REN breathable ENERGY IN CROATIA

ZAVRŠNI RAD

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RENEWABLE ENERGY IN CROATIA

ZAVRŠNI RAD

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Međimursko veleučilište u Čakovcu
ABSTRACT

This final paper is devoted to renewable energy sources, both conventional and modern, that are present in the developed parts of the world, including Croatia. It is pointed out why we must focus on renewable energy sources and stop the depletion of fossil fuels as soon as possible, as well as preserve the environment which has already suffered a lot of pollution. Most commercial renewable energy sources are listed and explained and it is explained how the world and Croatia itself must adapt to a larger percentage of energy production from renewable sources. Already available and tested potential solutions are given, which could, with a good motivation and some legal adjustments, become an advantage for Croatia over the previous, less famous trend of investment and building of renewable energy sources. Croatia, with its geographical position and biological diversity, has a lot of potential, on water as well as on land, which could be used for the benefit of obtaining renewable energy. With proper and wise management, Croatia could become an example for some developed countries. With such an effort to set up the equipment to collect energy from renewable sources, we haven’t solved the whole preceding problem, because every solution of energy production on this way has shortcomings that need to be kept at a minimum level. In fact, there is a solution that is already available thanks to new technologies that have recently been developed, which are listed and described in this paper. The solution is the storage and conversion of excess energy and exploitation of this surplus energy when we do not have sufficient production from renewable sources. Finally, it is displayed how to set up a parameter between the production, supply and demand for energy, and all the potential that Croatia has for such a system is shown.

Key words: Croatia, Europe, renewable energy, storage, sustainable.
SAŽETAK

Završni rad posvećuje se obnovljivim izvorima energije, kako konvencionalnim tako i modernijim, koji su prisutni u razvijenim dijelovima svijeta pa tako i kod nas u Hrvatskoj. Iстичо se зашто се moramo usmjeriti prema obnovljivim izvorima energije te što prije obustaviti iscrpljivanje i korištenje fosilnih goriva te tako očuvati okoliš koji je već sada pretrpio mnogo onečišćenja. Navode se najkomercijalniji obnovljivi izvori energije zajedno sa sažetim opisom, te se objašnjava kako se svijet, a i sama Hrvatska, mora prilagoditi što većem postotku proizvodnje energije iz obnovljivih izvora. Navode se već ispitana i dostupna potencijalna rješenja koja bi se uz dobru motivaciju i neke zakonske prilagodbe mogle pretvoriti u prednost za Hrvatsku u odnosu na dosadašnji nimalo slavni trend investiranja i izgradnje u obnovljive izvore energije. Hrvatska svojim klimatskim položajem i biološkom raznolikošću ima puno potencijala, kako na moru tako i na kopnu, koji bi se mogli iskoristiti u korist dobivanja obnovljive energije.

Uz pravilno i pametno upravljanje, Hrvatska bi mogla postati primjer na koje bi se mogle ugledati neke razvijenije zemlje. Uz toliki trud postavljanja opreme za prikupljanje energije iz obnovljivih izvora nismo još riješili cijeli problem koji nam prethodi, jer u svakom rješenju dobivanja energije na taj način imamo nedostatke koje treba svesti na najmanju razinu. Naime, za sve to postaje rješenja koja su već sada dostupna zahvaljujući novim tehnologijama koje su nedavno razvijene, a koja se navode i opisuju u ovom radu. Rješenje je pohranjivanje i pretvorba viška energije kada ga imamo u izobilju te iskorištavanje tog viška energije kada nemamo dovoljnu proizvodnju iz obnovljivih izvora. Naposljetu, prikazuje se kako bi trebalo postaviti parametar između proizvodnje, ponude i potražnje za energijom te koje sve potencijale ima Hrvatska za takav sustav.

Ključne riječi: Hrvatska, Europa, obnovljivi izvori, održivo, energija, pohrana.
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1. INTRODUCTION

Today, one of the world's current issues is how to stop global climate change. The solution to this is to reduce the emissions of greenhouse gases, which is achieved by replacing the use of fossil fuels with renewable energy sources (hereinafter referred to as RES). Today, we have a variety of ways for gaining RES and infinite sources of energy such as light and heat of the Sun, the internal heat of the Earth, stream, wind, heat and motion of the sea. The production of energy through such sources of energy can protect the environment and reduce the emission of polluted gases into the atmosphere. These energy sources can be used for an unlimited period. So, if we find and use the best technology for the exploitation of renewable energy, that energy will be cheaper and more easily available, so on one hand, we can say that we ourselves determine the price of survival on the planet.

The problem presented here, with the description of the best methods of production of renewable energy, will be the fluctuations of the production and consumption of renewable energy, in the case when it is going to be the main source of energy. There are several solutions to the problem which already exist and are already in use and must be carefully considered to ensure an ideal fit with the existing infrastructure for distribution and storage of energy products. Also, the main objective is energy production through renewable energy, how to fit in with the existing infrastructure for power distribution and its storage in the cases when renewable energy is not able to produce the necessary energy, and to draw the required energy out of the storage and to power the system in order to function at an optimum level.

By optimizing and using energy for various purposes, the end of result of getting free energy is achieved, which does not harm the environment, and of storing surplus energy from RES and use it when the production is bottlenecked.

Today, we have the technology to do this and we know how to use it. It is a long way to the realization of this essential goal, which is inevitable if we are to some extent to preserve what is left of the world. Perhaps the biggest problem is that we have relied on fossil fuels too much and it is now difficult to adapt to the present state, because everything is brand new. Therefore, the humanity acts slowly and with caution in the case of RES.
2. MOTIVES FOR TRANSITION TO 100% RENEWABLE ENERGY

Europe's loads of fossil fuels (oil, gas and coal) won't, in any case, keep going forever. They should be wisely overseen while we investigate new wellsprings of energy. Europe is devouring and importing expanding amounts of energy. EU nations are very much aware of the upsides of composed activity in this profoundly vital field. This has prompted regular principles all through Europe and a pooling of Europe's endeavours to secure the energy that it needs at a reasonable cost, while creating the slightest conceivable contamination. Europe relies on whatever is left of the world for its energy.

The European Union, the world's second biggest economy, devours one fifth of the world's energy. However, it hasn't got many stores of its own. Luckily, here in Europe, our portfolio — known as the energy blend — is exceptionally various: from Austria's numerous dams, Poland's coal mines and France's nuclear power plants to the oil apparatuses of the North Ocean and the gas fields of Denmark and the Netherlands, none of Europe's nations are similar, and that is not a burden, given, that those nations cooperate to capitalize on their assorted qualities. Europe's energy reliance enormously affects Europe’s economy.

We purchase our oil from the Association of Petroleum Trading Nations (OPEC\(^1\)) and Russia, and our gas from Algeria, Norway and Russia. Energy expenses are continuously increasing. That leaves us with no other choice: EU nations must be proficient, set objectives and cooperate with the hope that they are to broaden their energy sources and supply channels.

\(^{1}\) OPEC- Organization of the Petroleum Exporting Countries
2.1. Europe’s goals

The European Union has the force and instruments that it needs to execute an energy strategy equipped towards:

- securing Europe’s energy supply
- ensuring that energy costs don’t make Europe less focused
- protecting the earth and fighting environmental change
- improving energy networks

![2052 Forecast Energy Consumption](http://powerlab.fsb.hr/enerpedia/index.php?title=Sljena:2052-forecast-energy-consumption.png)

**Figure 1. Forecast energy consumption of power energy until 2052**


The most widely recognized contention that is utilized when discussing renewable assets is to decrease outflows of harmful gasses. Europe is a pioneer in the appropriation of focuses for the decrease of greenhouse gas emanations, has an exceptionally dynamic strategy and project diminishments and is attempting to push through such an approach on a worldwide level. Be as it may, as indicated by the system for the insurance of the Assembled Countries Environment program (UNEP\(^2\)) in 2005, Europe makes just 12

\(^2\) UNEP-United Nations Environment Programme
percent [1] (hereinafter referred to as %) of the aggregate of the world's g. g. discharges. In this manner, at the worldwide level, the European Union can't freely generate the improvements towards which it aspires.


**Figure 2. Share in the global emission of greenhouse gases**


The following reason implies to the reliance on imports of energy items. In September 2010 the European Union issued a report about the reliance on imports of fossil fuels (Net Energy Import Reliance) led by the European Environment Office (European Environment Organization) in which it expresses that the import of fossil fuels developed from 47.8 % in year 2000 to 54.5 % in 2007 [1]. Around 33 % of import originate from Russia, as shown in Figure 3.
Figure 3. Net EU27 imports of natural gas, oil, solid fuel, and the sum of all by country of origin as a percentage of the total of the specific consumption of a particular fuel (source: Eurostat, Energy statistics, Imports).

Russia supplies Europe with around 20% of energy, and with uranium from around 17%, which is required for European nuclear power plants. Other fossil fuels are offered from nations of North Africa and the central East. This made Europe think of a possible solution to its dependence on foreign energy sources and it therefore turned to RES, as a cleaner and more reliable alternative. Europe is pioneering with its technology and is in the position to enlist a highly qualified workforce, necessary for the development of an effective energy administration. This also motivates specialists to stay in Europe and contribute to the progress of this quickly developing area.

2.2. Methods to achieve the renewable energy source (RES)

The goal is difficult to achieve if a favourable environment isn’t created. In this case, it means the creation of an encouraging star investment climate, which implies a stable legal framework and supportive financing conditions.

The Directive from 2009 prescribes the adoption of the so-called National Action Plans for renewable energy (National Renewable Energy Action Plans - NREAPs), which the Member States have already given to the European Commission. Each Member State has committed itself to specific targets to introduce legislation to achieve those goals. Member States should actively work towards fulfilling the goals i.e. customize all existing regulations of these goals. The directive refers to the policy of regional planning, facilitating and non-discriminatory access to electricity, respecting the environment and nature protection and other measures, and will be maximally adapted to new energy sources.

The European Union funds the research and development of new technologies, development of pilot plants, testing of the energy potential of various technologies, innovation in technical and technological processes, smart grids, etc. Also, the European Bank ensures investment in renewable energy projects. Commercial banks, reluctant to unnecessary risks, had partly taken over the financing of more mature technologies, such as terrestrial wind farms, while the financing of new and risky technologies, such as offshore wind farms, is provided from funds from European, national and commercial banks.
The cause of the strong increase in production is, on the one hand the technological advance in materials research, new concepts and new production processes, and on the other hand, is determined as political support expressed through incentives for the installation of photovoltaic systems. The incentive system was introduced in Croatia in the summer of 2007. The basic legal framework governing the use of renewable energy sources and cogeneration in the electricity generation is represented in the Energy Act ("Narodne novine", issues 168/2001, 177/2004, 76/2007) and the Law on Electricity Market ("Narodne novine, issues 177/2004, 76/2007). [2]

3. TYPES OF RENEWABLE ENERGY PRODUCTION

The creation of renewable energy today can be accomplished in a wide range of ways. Every method of production is not quite the same and is specific to itself and adjusted to the diverse conditions under which it is collected, and used.

Renewable energy sources can be separated into two primary classifications:

- Traditional renewable energy sources, for example, biomass and hydroenergy
- *New renewables*, for example, energy of the Sun, wind energy, geothermal energy, etc.

In this section, some of the commercially and economically more accepted technologies of RES will be represented

3.1. Exploitation of the energy of the Sun

Under ideal conditions, we can get about 1 kW/m² on the surface of the earth. The precise value of sun energy depends upon the area, the season of the year, time of day, climate conditions, and so on. In Croatia, the normal value of day insolation on a horizontal surface amounts about 3-4.5 kWh/m². Figure 4., which demonstrates the insolation level, shows that Europe is not in an extremely good region for utilization, but despite that, the utilization of sun based energy in Europe is on the increase. It is for the most part a result of the arrangements of individual nations to finance the component installations to change sunlight based energy into a usable type of energy.
When solar energy is transformed to thermal energy, sun oriented energy can be used to heat drinking water in homes, greenhouses, or pools, to heat spaces inside homes, and to heat liquids to high temperatures to run turbines that produce electrical power.

Technology for the conversion of solar energy can be divided into:

- Thermal-solar radiation is first converted into heat, the heat into mechanical and mechanical to electrical energy
- Photovoltaic-direct conversion of solar energy into electricity
- Photochemical-is still at laboratory scale [3]

![Figure 4. Insolation world map](http://www.eea.europa.eu/data-and-maps/indicators/net-energy-import-dependency/net-energy-import-dependency-assessment-1)

**Advantages:**

- Solar energy systems don’t produce air toxins or carbon dioxide
- When solar systems are mounted on structures, they have no big influence on the environment

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3 Insolation- the solar radiation that reaches the earth's surface
Disadvantages:

- The quantity of sunlight (energy) that arrives on the world's surface is not consistent
- Sun does not transport much energy to any area at any time, so a large surface is required to collect useful energy

3.1.1. Solar power in Croatia

According to estimates of the potential of solar energy in a solar manual from 2007, the technical potential of electricity generation from photovoltaics and concentrated solar power plants in Croatia is about 33 TWh / year.

Electricity produced from solar energy in photovoltaic systems and concentrated solar power could compete on the market around 2020, and with exploitation of something less than 1% of the technical potential and of the economic potential, the amount would be around 0.3 TWh / year, which would be equivalent to about 200 MW.

The Energy Strategy of the Republic of Croatia from 2008 was given the goal to which the photovoltaic systems’ situation in Croatia by 2020 should be able to equalize to the Spanish state, with regard to the amount per capita in 2008 11.71 W/capita, and the state of Germany from that year until 2030 (more than 45 W/capita. In addition, the assumed growth rate of the use of photovoltaic systems is 68% per year by 2020 and 20% by 2030. [4]

Figure 5. shows the dynamics of growth in the use of solar energy in Croatia to 2030.

Figure 5. Dynamics of growth in exploitation of solar energy in Croatia to 2030
The Energy Development Strategy of Croatia states, that it is expected that by 2030 15% of existing buildings and 50% of new buildings are to participate in their own energy balance with some form of exploitation of solar energy; that the installed capacity of photovoltaic systems will exceed 45 W/capita; and that Croatia will be in fourth place in Europe, observed by megawatt MW solar thermal systems per capita.

According to data from the Registry of projects and plants for the use of renewable energy sources and cogeneration and eligible producers, led by the Ministry of Economy, Labour and Entrepreneurship (MINGORP), until the beginning of February 2011, 87 plants were recorded for the use of solar energy for production of electricity in total power of 49.3 MW in Croatia. [5]

We can conclude that, if Croatia continues at this rate of incentives, installation and development of the network, it will not fulfil default goals despite the proven great potential. We can also conclude that, looking at last year's trends in the world, the aims determined by Croatia with regard to their position and potential are below the trends that are taking place in other developed countries.
The scope of radiation in Croatia is shown in Figure 6., with data for specific regions in Croatia and Europe shown in Table 1.
### Table 1. Comparison of radiated solar energy on an optimally slanted sheet in various selected areas in Croatia and Europe

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>YEARLY AVERAGE OF EMITTED ENERGY [kWh/m²d]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Croatia, south Adriatic coast</td>
<td>5,0-5,2</td>
</tr>
<tr>
<td>Croatia, north Adriatic coast</td>
<td>4,2-4,6</td>
</tr>
<tr>
<td>Croatia, continental part</td>
<td>3,4-4,2</td>
</tr>
<tr>
<td>Central Europe</td>
<td>3,2-3,3</td>
</tr>
<tr>
<td>Northern Europe</td>
<td>2,8-3,0</td>
</tr>
<tr>
<td>Southern Europe</td>
<td>4,4-5,6</td>
</tr>
</tbody>
</table>

**Source:** Zeleni alati: Grijemo se i kuhamo suncem. Zelena mreža aktivističkih grupa (ZMAG)

### 3.2. Hydropower

Solar energy that reaches the earth's surface causes evaporation of water (sea, lake and river) from soil and plants. In the form of water, vapour rises to a height at which clouds are formed. Water vapour condenses and falls to earth as precipitation. [6]

About 78% of the precipitation falls on oceans and 22% on land. This creates a transport of water from the oceans to land and an equally large flow of water back to the oceans as river and groundwater runoff. This flow of water in rivers can be used to generate hydropower driven by the force of gravity.

The potential energy of this cycle is huge and yet not technically full utilized. Most of the unused potential is in developing countries, which is convenient, because in those countries a significant increase in energy consumption is expected. Hydropower is the
most important renewable energy source, but also the only one, for now, that is competitive to fossil fuels and nuclear energy.

Hydropower has limitations. It can’t be used everywhere because it has to have access to fast flowing water (river), and it is preferable to be accessible throughout the whole year, because electricity can’t be cheaply stored. In order to negate the effect of fluctuations in water level, dams and reservoirs are built and this significantly raises the price of the entire plant with rising groundwater levels around the reservoir. The groundwater level has a lot of impact on wildlife, and therefore hydropower is not completely harmless to the environment.

The major hydropower project types are:

1. Run-of-river and storage based hydropower
2. Tidal power
3. Power of the sea waves

3.2.1. Hydro Power potential in Croatia (small hydropower plants – SHPPs)

In Croatia, there is a plan to build seven hydropower plants by HEP\(^4\) and one has been built and put into operation - HE\(^5\) Lešće). As we know, the initial investment costs are very high for the construction of hydroelectric power plants, so it is expected that HEP will turn to less demanding investment, construction of thermal power plants. Nevertheless, the situation in hydropower in Croatia is good, because the existing hydro potential is still pretty well used - about 55 % of electricity production in Croatia comes from large hydropower plants (which covers about 40 % of total energy consumption). The development of small hydropower plants is rather weak, partly because of the relatively small resources, but even more because of the purchase price of energy and complicated administrative procedures, where the biggest problem are requirements for environmental protection and the fact that almost all Croatian rivers are included in the EU's Natura 2000 program.

\(^4\) HEP - Croatian Electricity Company (Hrvatska elektro privreda)
\(^5\) HE - Hydro power plant (Hidro elektrana)
Considering that small hydropower plants (SHP) are hydropower low-power systems, they are mainly built on smaller streams, such as smaller rivers, various channels and even water supply systems. The power limit values vary from country to country, and therefore, in Croatia, plants of 5 and 5000 kW are considered small hydropower plants. Research on exploitation of hydropower from small hydro power plants in Croatia started in 1980. One of the watercourses with many opportunities for the construction of small hydro power plants is the river Mrežnica with a total length of 64 km, the altitude difference of 148 m and the average annual flow of 34 m³/s. [7]

Based on the cadastre of small water power (KMVS⁶) and the cadastre of small hydropower plants (KMHE⁷), 67 potential exploitation locations are presented for small hidro power plants (SHPPs⁸) along the following water courses: Boljunčica, Bijela, Bregana, Brzaja, Butišnica, Čabranka, Čučkov jarak, Jadova, Jadro, Krupa, Kupčina, Kupica, Ljuta, Oršava, Ovrinja, Ruda Velika, Rumin Veliki, Slapnica, Vitunjčica, Vočinka and Žrnovnica. [8]

This investigation determined an annual possible production from these 67 locations at around 100 GWh.

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⁶ KMVS - Cadastre of small water power (Katastar malih vodenih snaga)
⁷ KMHE - Cadastre of small hydropower plants (Katastar malih hidroelektrana)
⁸ SHPP - Small hydro power plant (Male hidroelektrane)
Figure 7. Potential locations of SHPPs


Table 2 and

Figure 8 show the forecasts of growth in utilization of energy from small water courses in small hydropower plants (up to 5 MW) until 2030.

<table>
<thead>
<tr>
<th>Electricity production [GWh]</th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity production [PJ]</td>
<td>0.40</td>
<td>0.97</td>
<td>1.55</td>
</tr>
</tbody>
</table>


3.2.1. Tidal power potential in Croatia

Potential locations for tidal power in the Croatian part of the Adriatic Sea are open sea off the Dugi Otok island with good sea current velocity and direction and depths between 60 m and 70 m, open sea off the Mljet and Lastovo islands, open sea in line connecting the Gargano Peninsula in Italy and the Croatian coastal city of Split with
depths between 80 m and 140 m, and north Adriatic Sea. More should be done to increase the potential of locations for utilization of tidal power and we could say that the potential might lie in channels between the islands.

Table 3. Comparison of the largest measured sea current velocities at sea surface for different selected locations

<table>
<thead>
<tr>
<th>Location</th>
<th>Tidal current velocity [m/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open sea off the Dugi Otok island</td>
<td>0.24</td>
</tr>
<tr>
<td>Open sea off the Mljet island</td>
<td>0.20</td>
</tr>
<tr>
<td>Open sea off the Lastovo island</td>
<td>0.20</td>
</tr>
<tr>
<td>Open sea off the Vis island</td>
<td>0.22</td>
</tr>
<tr>
<td>North Adriatic Sea</td>
<td>0.20</td>
</tr>
</tbody>
</table>


Croatia could benefit from the development of this kind of power plants. New jobs could be created, and Croatian shipbuilding and the overall industry would be revived. Development of an offshore renewable energy power plant would significantly contribute to the independence of Croatia on imported fossil fuels and would additionally strengthen its geopolitical role.

3.2.2. Wave power potential in Croatia

Croatia has the length of the coastline of 1777 km. With the coast of 1246 islands, it reaches the length of 6000 km. The average daily amplitudes of tides are not remarkable: In Dubrovnik, the amplitude is 22 cm and in Rovinj 47 cm [9], and is therefore not interesting from an energy viewpoint. The Adriatic Sea belongs to seas with an energy potential below 5 kW/m which is not economically profitable.
3.3. Biomass

Biomass is a renewable non-conventional source with considerable content of chemical energy received by converting solar radiation. Thus, biomass is the actual solar energy, and produces from the organic material contained in plants and animals, as well as in industrial and municipal waste. Biomass energy is released during combustion or digestion processes, converting it to fuel. It includes organic substances which react with oxygen in the combustion process and the natural metabolism with release of heat. Starting material can be transformed by chemical or biological processes, resulting in gaseous, liquid and solid biofuels as methane, ethanol and wood charcoal. The basic process in which a conversion of solar energy into chemical i.e. biomass energy is photosynthesis. Biomass is a renewable non-conventional source with considerable content of chemical energy received by converting solar radiation. [10]

Figure 9. Biomass sources

Source: https://goodenergiesalliancedotcom.files.wordpress.com/2014/12/biomass-sources.jpg

Biomass materials can be in solid form or, through a wide range of conversion, made into liquids or gases which can be used to produce electric power, heat or fuel. Biomass
can also be used in a majority of man-made materials, including fabrics, medicines, construction materials and chemicals.

Biomass is organic matter just like fossil fuels (coal, natural gas or oil). The difference is that fossil fuels were formed long ago in the inside the Earth from plant and animal remains, while biomass is renewable on a much shorter time scale as plants grow continuously, animals constantly produce manure or die, and people throw away waste material every single day.

Division of biomass by type:

Biomass is a renewable energy source, but in general can be divided into solid, liquid and gas biomass, within which following can be distinguished:

- **Solid biomass**: Wood & wood remains, agricultural remains, plant & animal waste, municipal solid waste etc.

- **Liquid biomass**: Vegetable oils, methanol\(^9\), ethanol\(^{10}\) and alcohol (fermented from plant matter), biodiesel etc.

- **Gas Biomass**: Methane\(^{11}\) from decomposing plants, animals and manure, biogases generated from rotting rubbish in landfills etc.

### 3.3.1. Biomass potential in Croatia

The Republic of Croatia has great potential forest (with 44 % of the territory covered with forests), a significant role of agriculture and a number of wood-processing plants, and has access to large amounts of biomass of different origins that can be used for energy production. According to various forecasts (development of agriculture and forestry, introduction of new technologies and mechanisms of support and the like), it is expected that the technical potential of biomass in 2030 will be between 50 PJ and 87 PJ. So far, a small amount of available biomass (12.24 PJ in 2001) was used, mostly in the energy-inefficient way of heating homes, so in general, biomass has not occupied an important place in energy policy and balance of Croatia. [11]

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\(^{9}\) Methanol- is the simplest alcohol known as wood alcohol with chemical with the formula CH\(_3\)OH

\(^{10}\) Ethanol- type of alcohol found in alcoholic beverages with chemical formula C\(_2\)H\(_5\)O

\(^{11}\) Methane- the simplest alkane and the main component of natural gas with chemical formula CH\(_4\)
In Croatia, we have the following resources in the field of biomass:

- The potential of forest biomass in Croatia, i.e., of the remains and waste from the timber industry generated through regular forest management, as well as all forest areas and firewood, Croatia has 44% of forest area, and the annual growth is 9.6 million m$^3$.
- Biomass from wood industry (remains and wastes)
- Agricultural biomass - the remains of annual crops (straw, corn stalks, cobs, stalks, husks, seeds)
- Energy crops - fast-growing trees, Chinese reed with an annual growth rate of 17 tons per hectare; in Croatia, the best results are achieved with cottonwoods, willows and poplars [12]

### 3.3.2. Biofuel production potential in Croatia

In line with the EU policy, Croatia will encourage the production and marketing of biofuels on the market, as well as promotional campaigns and pricing policies to encourage their use.

Biodiesel and bioethanol, and other liquid and gaseous fuels are included in biofuels, as defined in the “Regulation on the quality of biofuels”. The raw materials for biodiesel production are rapeseed, sunflower, soybean, palm oil, waste cooking oil and beef tallow, and for the production of bio-ethanol corn, wheat and barley.

Total capacities for liquid biofuels in Croatia in late 2013 were in the level of 69 000 tons per year of biodiesel. During 2013, in Croatia, 33 007 t of biodiesel were produced or 1.238 PJ, out of which a 94% share ended up in the domestic market. [13]
Another source to produce biofuel and biodiesel could come from edible oil. In Croatia, the average consumer produces about 2 litres of waste edible oil per annum. The potential is accounted for cities with a population of more than 20,000 residents. This makes for around 2.2 million people and if we transform into amount of edible oil, we get 4.4 million litres, which can annually produce around 3,800 tonnes of biodiesel.

The following table and graph show the dynamics of the growing production of biofuel in Croatia to 2030. [4]

**Table 4. Dynamics of the growing production of biofuel in Croatia to 2030**

<table>
<thead>
<tr>
<th></th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production of biofuels [t]</td>
<td>90.060</td>
<td>344.031</td>
<td>380.055</td>
</tr>
<tr>
<td>Production of biofuels [PJ]</td>
<td>2.5</td>
<td>8.91</td>
<td>10.55</td>
</tr>
</tbody>
</table>


**Figure 10. Dynamics of the growing production of biofuel in Croatia to 2030**

The second-generation biofuels includes biofuels made from waste, residue of agricultural production, non-food cellulosic material and lignocellulosic materials. It is not possible to take advantage of all the available raw material. Namely, of the total biomass produced in the field, 40\% must be returned to the soil, 30\% is used in animal feed or on farms, and the remaining 30\% is used in the production of biofuels.

3.4. Wind power

Solar heat energy warms our planet unevenly, making the air hotter around the equator, as it retains more energy, and colder close to the poles. Air dilates when it is warmed and contracts when it is cooled. These differences in temperature make convection streams stream around the world as the denser air from the colder districts moves to the hotter place were the air is lighter. This development of air within the climate of the earth from a hotter spot to a colder spot is the thing that we call the "wind", and which can be powerless or strong relying on the solar energy striking the earth at present time.

Earth’s land mass and its oceans absorb and release solar energy back into the atmosphere at different rates. So, there is a constant shift of air between the Earth’s surface and the atmosphere, causing the air to move and generating “wind energy”. The Earth’s rotation also plays a big role in wind energy.

In theory, wind is “air in motion” and the world has an inexhaustible supply of free wind energy as every corner of the earth receives the effects of the wind at some time during the day.

From an environmental viewpoint, wind energy is an acceptable source of energy because it does not provide additional thermal load, does not pollute the environment nor requires the use of water resources. Technological solutions are developed in proportion to the amount and are tested in practice, so that, along with solar energy, it is one of the first renewable sources which has commercial use. Wind power plants in recent years experienced a boom in the world, and particularly in the EU where more than half wind farms in the world are located. The construction of wind farms in the EU has a growth rate of 21\%. [14]
3.4.1. Wind turbines

Wind turbine is a mechanical device that converts the kinetic energy of the wind into electrical power. Simply stated, a wind turbine is something like fan, just opposite. Wind turbines have blades like aircraft, the moving wind is turning the blades which spins the shaft and through transmission the generator is producing an electric current.

There are manufactured many types of vertical and horizontal axis wind turbines, and also many sizes of it. The small turbines are used for applications such as battery charging on boats, off grid weekend houses or to power some lightning out in the streets. Slightly larger turbines can be used for making a domestic power supply with possibility to sell surplus power to supplier via the electrical grid. Large turbines are becoming an increasingly important source of renewable energy and are used by many countries as part of a strategy to reduce their reliance on fossil fuels.

We have to mention some of their main advantages and disadvantages:

**Advantages:**

- Wind energy is a clean and renewable energy, the technology doesn’t release any kind of pollutants, emissions or by-products into the atmosphere during operation
- Modern turbines produce very little mechanical noise when operating
- Wind energy is a by-product of solar energy. So, as long as the sun continues to heat, there will always be wind
- Total output of wind energy varies only by a small percentage as wind turbines are designed to operate within a wind speed between 4 m/s to 25 m/s
- Land on a wind farm can be used simultaneously for wind generation, crops growing, animal grazing or anything else below the turbines
- Wind generation can be done in remote areas and on any scale (from small to full size wind farms)

**Disadvantages:**

- Environmental impact-negative visual impact (visual pollution)
- Wind farms require large areas of land and have to be placed in environmentally sensitive areas where wind is stronger (hills, deserts etc.)
- Low wind speeds or no wind (calm weather), don’t make useful electricity
- Wind farms injure, kill and disturb birds that migrate
- Wind turbines cause noise pollution
- Wind energy investments are higher than conventional fossil-fuels
- The best locations for wind turbines are away from urban areas, and that means additional costs for storing and/or transporting to urban areas
- Annual winds and power output are relatively predictable, but hourly and daily wind energy output is not

3.4.2. Wind turbines and wind potential in Croatia

Croatia has large potential for wind energy, especially in the coastal area. According to preliminary estimates, the potential is around 1300 MW power that can be installed with a production of 3 TWh / year. Although the Croatian coastal area has a lot of potential wind sites, according to regulations of the Ministry of Environmental Protection, Physical Planning and Construction and the new law for construction, construction of plants for the production of electricity from wind energy on Croatian islands and in the coastal zone from the sea is not permitted under distance of 1000 m until further notice. [15]

HEP-Transmission System Operator, which is responsible for the security of the Croatian electricity system has recently decided that the maximum power from the wind farm, which is now able to connect to the network, is 360 MW. This decision was made by the Croatian Government and accepted, although investor interest is far greater and exceeds the figure of 1500 MW. [15]

The continental regions in Croatia have not been considered as potential sites of wind farms, but there is an interest for their development. [15]

The Croatian Government will create favourable investment climate and encourage the construction of wind farms so that their share in the total electricity consumption in Croatia amounts to 9-10 % in 2020. It is expected that the installed capacity of wind power in Croatia in 2020 will amount to 1,200 MW.
Average wind speed on the Adriatic Sea in the coastal areas is ranging from 3 to 6 m/s. The annual cycle for the largest average wind speed occurs in January or February. These are the months with the most wind. Since the Adriatic sea isn’t abundant with strong wind, it’s suitable for wind energy.

_Bura_ and _Jugo_ winds vary in direction by 90 degrees and are blowing throughout the whole year. They are especially frequent in the colder part of the year, when their speeds are higher and reach over 100 km/h and have large fluctuations in speed and that is not suitable for the exploitation and production of electricity. That additionally increases the costs and demands on the mechanical stability of wind turbines.

Therefore, the potential of the two most frequent winds in Croatia can’t be fully utilized. So, locations must be chosen where storms rarely reach hurricane strength. Unfortunately, a wind atlas in Croatia does not exist, nor do the wind maps. Thus, the positions of wind farms demand individual measurements.

### 3.5. Geothermal energy

The sources of geothermal energy are the result of complex geological processes that led to the build-up of heat at reachable depths. The temperature of the Earth's interior increases with increasing depth. In the last one billion years, the Earth's core heat was reduced by 300-350 °C. The heat is continuously flowing from sources in the Earth's interior to the surface. The temperature on the surface of the Earth largely depends on solar radiation. The impact of this radiation can be seen in the upper parts of the Earth's crust and to a depth of 30 m. At that depth the temperature is constant. [16]

To date, there is no defined standard on international terminology for the classification of geothermal resources.

There are several ways of classification of geothermal resources:

- According to the degree of severity and proof sources
- According to the type of geothermal reservoirs
- According to the temperature of reservoir fluids [16]
Most intensive exploitation of geothermal energy in Europe, looking at heat capacity and annual energy from geothermal sources, with the exception of Iceland, is located in Turkey, Hungary, Italy, Romania and Austria. This abundance of heat is what we use as geothermal energy because it is considered environmentally friendly, free, non-polluting and renewable. [16]

Water either from the rain or oceans seeps down through geologic holes, cracks and faults in the Earth’s crust, absorbing heat as it travels through the hot rocks below. As a result, the water becomes heated by the huge heat and pressures just a few hundred metres down, emerging back under pressure to the Earth’s surface as geysers and hot springs. We can use this water for cooking, bathing or heating.

The average geothermal heat source just below the Earth’s surface (usually 2 to 3 m), never deviates far from 10 to 21°C, and can be used directly for building heating or preheating. At specific locations around geysers, hot springs or volcanic areas, increased temperature gradients occur due to the formation of the ground providing a significant geothermal resources hotter than at other locations.

Deep enough beneath the Earth’s surface, temperatures are so hot that water can change into superheated hot water and steam. This geothermal energy can then be used for power generation.

For the production of geothermal electricity, we have to sometimes drill 1.5 kilometres deep into the ground or more to get to the underground reservoir and be able to make use of steam and very hot water to power turbines that are connected to generators of electricity.

The three free major types of geothermal applications:

- **Power generation**: Most power plants need steam to generate electricity. The steam rotates a turbine that activates a generator, which produces electricity. Geothermal power plants use steam produced from reservoirs of hot water found a couple of kilometres below the Earth's surface.

- **Direct use**: This type of heat can be used for various applications as for heating buildings, industrial processes, greenhouses, breweries, fruit and vegetable drying,
spas, pulp and paper processing and wood drying and offer attractive and innovative opportunities for local entrepreneurs and businesses, farms and resorts (wellness and spa)

- **Heat pumps**: A geothermal heat pump is a central heating system that transfers heat from the Earth's ground. It works on principles like refrigerator, just opposite

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### Advantages:

- Geothermal energy can be used to provide heat and electricity
- It’s a clean energy, there are no air pollutants
- Geothermal fuel is “free” for extraction
- Geothermal energy produces little or no emissions
- Once built, geothermal power station operating costs are small
- The used steam is turned into water and recycled back into the Earth
- Using geothermal energy directly for heating applications can be up to 70% more efficient

### Disadvantages:

- Geothermal energy may not be considered as a renewable resource, only a sustainable one
- Not every area has access to a geothermal source
- Initial capital & installation costs are higher but has potential long term savings
- Requires drilling boreholes deep into the ground for vertical wells
- Problems with corrosive water and mineral deposits taken from the ground and exposed at the surface
- Geothermal sites can run out of steam, as their temperature drops too low or is too exploited, in which case a new drilling is required
3.5.1. Geothermal energy in Croatia

Geothermal energy from natural resources in Croatia is used for many years for medical purposes and bathing. Geothermal waters in mineral springs are created by natural flows.

Geothermal sites were found when exploration of oil and gas reserves were made. The exploitation of geothermal energy in Croatia will in the future be tied to complete exploitation of existing geothermal bores that were drilled to obtain oil and gas with economically feasible boring techniques.

There are two main sedimentary basins that cover the entire area of Croatia. However, there are significant differences in geothermal potential for each of them. In the southern part of Croatia, the Dinaride basin has geothermal gradient of 0,018 °C/m with thermal flow of 29 mW/m² (Jelić, 1979) and there can`t be expected any significant geothermal potential in this area. As opposed to Dinarides, in the Pannonian basin, the average geothermal gradients and thermal flow (G=0,049 °C/m i q=76 mW/m² are considerably higher than Europe mean values, with many discovered geothermal reservoirs. These large variations in geothermal potentials of the Dinaride and Pannonian basins could be explained with the Moho plate of discontinuity, which is in the Pannonian basin at approximately 28 km, as opposed to the Dinaride, where it is at 50 km. This resulted with a spa complex construction in the late 80’s. [17]

Today, Croatia exploits 0.14 PJ of geothermal waters for energy purposes (warming and hot water use) and 0.42 PJ for recreational purposes (pools and other comparable recreational buildings).

Some of the noteworthy sites for geothermal power plant utilization are Bizovac near Valpovo, the region between Koprivnica, Ludbreg and Legrad and the south-western outskirts of Zagreb. The possible power of these thermal power plants to transform internal hot water energy into electricity at a medium temperature (at water temperature between 120 – 170 °C) in already drilled bores amounts to about 11 MW, and with complete utilization of the basin its amounts to 48 MW. Projects are currently being prepared regarding electricity generated using geothermal energy at the Lunjkovec-Kutnjak and Velika Ciglena bores.
Potential springs at extremely low temperatures (up to 65 °C) in already drilled bores amount to 9 MJ/s. This group of springs belongs to geothermal springs that are used for medical and recreational purposes. These include springs in Daruvar (Daruvarske Toplice), Ivanič Grad (Naftalan Hospital), Krapinske Toplice, Lipik (Lipičke toplice), Livade (Istarske toplice), Samobor (Šmidhen SRC\textsuperscript{12}), Stubičke Toplice, Sveta Jana (Sveta Jana RC\textsuperscript{13}), Topusko (Toplice Topusko), Tuhelj (Tuheljske toplice), Varaždinske Toplice, Velika (Toplice RC), Zagreb (INA\textsuperscript{14}-Consulting), Zelina (Zelina RC) and Zlatar (Sutinske toplice).

Figure 11. Geothermal potentials in Croatia

Source: https://www.linkedin.com/pulse/geothermal-energy-nenad-jarić

\textsuperscript{12} SRC- Sport and recreation center (Sportsko rekreacijski centar)
\textsuperscript{13} RC- Recreation center (Rekreacijski centar)
\textsuperscript{14} INA- Oil company (Industrija nafte)
4. THE PROBLEM OF STORING ENERGY FOR PRODUCTION THROUGH RENEWABLE ENERGY SOURCES

If we want to switch to 100% renewable energy, then we have to solve the problem of energy supply in all sectors (transport, industry, heating and electric power) and not focus only on getting electricity from renewable energy sources (wind-power plants, photovoltaic cells ...), but cover other forms of energy that are necessary for the normal functioning of the economy and the public in general. Getting electricity from RES is just a 20% solution of the overall problem. Predictions for the future are that by 2050 Europe will receive 100% of energy from RES.

When going 100% renewable, the electricity sector is only 1/5 of the problem in Germany; residential heat and mobility add up to more than 60%


Figure 12. Display of the all sectors that need energy
Figure 13. shows fluctuating production and consumption of electricity during the year and the biggest problem is that, when we need energy, we may not be able to get it from RES (e.g. wind or PV). The red part shows the need for energy when we have demand for electricity. The blue line shows the period when we have a surplus of energy produced and when it should be used, consumed, sold (export at that time), stored, if possible, or it stays unused. Figure 13. shows that the area of demand and the area of production of energy are roughly the same size, therefore, the best solution would be if we could map up the blue surface (production of excess energy) onto red surface of the diagram and thus succeed to cover almost all needs of energy demand through the year. Of course, this can’t be mapped up, but the best solution would be that during excess energy production, when we have surplus energy, we stored it and used it when needed, for example, when we didn’t have the conditions for such a large production from RES.

In systems with close to 100% renewable energy in the electricity system, a key challenge will be the utilization of energy surplus to provide power in times of deficit.

Residual load (GW), deficit in red, surplus in blue, simulation for a 100% scenario in the year 2050

Figure 13. Showing fluctuations between demand and production power energy

15 PV-Photovoltaics—a technology for converting sunlight directly into electricity
Today, one of the best and most efficient solutions that we have to store energy is the "PHES"-Pump Hydro Energy Storage to the so-called Reversible HYDRO\textsuperscript{16}, and Croatia has one of them on the Velebit mountain. Although this technology was tested, works, and has a good efficiency of 80-90\%, we have a problem with the storage of energy in this way. If we pump the water into upper "potential energy" pool (Lake), it will be maximum loaded in a few days. And from renewable sources of energy, such as on land (onshore) or at sea (offshore), renewable energy from wind power plants can produce electricity in a period of a couple of weeks (such as 2-3 weeks), and then we have a surplus of electricity of 1-2 weeks, and for example, the capacity of Reversible HYDRO has space in upper pool (Lake) to store energy for just a few days. Namely, if we wanted to make use of excess energy from wind farms, that would, for example, produce electricity from wind that is blowing 2-3 weeks consistently, we would have to have a tenfold higher and wider pool (Lake) to cover excess converted electrical power. It would spend too much ground level for the dam built without taking into account the costs of construction and the dam.

While it is possible that fluctuation can be "covered" by conventional sources of energy production, the "jumping" up and down for different electrical requirements and generator is a challenge and for the most part is not efficient for any plant power output.

\textsuperscript{16} Reversible HYDRO-Reversible hydro power plant
5. THE SOLUTION TO THE PROBLEM OF TRANSITION TO A 100% RENEWABLE ENERGY WITH NEW ENERGY STORAGE TECHNOLOGIES

5.1. Vanadium Redox Flow Batteries

Vanadium\textsuperscript{17} redox\textsuperscript{18} flow batteries offer an effective way to balanced fluctuations in the supply of renewable energy and so ensure continuous availability of the necessary energy.

Vanadium redox flow battery (VRFB) consists of electro-chemical cells, divided into two parts by a membrane. Each half of the cell consists of Vanadium-sulfur electrolytes. Both parts of the electrolytes\textsuperscript{19} are pumped through two separate reservoirs (positive and negative) in which two electrolytes are separated by a proton membrane\textsuperscript{20}.

In the Vanadium flow battery, both semi-cells are additionally connected and are clumsy in dimensions. That limits the use in the mobile application, but they are applied effectively with large fixed installations.

Other useful properties of Vanadium flow batteries are:

- Quickly respond to changes in load and their extremely high capacity charging
- Response time is less than half a millisecond to change the load of 100 %
- The time response is mainly limited by electrical equipment
- The efficiency in practical application is around 65-75 %

For several reasons, including the relatively large size, most Vanadium batteries are currently used for storage of network energy (electricity), so they are attached to the power plant and power system.

\textsuperscript{17}Vanadium - chemical element, hard, silvery grey, ductile and malleable transition metal.
\textsuperscript{18}Redox - is a contraction of the name for a chemical reduction-oxidation reaction.
\textsuperscript{19}Electrolyte - substance that produces an electrically conducting solution when dissolved in a polar solvent, such as water.
\textsuperscript{20}Proton membrane - semipermeable membrane generally made from ionomers and designed to conduct protons while acting as an electronic insulator and reactant barrier
Advantages:

- Can offer almost unlimited energy storage capacity simply by adding a larger electrolytic tank
- The battery can be left fully discharged for a long time without any harmful consequences
- If accidentally mixed with electrolytes, the battery will not suffer any permanent damage
- The electrolyte is water, inherently safe and non-flammable [18]

Figure 14. The principle of how the Vanadium Redox Battery works
Disadvantages:

- A relatively poor ratio of energy-to-volume, although the third generation formulation has doubled energy density
- The complexity of the system compared to standard batteries for energy storage
- Water electrolyte makes the battery heavy and is therefore only useful for stationary applications [18]

5.2. CAES-Compressed Air Energy Storage

Saving energy by means of compressed air (CAES) power plants is mainly equivalent to reversible hydro power plants in terms of their application, output and storage capacity. Instead of pumping water from a lower to a higher pool during periods of excess power, the CAES power plants compress ambient air and store it under pressure in an underground cave. When in need of electricity, compressed air is heated and expands in the expansion turbine which drives a generator to produce electricity. The effectiveness of the "power-to-power (Power-to-Power) is approx. 42 % without and 55 % in the use of waste heat. These power plants use a machine shaft, where gas turbine-generator and compressor-motor are both located on the same axis and are connected via transmission. In the current planning of CAES power plants, motor-compressor unit and the turbine-generator units will be mechanically separated. This makes it possible to extend the modular factory due to the allowed input and output.
The special thing about compressed air storage is that the air heats up strongly when being compressed from atmospheric pressure to a storage pressure (about 70 bar). That heat can be utilized when the compressed gas is released and heated with the heat stored in thermal reservoirs, and with this technique, the efficiency of the CAES power plant is boosted. Using conventional gas turbine and its exhaust heat gases for heating air under pressure before expansion, enables to build CAES plants of variable sizes based on the volume and the amount of pressure of the cave in which the air is stored. Independent of the selected methods, very large warehouses are required due to the low density of the storage. Desirable locations are artificially constructed in salt caves in the deep salt formations (former salt mines).
5.3. Flywheel energy storage

Flywheel energy storage systems (FESS) use electricity for input and that electricity is stored in the form of kinetic energy. Kinetic energy can be described as the "energy of movement", in this case the movement of the rotating mass which is called the rotor. The rotor rotates in almost frictionless housing.

When a short-term backup power is needed due to the change of electric power or its absence, inertia allows the rotor to continue spinning and the resulting kinetic energy is converted into electricity. Most modern systems for energy storage by means a high-speed impeller consist of a massive rotating cylinder (fixed to the wheel shaft) supported on the stator side of the magnetic floating bearings. To maintain efficiency, the flywheel system is used in vacuum housing in order to reduce resistance. The flywheel is connected to the auto-generator that works in conjunction with the utility network through advanced power electronics.

Some of the key advantages of flywheel energy storage are low maintenance, long life (some flywheels are capable of well over 100,000 full depth of discharge cycles and the newest configurations are capable of even more than that, greater than 175,000 full depth of discharge cycles), and negligible environmental impact. Flywheels can bridge the gap between short-term ride-through power and long-term energy storage with excellent cyclic and load following characteristics. [19]

In addition, they have several advantages over chemical energy storage. They have a high density and considerable durability, which allows them to often complement without affecting the performance. They also have very fast response rates. In fact, they can go from full discharge to full charge within a few seconds or less.

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21 Flywheel - is a rotating mechanical device that is used to store rotational energy.
22 Rotor- A rotating part of a mechanical device.
23 Impeller- is a rotor used to increase the pressure and flow of a fluid.
24 Stator- is the stationary part of a rotary system.
5.4. PHES-Pumped Heat Electrical Storage

In a Pumped Heat Electric Storage (PHES) system, electricity is used to drive the motor which is in charge for energy storage, connected with two large thermal reservoirs. For storing electricity, electrical energy drives the heat pump, which pumps heat from the "colder tank" to "hotter tank" (operation like in the process of the refrigerator).

For energy recovery, heat pump has inverse sequence and becomes a heat engine (machine). The engine extracts heat from the hotter tank, brings waste heat to the cooler tank and produces mechanical work. When we want recover electricity, heat engine (machine) drives a generator.

PHES has following elements:

- Two cheap (usually made of steel) tanks filled with mineral particles (gravel or crushed stone)
- Closed piped circle filled with working gas (like argon) that connects these two tanks
- Compressor and expander

The process starts when argon, at ambient pressure (≈1 bar) and temperature (≈20°C) enters the compressor which is driven by a motor using the electricity. Then the argon is compressed to 12 bar and +500 °C. Hot argon enters hot reservoir and flows through the
particulate (gravel, sand or crushed stone), heating it and cooling the gas. As the particulate heats up, heat moves down the reservoir. At the bottom of the reservoir, the cooler argon\textsuperscript{25} exits still at approximately 12 bar like before, but cooler ($\approx 20^\circ$C). The argon then comes to the expander at the bottom and expands back to ambient pressure ($\approx 1$ bar), cooling to minus -150 °C to -180 °C. The argon then enters the bottom of the cold reservoir, cools the particulate, but warms itself. The argon leaves the reservoir at ambient pressure and temperature.

Power stations of such size are expected to be built in the range of 2-5 MW per unit. Grouping units can provide the size of the installation of gigawatt GW. It covers all markets currently related to reversible power plant and a number of others which are suitable for local distribution.

\textbf{Figure 17. Pumped Heat Electricity storage (PHES)}

\textbf{Source:} http://www.treehugger.com/clean-technology/breakthrough-grid-scale-renewable-energy-storage-battery-made-gravel.html#14715299912951&action=collapse_widget&id=0&data=

\textsuperscript{25} Argon - Chemical element, third most abundant gas in the Earth's atmosphere.
5.5. **PHES-Pumped Hydro Energy Storage**

PHES project stores and produces energy by moving water between two reservoirs at different heights. During low power consumption, such as at night or at weekends, the excess energy is used to pump water to the upper reservoir. The turbine is then able to act as a pump, which pumps the water uphill. In periods of high electricity demand, the stored water is discharged through the turbine in the same way as a conventional power plant, the water flows downhill from the upper reservoir into the lower, and thereby spins the turbine and produces electricity.

This technology is currently the most cost-effective in terms of saving large amounts of electricity, but the start investment costs and the problem, as well as finding a proper difference in height between the tanks, and the environmental issues are critical factors in deciding on the construction.

The relatively low energy density with PHES system requires a large amount of water (occupies a large part of the territory) or a large difference in height between the two containers.

The system can be very cost-effective because it aligns the differences in network load. This allows the system to work at peak power efficiency and allows avoid the operation power plants to work above maximum power. This entails big savings on more expensive fuels. But the investment costs for the construction of the reservoir are quite high.

![Figure 18. Schematic of operation reversible power plant](http://sites.uoit.ca/sustainabilitytoday/blog-posts/blog-posts/2014/09/Capturing-the-power-of-water.php)
5.6. "Power to gas" technology

This technology as input "material" needs water, electricity and carbon dioxide (CO₂), and as output we become oxygen, hydrogen and methane.

**How the process works:**

1. We use electricity and through the process of water electrolysis we get hydrogen (H₂) and oxygen (O). However, oxygen isn’t stored, it is emitted into the atmosphere - perhaps it could be stored for later to take advantage of better combustion in the final process.

2. "Clean", purified carbon dioxide (CO₂), stored in tanks and kept in reserve (available in the needed quantities) is taken, and is combined together with hydrogen (H₂) in the process of methanisation into methane. The synthetic gas methane is almost identical to methane in the gas system and therefore can be forwarded through the gas network to all households, industries and power plants that use this gas as fuel to obtain the necessary energy.

3. If necessary, hydrogen can be released and exploited through the gas network at the same time, but only in cases of shortage of carbon dioxide (unlikely to happen), or in demand for pure hydrogen instead of methane.

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26 Electrolysis - (of water) is the decomposition of water (H₂O) into oxygen (O₂) and hydrogen gas (H₂) due to an electric current being passed through the water.

27 Methanisation - process where it’s combine hydrogen (H₂) and carbon dioxide (CO₂) into methane (CH₄).
Advantages:

• We can use existing infrastructure - a network of gas pipelines

• Storing gas in gas tanks

• Gas has a great thick energy saving and therefore can store a lot more energy on a lot less space and with a much smaller investment than, for example Pumped Hydro Energy Storage (PHES)

• Storing energy when we have a surplus in production by means of renewable energy sources and convert it into methane gas, store it in the gas tanks and convert it back into energy (by means of thermal power plants) when we have a need for additional energy

Disadvantages:

• The efficiency of Power to Gas technology is about 54 %, if we look at the Power to Power (energy recovery, e.g. electricity) through thermal power plants, the efficiency is even lower - depending on the efficiency of the specific power plant
Another small usability of P2G (Power-to-gas) technology occurs if a CO₂ separation directly from the air (industrial plant or thermal power plant) is implemented. When this process (CO₂ capture) is carried out with a biodigester, then we can talk about 54 % efficiency. Otherwise, it is smaller.

Areas of use of the Power-to-Gas technology final product:

- It can be used in all necessary sectors that use energy: transport, industry, heating and electricity
- BEV - Battery Electric Vehicles realize charging batteries from excess electricity
- FCEV - electric car with a fuel cell (Fuel Cell Electric Vehicle) from the produced hydrogen, after the electrolysis of water, we can immediately charge such cars or distributed systems that use only hydrogen
- The CNG - Compressed Natural Gas which is used in all possible sectors and can be stored in large quantities and be reconverted into electrical energy if necessary
In Figure 20, the heading sentence refers to orange fields. The green colour of the graph describes problems that can be solved by using the above presented technologies: Pumped Heat Electro Storage (PHES), CAES, Flywheel, Vanadium Redox Battery flow and Pumped Hydro Energy Storage (PHES); these are the technologies that will be available from 2020 and some are already available today.

However, if we take all this technology, what still remains are the orange fields that these technologies can’t cover:

1. Save the amount of energy that exceeds more than two days – it was mentioned before that we could have periods, when the wind can blow and produce electricity (e.g. wind farms) over the period of 2-3 weeks
2. Do not cover the heating and industry as a whole (which together make up 60% of the energy demand); Don’t cover the supply of energy and their decarbonisation
3. The problem of covering long distance road transport sector (part of the 20% demand of the overall energy demand) and also of their decarbonisation

That’s more than 50% of the overall problems for energy demand, which existing techniques can’t solve.

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28 Decarbonisation – removing or reducing of carbon
Technology P2G "Power to Gas" is able to solve all these problems, and it is possible to use all the existing infrastructure of the gas network. Gas can be immediately put into the gas network without any modification to the network.
6. CONCLUSION

Croatia currently has economic, political and structural problems that obstruct the development of not only renewable energy sources but also the whole country. Although there are ambitions, Croatia lags behind of the development trends and investment lasting in similar transition countries of north-eastern Europe and there is a belief that Croatia will not be able to meet its 2020 and 2030 targets that have been set for the development of renewable energy sources.

By joining the EU, Croatia made a small jump with the progress in the direction of renewable energy sources. There are various forms of co-financed renewable energy sources but this is a far smaller percentage of what it could be if European funds would be used in a better way in order to encourage greater economic development.

Before war, Croatia had a quite well developed program of hydro power. But because Croatia has a lot of good potential for solar and wind energy, it is necessary to make efforts to develop in these additional directions. Full potential must be utilized, which again would greatly contribute to economic development.

Another of the major problems that hinder the development of Croatia in using renewable sources is, that Croatia has outdated and poorly developed infrastructure of electric power grid and thus has difficulties with overload current when we have larger amounts of electricity generation through renewable sources. Croatia needs to do a lot of work and even more to allocate resources to solve this problem.

Nevertheless, Croatia has managed to make a noticeable amount of electricity from renewable sources. Although the storage of energy from renewable sources has already been mentioned, which will sooner or later have to be an integral part of electric power grid, Croatia is not yet on the path to think over this issue. Although we have a reversible hydro power plant that may be considered as a type of energy storage, this is by far not a sufficient energy storage system which will have to be provided for the storage of energy.
Overall, Croatia is on the right path to progress, but more could be done to accelerate the development, which can’t be done without political and macroeconomic policies’ background. We hope for better decisions from the government and rapid achievement of European objectives.
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Labels and abbreviations:

- m - metre
- m² - square metre
- m³ - cubic metre
- km - kilometre
- km² - square kilometre
- m/s - metres per second
- t - tons (1000 kilograms)
- W - watt (joule per second)
- kW - kilowatt (watt x 10³)
- MW - megawatt (watt x 10⁶)
- GW - gigawatt (watt x 10⁹)
- TWh - terawatt hour (watt x 10¹² per hour)
- GWh - gigawatt hour (watt x 10⁹ per hour)
- km/h - kilometre per hour
- °C - Celsius
- MJ/s - mega joules per second
- bar - pressure
- PJ - Peta joules (joule x 10¹⁵)
- % - percentage
- kW/m² - kilowatt per square metre
- kWh/m² - kilowatt hour per square metre
- kWh/m²d - kilowatt hour per square metre per day