What processes can be expected in the Croatian energy sector by 2050

Goran Granić et al.

REVIEW

The article analyses processes that can be expected in the energy sector of the Republic of Croatia by the year 2050 in terms of significant reduction of CO_2 and other greenhouse gases. It takes into consideration basic influential factors affecting consumption of energy, constraints in the development of the energy sector as a result of climate change and environmental protection, technological advancements and their influence on the development of energy sector, potentials of available energy sources and energy infrastructure for transport/transmission of energy including import and security and reliability of energy supply. The paper points to big changes in the energy sector, the need of building a new social and economic policy that would be based on improved energy efficiency, renewable energy resources and technologies that enable power generation with minimum CO_2 and other greenhouse gases emissions, or that contribute to significant decrease and efficient use of fossil fuels.

Key words: power sector, technological development, year 2050

1. Introduction

The period from 2010 to 2050 represents a long enough time frame when significant changes are likely to take place under the impact of various influential factors: technological development, growing needs, changes in energy efficiency, limitation of resources, climate change and rise of population. As development constraints, which are caused by necessity to implement measures and activities aimed at preservation of climate as the main influential factor, the period up to the year 2050 can be assessed in advance as a period of discontinuity in respect to former periods. This very fact points to the need for special approach in planning and analysing of this period so as to enable overview of all influential factors.

In the early phase of the observed period Croatia will become the EU member and thus it will share all positive and less positive impacts with other EU members. In the energy sector, the observed period will not be the same and we could differ three stages: the first stage when Croatia will start off with all the problems of a country in transition and a new member by the 2030s, then the medium term and the end of the observed period. Integration of Croatia's economy with the EU economy will gradually grow including the probability for change to the better. This is a process with positive trend.

Development of energy transport for all types of energy by all transport means and infrastructure will enable higher degree of Croatia's integration into international energy market. Of course, higher degree of integration into international flows will increase its exposure to all kinds of market risks, but also risks stemming from political problems, terrorism, wars, natural disasters and similar risks beyond the market. Security of supply is absolutely important influential factor that must be taken into consideration in the planning process.

Development of energy sector must be observed within the scale of IT and communication technologies advancement which can ensure additional improvement of security of supply and efficient use of energy by 'smart' management of energy generation, networks and consumers.

2. Basic influential factors impacting energy consumption

The main impacts affecting the trends in consumption of useful or final energy are: technological development and growing personal and public standard of living which influence increase of energy consumption. Technological development brings new appliances to replace physical work in residential and business premises or improves possibilities for work or use of free time by creating new energy consumers. Personal and public standard of living is closely related to energy consumption through increased surface of housing units and business premises in which various services are offered and increased surface of other business premises. All these factors cause higher final energy consumption.

On the other hand, technological development has positive impact on improvement of energy efficiency. There is a continuous trend of decreasing energy consumption for equal service or use of an appliance. It is realistic to expect further improvements in energy efficiency in the future, both on international level and in Croatia which follows technological advancement, albeit with some lagging behind, however, in due time this lag will decrease and the pace of advancement will be harmonised with other EU countries.

Heating and cooling energy represents a specific problem. In case of new buildings, Croatia can catch up with the EU best practices in a relatively short time by implementing good legislation and monitoring, however, introduction of necessary modifications in the existing housing and business premises, particularly the buildings constructed before 1990 will require considerable efforts and investments. It will be quite an undertaking to design and implement the concept of reconstruction of existing business and residential buildings both from organisational and financial aspect. Apart from realistic energy prices, in the initial phase the reconstruction efforts will require some form of incentives in order to speed up the process.

It is expected that the number of housing units will increase from the current 1.5 to 1.8 million, despite current estimations on decrease of population in Croatia by 2050 from the current 4.43 million to 3.9 million. The other important characteristic of Croatia's residential and business dwellings is that 47% of today's buildings were constructed before 1970 and it is likely to expect that by 2050 at least 25% of the current buildings will be demolished.

According to this assumption, by the year 2050 average heat losses could decrease from the current 200 kWh/m^3 to only 35 kWh/m^3 if 300 thousand new houses and 370 thousand new apartments in buildings were built according to low energy standards, if 460 thousand of today's houses and 390 thousand new apartments were additionally insulated to meet low energy standards, in addition to 225 thousand of today's houses and 45 thousand apartments to be insulated according to average energy efficiency standard. The same applies for the buildings in service sector.

From 2020 onwards, the need for new housing is estimated at 17 thousand housing units per year. In order to achieve 20% lower heat consumption for heating purposes by 2030, it would be necessary to improve insulation of 40 thousand housing units per year.

In the future we can expect higher mobility of people and goods which will result in increased transportation and higher energy needs for this purpose. On the other hand we are witnessing the trend of improved energy efficiency in transport as new generations of engines and tyres require less energy for the same effect. Further development involving hybrid vehicles and electric cars will contribute to improved energy efficiency in transport.

From the point of view of energy buyers, they will be interested in application of new technologies and products for personal and business purposes on one hand, and on the other hand they will be keen to manage and minimise energy costs. Advancement of IC technology in combination with the development of new consumers and appliances will enable achievement of these targets on daily, monthly or annual level.

3. Long-term prospects of smart grids in electric energy systems

Smart grids comprise conceptually wide area characterized by use of modern information, communication and measuring technology which enables improved utilisation of the potentials of traditionally passive grids, including active management of systems depending on given circumstances in real time. Contrary to traditional systems which are managed on the level of large power generation facilities and predominantly passive transmission and distribution grids, smart grids enable managing of systems on lower hierarchical levels down to individual energy consumer at customer's location connected to low voltage system. Also, the direction of energy flow is not necessarily limited to flow from a grid toward consumer, as is the case in traditional systems, but it also enables flow of energy from small sources on customer's location to the grid (ex. from photovoltaic panels or micro co-generations).

Advancement of IC technologies has a key role in the development of smart grid concept as such grids ensure faster, better and more reliable processing and transfer of data. For example, smart measuring devices enable two-way communication between the customer and a grid, by transmitting system management and measurement signals and information on energy price, including monitoring of consumption in real time, contrary to traditional measuring devices which can only record total energy consumption.

Motivation for the development of smart grids can be observed on several levels. On one hand, it is considered that better insight in customer's habits will lead to more efficient use of energy with less burden on the environment. On the other hand, smart grids provide additional flexibility in managing systems in comparison with traditional approach. Strong political support for the development of renewable energy sources and low carbon technologies should lead to significant increase of their share in the energy source structure. Many of these sources (particularly renewable resources) are poorly manageable, while their production oscillates and is quite unpredictable. For this reason it is likely that the need for improved flexibility in managing such systems will become more prominent, although the share of fossil fuel technologies, which even today grant high level of flexibility in managing systems, is expected to decline dramatically.

Growing need for flexible power supply, while at the same time possibilities for such supply become reduced, represents certain gap which in the long run could be resolved by wider implementation of smart grids. Additional advantage of such a solution lies in the fact that in the long term energy consumption in transport and heating of buildings will be transferred to electrical supply system through wider use of electric cars and heating pumps in order to reduce the burden of the entire energy system on the environment (it is assumed that power generation will be based on renewable sources and other low carbon technologies). As for electric cars, these consumers require energy, however they are rather flexible in timing of power supply. Heating pumps would have similar flexibility when equipped with a heat tank. In order to achieve full utilisation of flexibility, it will be necessary to establish mechanisms for measurement and management on different system levels, or to introduce flexible consumers in smart grid operation to enable more efficient and environmentally less harmful operating system. The speed of introduction of new and smart solutions will depend on the support of energy policy makers and achieved increase in share of ecologically acceptable technologies in total energy supply structure.

4. Energy sector development constraints due to climate change and environmental protection issues

The climate change issue or global warming caused by higher GHG emissions, was recognised as a serious ecological and political global problem about forty years ago. In response to climate change challenge, the United Nations Framework Convention on Climate Change (UNFCCC) was established and on the third Convention (COP-3) the parties signed the Kyoto Protocol.

The intention of the Kyoto Protocol was to quantify obligations for reduction of GHG emissions of the developed countries and countries in transition, like Croatia. The Kyoto Protocol also defines mechanisms for easier achievement of undertaken commitments, such as Joint Implementation of Clean Development Mechanisms and International Emissions Trading. The implementation of these, so called flexible mechanisms from the Kyoto Protocol, enables the parties to work toward meeting their own obligations under the Protocol by taking part in an emission reduction project in any other country with a commitment under Protocol and count the resulting emission units towards meeting its Kyoto target. Despite many positive measures, the Protocol has also many shortfalls. The set targets are expressed in percentages, and take into account average emissions in the period from 2008 to 2012 against reference year, so that relatively low emissions per capita in the reference year, make meeting of the set targets more difficult. The other problem is that the emissions reduction obligation is defined only for a smaller number of countries (38 countries of the Annex B to the Kyoto Protocol). Despite considerable shortfalls, the Protocol represents the first serious effort in curbing greenhouse gas emissions.

However, the question is what will happen after 2012 when the Kyoto Protocol expires. A new global agreement on reduction of GHG emissions failed to see the light during the meeting in Copenhagen. It is likely that the parties will come to some compromise at the forthcoming meeting in Mexico or at latest by the end of 2011. Then the agreement would be ready for implementation from 2013 onwards.

According to estimations of the Intergovernmental Panel on Climate Change (IPCC) the developed countries should reduce emissions by 25-40% by 2020 compared to the emissions recorded in 1990, while by 2050 total global GHG emissions should be reduced even by 60-80%. Reduction of anthropogenic GHG emissions by at least 50% by 2050 on global level is a condition precedent for the realization of IPCC's optimistic scenario which foresees concentration of greenhouse gases to 450 ppm and increase of average temperature by 2 °C by 2100 compared to 2000 levels. In case we fail to reduce dramatically greenhouse gas emissions, the concentration of greenhouse gases could go up to 1 000 ppm and average temperature increase by even 6 °C by the year 2100 which might cause unimaginable consequences on climate change.

As the threat of global warming becomes more and more alarming, the European Union has designed its own emission reduction policy and set targets by the year 2020, which include reduction of greenhouse gas emissions by 20%, increase of renewable resources share by 20% and increase of energy efficiency by 20%. The EU has an active role in finding solutions for climate change and is ready to make commitment for curbing emissions by 2020 even by 30%, in case the other countries commit to reduce significantly their GHG emissions. However, without participation of all countries, particularly the USA and fast-growing large countries like China and India, it will not be possible to reduce anthropogenic greenhouse emissions on global level.

For the purpose of greenhouse gas emissions reduction, the ETS (Emissions Trading System) Directive *(2003/87/EC)* was implemented. It defines rules for trading of CO_2 emissions allowances in the EU countries. The system was established in 2005. Currently, the second phase of the ETS is in implementation which is in line with the fulfilment of the Kyoto Protocol commitments for the period from 2008 to 2012. Within the ETS framework, the EU member countries are obliged to limit total emissions from the factories and plants included in ETS Directive, and set allowances for each facility. Emissions allowances are most frequently distributed in such a way that facilities and plants are forced to implement measures for CO_2 emissions reduction or to buy allowance from other plant on the ETS market. The system comprises all 27 EU countries.

5. Technological development and its impact on energy sector development

Technological development is a key influential factor for achievement of development goals of energy sector in terms of radical reduction of CO_2 and other greenhouse gas emissions, specifically technologies that do not produce, or produce minimum level of greenhouse gases, new advancements in the area of fossil fuels and renewable energy sources.

Today we can say that power generation by nuclear fission is a competitive, well known technology with low emission of carbon dioxide. Operational safety of such plants is also at a high level. The share of nuclear plants in total power generation in the world is 14% (according to 2007 IEA data). Most of the plants use second generation Light Water Reactor (LWR) technology. Nuclear plants are primarily used for covering baseload power needs. Availability factor can be over 90%.

Relatively small number of new nuclear plants has been connected to the grid in Europe during the last decade, but some have been put out of operation. The situation is different on international level, particularly in Asia (China, Taiwan, India, South Chorea and Japan), in Russia and South America (Brazil, Argentina) where a number of new nuclear plants is in construction (according to WNA data for September 2010). It seems that power generation by nuclear plants remains stable in the last twenty years. Levelised generation costs decreased thanks to continuous improvements - improved efficiency, higher generation capacity and higher availability. In the last few years we have witnessed growing interest for the construction of nuclear plants (so called žnuclear renaissance') as a reaction to concerns for higher emissions, concentration of carbon dioxide in the atmosphere and consequences in the form of climate change.

Operational experience indicates that the second generation nuclear plants can operate reliably even up to 60 years (which requires implementation of certain procedures for extension of operational life, issuance of permits and other). Technological advancement in preparation and management of nuclear fuel enabled improvements in reactor operation. The construction of the first reactors of the third generation is in progress. They represent a step further in evolution of the second generation with improvements in safety systems and performance. It is expected that in the future period nuclear power generation will remain at least at today's level or grow, as a result of extended operational life of the existing units and construction of new ones. Currently, two 1.6 GWe third generation reactors are in construction in Europe (in Finland and France), with foreseen start of operation in 2012. In Finland this is the first new generation reactor so overnight costs rose from the originally estimated 2 000 EUR/MWe to 3 100 EUR/MWe. Estimated costs of the reactor in France amount to 2 400 EUR/MWe. Investment costs account for 60-70% of levelised generation cost, operational and maintenance cost about 20-26% and fuel costs about 10-15% (including the costs of permanent disposal).[2] Such cost structure indicates that levelised generation cost is very sensitive to investment costs, construction period and financing options.

Geological uranium deposits are relatively large, however, availability projections are always connected with extraction costs (i.e. rise of uranium prices on international market results in larger number of economically viable deposits). According to 2007 forecasts[3], about 5.5 million tonnes of uranium (MtU) could be extracted at the cost lower than 130 USD/kg. Total volume of undiscovered reserves at extraction cost below 130 USD/kg is estimated at 10.5 MtU. Nonconventional resources from which uranium is obtained as by-product (ex. phosphate production) are estimated at 7 to 22 MtU, while sea water reserves are estimated at 4 000 MtU. Sea water uranium production costs are estimated at 300 USD/kg. At current technology and level of electricity generation from nuclear plants, proven uranium reserves are sufficient for about 80 years. If we take into account unproved reserves, the period of uranium use could extend to about 240 years. Apart from uranium, nuclear plants can use thorium the content of which is three times higher in the Earth crust than uranium. Application of thorium would require development of new reactors and fuel cycle.

In case of significant increase of nuclear energy use, the availability of reserves will become a serious issue, particularly in the view of extended life of nuclear plants. An investor must be sure even today that in the next 60 years he will have sufficient fuel for nuclear plant operation. In this context there is a prominent need for the development of the fourth reactor generation. The fast breeder reactors can produce 100 times more energy from the same quantity of uranium in comparison with the current reactors, while at the same time the quantity of waste radioactive material is reduced. During its operation, the fast breeder reactor converts non-fission material (U-238) into fission material (Pu-239) so that total quantity of fission material increases (this is why the reactors are called fast breeder). Treatment of consumed (burned) fuel enables separation of fission material and its reuse as a fuel. The concept of fast breeder reactors has been confirmed in research projects and prototypes; however, it needs further development to make this technology commercially viable. The main challenges in development of this technology are related to application of new materials resistant to high temperatures, higher burn-up, quantity of neutrons, corrosive cooling media, safety issues related to construction of reactors so as to reduce accident risk, reduction of waste material and proliferation of nuclear material. It is expected that the fourth generation reactors will be ready for commercial use around 2040.

Today, nuclear energy is primarily used for power generation. However, it could be applied in various industrial processes such as for example heating, desalinization of sea water, applications in refineries and in oil production, production of synthetic fuels (from CO_2 and hydrogen) and catalytic gasification of coal (converting coal into gas). There is also a possibility of smaller reactors development for some specific applications or use in distant areas. Higher power generation which could be made possible by improved nuclear reactors would represent a significant contribution for fuelling electric cars, which would have direct impact on reduction of harmful emissions from vehicles.

Management of nuclear waste is the most important factor affecting the acceptance of nuclear option by the public. Practically, the only safe method for long-term disposal of nuclear waste is disposal in geological deposits. It is expected that the first such deposit will be opened up in Sweden and Finland by 2020, to be followed by France few years later. Such projects would prove actual viability of such solutions. The development of fourth generation reactors would additionally reduce volumes and heat load of nuclear waste, which would contribute to better utilisation of geological deposits.

The main obstacles for wider use of nuclear power plants are high investment costs and sustainability and stability of revenues generated by the plats in the long run. As a result of slowdown in nuclear plant projects, some nuclear related industries decreased production or closed their operation. Therefore investors have to wait for delivery of some components even several years. Shortage of manufacturing capacity led to higher prices of individual components. There is also a problem of shortage of qualified personnel and decrease of educational programmes on universities. Development and application of nuclear technology requires stable regulatory, economic and political environment.

5.1. Nuclear energy – fusion

In long-term planning and meeting of long-term energy needs, nuclear fusion has certain features which make it quite an attractive option. Nuclear fusion is one of few technologies that offer generation of baseload electricity without CO_2 emissions. Technological breakthrough achieved in this area in the last few decades has been significant and today this technology is considered as a realistic future option for production of huge volumes of electrical energy. However, there are still considerable problems in implementation of this technology and intensive research and development programmes need to be done before its commercial use. The basic advantage of fusion is use of freely available and diffused fuel with significantly lower quantity of radioactive by-products which have short half-life (about 10 years). Key challenges in further development are new materials resistant to high temperatures and strong neutron flows.

The first demonstration plants can be expected after 2030, but it is considered that nuclear fusion could be put into commercial use only around 2050. Specific investments in demonstration plant are estimated at about 14 000 EUR/kWe, while putting into operation a commercial plant could range between 4 000 and 8 000 EUR/kWe.

Considerable problems are also expected in the area of industry motivation and incentives for the development of the technology which can be implemented only after 30 or 40 years. Although there are practically no political hinders in the form of acceptability of nuclear fusion, the public might negatively react to huge investments in research and development necessary to achieve the long-term goal of nuclear fusion application.

5.2. Carbon capture and storage – CCS

Development and implementation of carbon capture and storage technology – CCS, is one of possible solutions for the reduction of CO_2 emissions. Sequestration of CO_2 can be applied in all fossil fuel combustion processes in stationary industrial plants. However, due to high costs of CCS, practical implementation of the technology is limited to large individual emitters. One possible technological solution is separation of CO_2 from other components in flu gases, the other, separation of carbon from fossil fuels before combustion and the third, post-combustion method, is burning fossil fuel in nearly pure oxygen. From the technical point of view, the procedure is implementable at the current level of technological development, but the costs must be decreased and efficiency improved.

When Croatia joins the European Union and gets included in the EU ETS system, the preconditions for systemic implementation of measures for GHG emissions reduction will be met, including technologies for capture and storage of CO_2. According to literature, costs of CO_2 reduction by application of CCS technology amount to 25-80 EUR/t CO_2, depending on CCS method and size and characteristics of the emitting plant. Due to high investment costs, efficiency of separation and sequestration that needs improvement, difficulties in finding appropriate geological sites for CO_2 storage near sequestration units, CCS technology has not been widely applied yet. Nevertheless, if price of emissions credits goes up significantly after 2012 (which is a realistic option) compared to today's price of 15 EUR/t CO_2, the CCS technology might soon become economically viable. Generally, it is considered that this technology could become significant as a method of CO_2 reduction after the year 2020. The application of CCS technology could make possible operation of thermal power and industrial plants fired by fossil fuels almost without CO_2 emissions.

The CCS technology has a prominent role in energy planning, at least in the European Union. The Directive (2009/31/°C) on the geological storage of carbon dioxide confirms such orientation. According to the Directive, all new fossil fuel fired thermal plants with installed capacity equal to or exceeding 300 MWe must have reserved space for subsequent installation of CO_2 sequestration unit, but also defined location for CO_2 storage including solution for its transport from the plant to the place of storage.

6. Potentials of available resources

6.1. Hydro power

Total technically usable hydro potential for hydro plants in the Republic of Croatia is estimated to around 12.45 TWh/year. Out of this total, current hydro plants use around 6.13 TWh/year or 49.2%. So, there is about 6 TWh technically usable hydro potential. However, each day the available hydro potential is declining as a result of occupation and use of space for other purposes, because of environmental issues and protests by the public.

The remaining hydro potential on medium and larger water flows in Croatia could be used by some 60 hydro plants with total installed capacity of about 1 287 MW at average power generation of about 5 816 GWh/year. Since part of the hydro potential is located on the rivers bordering with Hungary, Slovenia and Bosnia and Herzegovina, Croatia's share is about 1 027 MW or about 4 614 GWh of average power generation.[1] A portion of hydro potential will remain unutilised due to ecological and other constraints; consequently it is realistic to expect that in new plants in the long run Croatia can utilise maximum up to 3.0 TWh/year.

About 10% of total technically usable hydro potential refers to small water flows (about 1 TWh/year. Review of small water flows and preparation of the "Cadastre of small hydro plants – 1st Phase" and "Cadastre of small hydro plants – 2nd A Phase" listed 63 potential sites, but until now only 20 sites were examined and analyzed. It was found that there are total 67 potential available locations for hydro plants up to 5 MW. However, further analyses showed that only smaller number of sites (18) can really be used for construction of small hydro plants because realization of such projects requires meeting of numerous preconditions (physical planning, environmental protection, economic viability etc.).

In case of 5 to 10 MW hydro plants, according to available sources, construction of such plants could render total of 125 MW, however, further research needs to be done which could show that fewer plants can really be constructed than previously expected.

If we take into consideration the above, including the fact that additional research needs to be done, it can be estimated that Croatia's potential for construction of small hydro plants is around 100 MW.

It is likely that the implementation of EU Water Framework Directive (WFD) in the member states will cause decline in hydro generation. Inconsistent implementation of the Directive might aggravate the situation. This leads to significant decrease in construction of new small hydro plants and higher costs, to the extent that in some EU members it is considered as a main obstacle for the development of small hydro plants.

Meeting of strict environmental standards in water management can sometimes limit generation capacity of a plant, but it can also be a trigger for innovation and improvement of performance of a hydro plant. Harmonized political framework and simplified administrative procedures remain the most important challenge that must be addressed. High transaction costs (concession, permits, etc.) pose additional problem in case of small hydro plants.

6.2. Biomass

Biomass is the most complex renewable energy source and its technical potential depends on measures that are in force: the same source can provide all three forms of final energy (electricity, heat and mechanical energy in the form of bio fuel). Economic potential depends on price of biomass which is not affected only by demand and supply movements but also by costs of production and preparation for energy conversion and transport costs. Biomass is the only renewable energy source for which place of production can be separated from the place of energy conversion and it is the only alternative energy source that can be cultivated for specific purposes. Theoretically, biomass potential will depend on the approach methodology: Croatia's biomass potential can be estimated to available 28.34 PJ (forests, biogas from agriculture and waste water purification plants, waste energy) while additional 20 PJ could be cultivated through planting of energy wood (forests) or energy crops (agriculture).

Lack of appropriate systemic measures for the production and use of biomass on national level can lead to inefficient and unsustainable use of energy from biomass and its export from forest and agriculture industry. Additional argument for the design and implementation of an action plan is the fact that biomass can render two different forms of useful energy. Technical potential of biomass utilisation will vary depending on government incentives and national goals. The most efficient way of biomass utilisation is heat generation and cogeneration. However, today, the existing incentive system for use of renewable energy grants incentives only for power generation from biomass. Thus, even up to 80% of theoretical biomass potential is lost, while in case of heat generation this loss could be decreased to only 10% and in case of co-generation to 20%.

Great hope is being placed on second generation bio-fuels which are made from lingo-cellulosic biomass feedstock instead of food crops.

Bio-gas is usually used for co-generation, however, recently considerable attention is paid on purification of bio-gas to obtain pure methane which can be then injected in natural gas grid. In this case bio-gas could become a substitute for natural gas.

6.3 Wind

Current situation in Croatia in the area of wind power development can be briefly described as follows:

- 137 wind farm projects have been registered with total 5 430 MW
- out of the above total only 246 MW (4.5%) projects are onshore projects
- out of total registered projects, only 80 MW is currently in operation or in commissioning phase
- Croatian government's goal of 5.8% power generation from renewable sources by 2010 was not achieved i.e. only 13% of set goal was met.

According to European Wind Energy Association – EWEA the long-term plans for wind power development are very ambitious and foresee extensive development of offshore and onshore wind farms by 2030 and after that more focus on offshore wind farms by 2050 (Table 1).

Today's capacity is around 80 GW, out of which only 3% refers to offshore wind farms. Croatia's projections for the development of wind farm projects also include onshore and offshore plants. In consideration of wind projects it is necessary to take into account the development of wind turbine technology such as (1) wind generators for less windy sites (high generators with over 100 m rotor diameter) and (2) offshore wind farm pontoon projects. Development of wind turbines for less windy locations is well in progress and such turbines are in the market, while offshore pontoon technology is in early development stage.

Projection of onshore wind capacity can be made roughly on the basis of 137 projects listed in the Register of renewable energy and co-generation projects (OIEKPP) with total 5 430 MW. The projection by the year 2050 assumes that over 50% of currently registered projects will be realized, together with some new projects in now less attractive continental part of Croatia by using new types of wind turbines for less windy sites. The wind farm outlook by 2050 is as follows:

- Total installed capacity of onshore wind farms: 5 000 MW
- Average potential production of wind energy onshore: 2 200 FLH
- Average annual potential production of onshore wind farms: 11 TWh.

Table 1. (source: Pure Power, EWEA, 2009)

Year	Wind farms - capacity (GW)			Power generation (TWh)		
	Onshore	Offshore	Total	Onshore	Offshore	Total
2020	210	55	265	479	204	683
2030	250	150	400	592	563	1 155
2050	250	350	600	635	1 380	2 015

Provided pontoon foundations for offshore turbines, as only feasible solution for deep sea wind farms at this moment, the projections of offshore wind farms development are mainly based on (1) higher potential production of wind energy due to generally better wind conditions – around 3 000 FLH and (2) more available space which is important for respecting basic design principle regarding prescribed distance between turbines. An estimate of necessary space as a resource is as follows:

Planned production	40 TWh
Capacity for assumed potential production of wind energy of 3000 FLH	13 500 MW
Number of units if capacity per unit is 5 MW	2 700
Number of offshore turbines under assumption 60 VTG per turbine (300 MW)	45
Surface of one wind turbine (rectangle) under assumption of construction in three rows	14 km^2 (10 km x 1.4 km)
Surface of all offshore wind turbines	630 km^2

Just for a comparison: the surface of the island of Krk in the Adriatic is around 405 km^2.

It is important to note that total surface depends considerably on the size and type of wind turbine.

6.4. Solar

At this moment the photovoltaic technology is one of the most expensive technologies for power generation, which in combination with relatively low energy efficiency makes the price of solar energy high. It is likely that the cost of photovoltaic technology will decrease in the future. As it is certain that price of electricity will grow, with improved photovoltaic technology, the price of solar energy will be equalised with the price of electricity generated from other sources. Croatia is located in the Mediterranean belt with relatively good potential for use of solar energy. It is likely to expect that prices of electricity from other sources and solar will be at equal level between 2030 and 2040, after that the capacity of photovoltaic systems will additionally grow. It is foreseen that by the year 2050 both centralised solar plants and small photovoltaic units on roofs and facades of buildings will be developed simultaneously. There are good potentials for the construction of solar concentrated plants using the sun's radiation on specific sites in Dalmatia.

It can be expected that by the year 2050 total installed capacity of photovoltaic systems will be above 1 500 MW, out of which 500 MW would be generated by centralised solar plants with individual capacity ranging between 10 and 30 MW, while the remaining capacity of around 1 000 MW will be installed on roofs and facades of buildings. The development of solar concentrated plants will be limited to sites with exceptionally favourable solar and space resources and it is likely to expect about 100 MW of installed capacity based on this technology. According to these predictions, total produced solar power would be around 2.1 TWh.

6.5. Gas

Croatia's natural gas reserves are estimated at 36 436.1 million m^3. It is expected that domestic gas production available for the Croatian market will gradually decline from around 2 billion m^3 to 500 million m^3 in 2030.

At the end of 2008 global proved natural gas reserves were estimated at 180 quintillion m^3 which is more than enough to meet demand by 2030. More than half of world natural gas reserves are situated in Russia, Iran and Qatar.

Total natural gas reserves are considerably higher than proved reserves and it is estimated that additional 400 quintillion m^3 of gas can be produced from conventional sources, which is enough for 130 years at current rate of production and consumption. Non-conventional gas resources are estimated at 900 quintillion m^3 of gas, out of which 380 quintillion m^3 is most probably recoverable from technical and commercial point of view.

6.6. Potentials of CO_2 storage

According to EU GeoCapacity Consortium data 2006-2008, Croatia has exceptionally favourable conditions for CO_2 storage, both in the Pannonian and Adriatic basins. (Table 2)

Considerable volumes could be stored in aquifers, while smaller volumes could be stored in hydrocarbon deposits. Under the assumption that total CO_2 storage capacity is used during hundred years, the potential of annual storage ranges from 30 to 40 Mt CO_2. Such annual capacity would be sufficient for storage of annual CO_2 emissions from 5 000 – 7 000 MW coal fired thermal plants which would correspond to their annual power generation of 35 to 50 TWh.

7. Potentials of infrastructure for transport/transmission of energy and its import

7.1. Electricity

In the last five years Croatia imported between 14% and 25% of electricity for meeting its domestic demand. Possibility of import into Croatian electrical energy system is limited by availability of cross border transmission ca-

Table 2.

CO_2 storage capacity	Category of assessment	Conservative assessment (Mt)	Assessment in data base (Mt)
Storage capacity in aquifers	Theoretical	2 710	4 067
Storage capacity in hydrocarbon deposits	Realistic	189	189
Storage capacity in coal deposits	N/A		
Total estimated storage capacity	Theoretical	2 899	4 256

pacity. Estimated capability of continuous import was until recently around 500 MW which results in maximum possible annual import of about 4.38 TWh, so, obviously in 2008 we reached maximum possible level of import and any additional shortage (ex. caused by increased consumption) could have endangered security of supply. In the meantime, the construction of a new interconnector with Hungary has commenced. It will enable additional import, but to a limited extent, depending on capacity of Hungarian transmission grid. Considering present deficit in electric energy balance of the countries in the region and lack of new power plant building, it will be important to undertake coordinated regional activities in the forthcoming period in order to increase flow capacity of regional transmission grids and maximise utilisation of the existing cross border transmission capacity, not only for the purpose of intensifying market activities but to ensure security of supply.

7.2. Gas

Croatia's natural gas import capacity from the direction of Slovenia is 1.5 billion m^3/year. The interconnector toward Hungary with the total capacity of 6.5 billion m^3/year is under construction. The long-term considerations for construction of LNG terminal in the Adriatic where favourable conditions exist for such facility, are still an option. The other option is connection to the international Trans Adriatic Pipeline (TAP). If only a part of these new gas supply routes is realised, Croatia will ensure sufficient capacity for secure supply. However, these pipelines must be connected to large international pipelines that will go through the region.

A number of large gas pipeline projects have been proposed for the region. Total capacity of all considered projects would be over 130 billion m^3/year. In the short term, all these projects can neither ensure big enough market, nor sources of gas supply. Although the final aim of all these pipeline projects is supply of gas for the western European market, it is clear that their implementation would also contribute to gas supply of the countries on their route. In the short run it is likely to expect that at least one large capacity pipeline construction project and two smaller ones could be realised. The most prospective projects seem to be South Stream, Nabucco and TAP. The realisation of at least one of them would ensure sufficient volumes of natural gas for consumers in Croatia.

7.3. Crude oil

Fuels refineries in Croatia are mainly supplied with imported crude oil as indigenously produced oil meets only about 20% of domestic needs. Crude is supplied partly through the Adriatic pipeline – Jadranski naftovod – JANAF, which is connected to five refineries in Croatia and the region: Rijeka, Sisak, Bosanski Brod, Novi Sad and Pančevo. Crude is supplied from the Mediterranean through the terminal in Omišalj and Russian oil through the Druzba pipeline from Hungary. Also, JANAF can provide transport of oil for the refineries in Hungary, Slovakia and Czech Republic; its pipeline installed capacity is 20 million tonnes/year but current utilisation is about 10 million tonnes.

Among larger development projects related to crude transport is certainly the Druzba Adria and Pan European Oil Pipeline – PEOP. Druzba Adria represents the project of Russian crude export to the international market by using free capacities of the existing oil pipelines within Druzba and JANAF pipeline systems which are 2 200 km long and extend from Samara in Russia, through Belarus, Ukraine, Slovakia, Hungary and Croatia to the tanker port and terminal in Omišalj. The Druzba and JANAF pipeline system are connected through the Adria pipeline at Szazhalombatta in Hungary and can enable transport of oil from Russia to Sisak.

PEOP project has been designed for transport of Caspian oil to consumers in Europe. Its aim is diversification of oil supply and decrease of tanker transport through the Adriatic Sea. Despite the fact that the main target of both projects is the supply of Western European markets, their realisation would certainly improve security of supply in all countries on their route.

In Croatia distribution of oil products is predominantly organised by truck and rail. In this context one of more significant projects in the oil sector is construction of product lines in order to ensure more efficient and secure supply, and at the same time to decrease harmful impact on the environment.

8. Possible structural changes in energy generation and consumption

Reduction of CO_2 emissions to 50% or more compared to initial amount for Croatia by the year 2050, along with growing consumption of energy, inevitably lead to conclusion that the structure of consumption and generation of energy will differ greatly from the current status. What processes can be expected:

- Decreased use of plants and facilities with fossil fuel combustion technologies on the buyer's (consumer's) side, or in technology process for energy generation.
- Development of CO_2 capture and storage technology and development of pipeline grid for transport of CO_2, will enable concentrated use of fossil fuels in thermal plants or larger industrial power plants in which application of this new technology will be economically viable.
- Growing consumption of electricity as a substitute for fossil fuels for heat generation and in vehicles for mobility.

Depending on the level of CO_2 reduction by 2050, expected electricity consumption will range from 40 to 60 TWh. Of course, all power generation will have to be practically free of CO_2 emissions.

According to analysed potentials of power generation from biomass and solar plants, it is clear that these potentials are lower than those offered by hydro, wind or coal or gas fired plants with CO_2 sequestration and storage, or nuclear plant. However, estimated potentials for power generation with minimum CO_2 emissions are sufficient for production up to 70 TWh, including hydro plants and most probably combination of all three, CO_2 free, power generation methods. It can be concluded that Croatia has sufficient resources in hydro potential, sea and wind, aquifers and tradition in nuclear generation, to ensure significant reduction of CO_2 emissions in the Croatian energy system.

9. Security and quality of energy supply

Social and economic development is growingly dependant on energy. Energy has also become a measure of social and civilisational inclusiveness. In the context of such trends, the level of integration of energy in overall development of a society, security and quality of energy supply become even more important, while on the other hand risks and consequences of incidents in energy supply pose a threat to normal functioning.

Apart from technological and energy aspect of security and quality of supply, security policy must also comprise all other influential factors that come from politics, wars and terrorism and economic crises.

Therefore it is important to identify entities that are responsible for each form of energy on national level, to realize construction of necessary infrastructure and to ensure funding of security and quality of supply.

10. Comment of the process

Review of possible energy future by the year 2050 and analysis of key challenges was performed with the goal to pinpoint to significant changes that can be expected in the entire energy sector: from generation, transmission and transport, distribution and energy consumption. For the achievement of these changes, we have to direct all activities aimed at meeting set targets already today, based on new philosophy of social and economic development. The key components of the new social and economic philosophy will be:

- Selection of technologies that ensure reduction of carbon dioxide and other GHG emissions which assumes providing support to technological development of a country and industrial breakthrough;
- Creation of social, legislative and economic climate that will facilitate achievement of long-term development goals based on improved energy efficiency, renewable energy sources and use of CO_2 free technologies or technologies which contribute to reduction of harmful emissions
- It is important to commence these processes "today" and the first step should be preparation of the document that will involve social, economic and energy development by the year 2050.

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Author:
Goran Granić, DSc, Energy Institute Hrvoje Požar, Zagreb Croatia, ggranic@eihp.hr

Contributors:
Damir Pešut, MSc
Mladen Zeljko, DSc
Robert Bošnjak, MSc
Biljana Kulišić, MSc
Mario Tot, MSc
Željko Jurić, MSc
Lazlo Horvath, MSc
Andro Bačan, grad. eng
Željka Hrs Borković, grad. eng
Nikola Matijašević, grad. eng
Goran Majstrović, DSc
Robert Fabek, MSc

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