements in the transmission network can increase penetration of wind power in the power system.

In 2014, installed biomass power plant capacity in Croatia was 6.73 MW, installed biogas power plant capacity was 11.14 MW and landfill gas power plant installed capacity was 2.5 MW. According to the Ministry of Economy [4], there is interest in additional 329.05 MW of biomass, biogas and landfill gas power plants.

Tidal and wave energy potential in Croatia is very small and there are no tidal or wave energy power plants. The reason for that is our coast with a great number of islands and tourism.

There is good geothermal energy potential in the northern part of Croatia. Currently, there are no geothermal power plants for electricity generation in Croatia. Geothermal energy is used only for space heating and spa centers. According to the Ministry of Economy, one geothermal power plant is planned to be built.

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