# Possible development of the Croatian energy sector by 2050 in the view of carbon dioxide emission reductions

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REVIEW

**The paper analyses a key question: Is it possible to achieve growth of the Croatia's energy sector in conditions when $CO_2$ emissions must be reduced by 80 percent by the year 2050, and what might be the consequences of this process? In considering this issue, the paper deals not only with expected increase of costs, but it also takes into account desirable effects on the development of technology, science and economic growth including creation of higher value added.**

**For the purpose of energy sector development projections by 2050 the authors used two models in modelling energy systems:**

- **MAED – Model for Analysis of Energy Demand[1],**
- **MESSAGE – Model for Energy Supply Strategy Alternatives and their General Environmental Impacts[2]. MESSAGE applies the results obtained by MAED model as input data and assumptions.**

**Possible developments in the sectors such as industry, households, services and transport were modelled by using simulations as a tool to evaluate their performance in terms of implementing measures for reduction of $CO_2$ emissions for that individual sector in line with the targets set by the European Union.**

**In 2050 the average cost of electricity generation is expected to increase by almost 140 percent compared to 2015.**

**Reduction of $CO_2$ emissions by 80 percent in total energy sector in Croatia, and 95 percent in electricity sector, is possible from technical and technological point of view, however with high costs and significant changes in the entire energy sector, which must be preceded by advancements in scientific and industrial development.**

*Key words:* energy sector, Croatia, development by 2050, electricity sector, $CO_2$ emission reduction.

## 1. Introduction

Measures to be implemented to mitigate climate change have strong influence on the vision of the entire energy sector. These measures should gradually decrease total emissions of carbon dioxide ($CO_2$). This paper explores opportunities and consequences of meeting the targets for the reduction of $CO_2$ emissions in energy sector by 80 percent compared to the reference year 1990. The 80 percent reduction target is set in the European Commisssion document: A Roadmap for Moving to a Competitive Low Carbon Economy in 2050.[3]

Low carbon economy concept focuses on possibilities offered by improved energy efficiency, higher share of renewable energy, advancements in the existing and introduction of new technologies, further use of fossil fuels fitted with carbon capture and storage facilities (CCS[4]), improved sustainability of possible solutions and their economic effects. Nuclear option has not be considered to avoid overshadowing critical issues of energy sector development by political dimension of building nuclear plants.

The analysis of possible developments by 2050 includes consideration of structural changes in the energy sector reflected in different methods of energy generation and consumption, expected technology breakthroughs and their improved efficiency, improved methods of energy storage and commercialisation of individual technology options.

The observed period will be marked by strong development of ITC technologies. It is likely that after 'smart measurement' and 'smart grids', a new era of 'smart energy' will pave its way, i.e. the era in which services will be adjusted to individual user's needs, providing simultaneously efficiency, improved quality and optimal use of a service, choice of services and billing communication.

The key question is: Is it possible to achieve growth of Croatia's energy sector in conditions when $CO_2$ emissions must be reduced by 80 percent by the year 2050, and what might be the consequences of this process? A possible consequence is not only expected rise of costs but also desirable effects related to the development of technology, science and economic growth including cre-

1 Model for Analysis of Energy Demand (MAED-2), Computer Manual Series 18, International Atomic Energy Agency, 2006
2 MESSAGE - Model for Energy Supply Strategy Alternatives and their General Environmental Impacts, User Manual, International Atomic Energy Agency, June 2007
3 European Commission: A Roadmap for Moving to a Competitive Low Carbon Economy in 2050, 2011
4 Carbon Capture and Storage

ation of added value. Understanding of new trends and timely actions to meet the set targets, including assumptions for their realization by 2050, open up possibilities for designing economic strategy for the forthcoming period that will be based on new technologies and innovations.

## 2. Proposal of EU strategy for emissions reduction by 2050

International community is confronted with the challenges of climate protection and change of the attitude toward exploitation of natural resources, protection of the environment and technology development. The European Union is a global leader in pursuing active policy for mitigation of climate change and implementation of low carbon economy. Croatia, as a new EU member has harmonized its legislation framework and follows the EU policy in the area of climate change mitigation.

According to assessments reported by Intergovernmental Panel for Climate Chage (IPCC), anthropogenic emissions of greenhouse gases in developed countries should be reduced by 25-40 percent until 2020 relative to 1990. By 2050 total global greenhouse gas emissions need to be reduced by minimum 50 percent, while developed countries should reduce anthropogenic emissions of greenhouse gases by 80-95 percent. A 50 percent emission reduction on global level by 2050 is a precondition for realization of the IPCC's optimistic scenario which foresees stabilisation of greenhouse gases concentration on 450 ppm and increase of mean temperature by around 2 °C up to 2100 relative to the year 2000. If emissions are not reduced, the concentration of GHG gases could rise to 1 000 ppm, and temperature could rise even by 6 °C up to 2100, with unforeseeable adverse effects on climate.

In its efforts to combat climate change, the EU set the following targets for the period up to 2020: reduction of antrophogenic greenhouse gases by 20 percent, increased share of renewable energy sources by 20 percent and improvement of energy efficiency by 20 percent. The European Union countries are ready to decrease emissions on their territory by more than 20 percent if other UNFCCC members fulfil their commitments. However, far greater emission reductions are needed by 2050, and the EU plans to reduce emissions by at least 80 percent in line with IPCC recommendations. This is the only possible solution in terms when the existing models of economic and energy sector development fail to evaluate properly the costs of harm to the environment and natural resources.

In the process of designing the EU targets for 2050, various sectoral analyses were performed and framework objectives defined for 2030, 2040 and 2050 in order to achieve gradual transition toward a competitive low carbon economy. European Commission modelled several scenarios that would lead to the desired 80 percent decrease of emissions in 2050 compared to 1990 levels. In order to achieve set targets, it will be necessary to intensify activities aimed at emission reductions, because the existing development model can ensure only 40 percent reduction. The reduction targets for individual sectors are presented in Figure 1 below.

The analyses of each sector's contribution to emission reduction indicate that the highest reduction is expected in power generation sector with around 95 percent reduction of GHG gases in 2050, relative to 1990, expected emission reductions in buildings (households and services) are also high - around 90 percent; they are followed by industry (around 85 percent), transport (around 60 percent), including non-energy sectors (agriculture, forestry, waste management...). Table 1. shows expected emission reductions in 2030 and 2050 relative to 1990 for denoted sectors, and the comparison of emissions in 2005 against the reference year 1990.

**Table 1. Achieved emission reductions in EU countries in 2005 and expected reductions in 2030 and 2050 relative to 1990**

| | 2005. | 2030. | 2050. |
|---|---|---|---|
| Power generation | -7% | -54 to -68% | -93 to -99% |
| Industry | -20% | -34 to -40% | -83 to -87% |
| Transport | +30% | +20 to -9% | -54 to -67% |
| Households and services | -12% | -37 to -53% | -88 to -91% |
| Agriculture | -20% | -36 to -37% | -42 to -49% |
| Other sectors | -30% | -72 to -73% | -70 to -78% |
| Total | -7% | -40 to -44% | -79 to -82% |

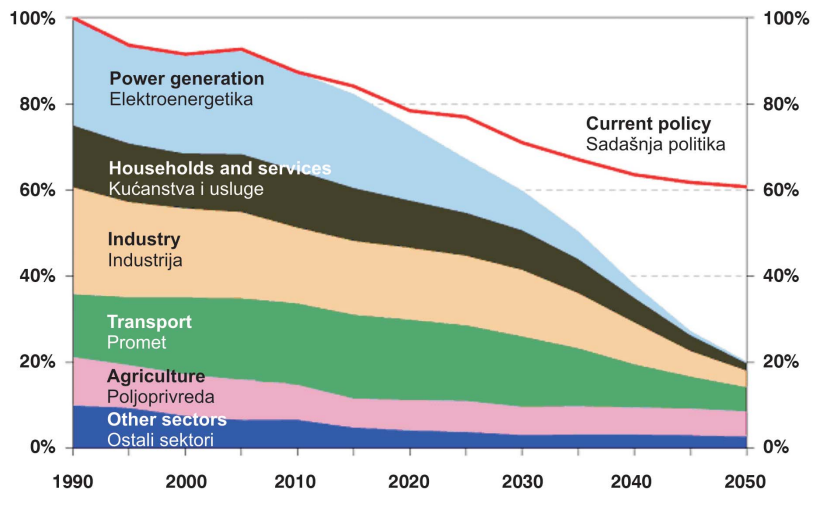


**Fig. 1. Expected reduction of GHG emissions in the EU by 2050**
Sl. 1. Očekivano smanjenje emisije stakleničkih plinova u EU do 2050. godinu

Power generation sector should play a key role in transition to the low carbon economy in the European Union. Scenario analyses indicate that it is possible to almost eliminate $CO_2$ emissions from power generation with higher use of electricity generated by low carbon, or carbon free technologies and use of so generated electricity in transport, household and services sectors. Nevertheless, in absolute terms electricity consumption will keep on increasing in the indicated sectors, however thanks to improved efficiency and way of electricity use, the pace of increase will remain at today's growth rates.

Following the short overview of the EU document, Roadmap for moving to a competitive low carbon economy in 2050, this paper explores how Croatia can achieve 80 percent reduction of $CO_2$ emissions in power generation sector until 2050 compared to the reference year 1990.

## 3. Key assumptions for the projection of Croatia's energy sector development by 2050

For the purpose of energy sector development projections by 2050 the authors of this paper used two models in modelling energy systems:

- MAED – Model for Analysis of Energy Demand[5],
- MESSAGE – Model for Energy Supply Strategy Alternatives and their General Environmental Impacts[6]. MESSAGE applies the results obtained by MAED model as input data and assumptions.

Possible developments in the sectors such as industry, households, services and transport were modelled by using simulations as a tool to consider possible development paths to achieve reduction of $CO_2$ emissions for that individual sector in line with the targets set by the European Union as described above.

The development of the Croatian power generation sector was modelled by using optimisation-simulation models which included the key demand - gradual reduction of carbon dioxide emissions. In several iterations of models, adjustment of sectoral targets and assumptions on implementation of measures for curbing emissions, a possible path of the energy sector development was projected that will ensure 80 percent reduction of $CO_2$ emissions in 2050, relative to 1990.

The key assumptions for modelling final energy consumption were the following:

- Population numbers will gradually decline and by 2050 Croatia could have 3.86 million people (projection by *United Nations, Department of Economic and Social Affairs, Population Division*),
- GDP per capita is expected to rise 5.5 times by 2050 to amount $USD_{2000}$ 30 000,
- The role of industry in the economy will be more prominent and despite technical improvements it is expected that the consumption of energy will rise,
- Freight transport will be dominated by electric traction and CNG, while in passenger car segment the share of electric cars is expected to grow to 50 percent by 2050,
- Up to 2050 half of the buildings will be newly constructed, while the other half will have improved heat insulation; accordingly, in 2050 heat losses of total building fund will be 27 kWh/m$^2$ of heated surface,
- In 2050 energy consumption for household heating will be as follows: 40 percent modern biomas, 30 percent heat pumps, 20 percent supply from heating plants and only 10 percent natural gas; 30 percent of water heating by solar collectors,
- Surface of service sector facilities will continue to grow, however, the measures aimed at reduction of heat losses will result in acceptable level of 25 kWh/m$^2$; similar structure of heating and hot water consumption is expected in households.

The key assumptions and development directions of the Croatian power generation sector are the following:

- The increase of $CO_2$ emissions is allowed by 2025 when they could reach the level of around 7.8 million tonnes. After 2025 the emissions will be gradually curbed and reduced to 0.5 million tonnes in 2050,
- Wider application of CCS technology is likely to start after 2020, either as new projects or subsequent build in the existing power plants. Estimated efficiency of CCS facilities is 85-90 percent,
- Construction of new nuclear plants has not been considered. It is assumed that the nuclear plant Krško will remain in operation till the end of 2032.
- It is assumed that some additional hydro capacity of around 750 MW will be constructed (of which 200 MW small hydro plants),
- Wind power plants capacity will grow to total 5 000 MW on locations around the coast and hinterland, including offshore locations. Development of offshore wind farms is expected after 2030,
- Construction of solar thermal power plants[7] with possibility of heat storeage, is not expected before 2020. It is assumed that the costs of construction of such plants will significantly decline by 2050, by roughly 40 percent compared to the current level of costs. Total potential of this technology by 2050 is estimated at 1 500 MW.

## 4. Possible scenarios of Croatian energy sector development by 2050

Further in the text we present the most important results of conducted analyses.

Final energy consumption according to segment of consumption is presented in Figure 2, while Figure 3 pres-

5 Model for Analysis of Energy Demand (MAED-2), Computer Manual Series 18, International Atomic Energy Agency, 2006
6 MESSAGE - Model for Energy Supply Strategy Alternatives and their General Environmental Impacts, User Manual, International Atomic Energy Agency, June 2007
7 CSP – Concentrated Solar Power

ents forms of energy and their final consumption. In the period up to 2035 it is expected that total final energy consumption will grow despite intensive measures for boosting energy efficiency on all levels, particularly in the area of heat insulation improvements and intensive renewal of housing units. After 2035 it is likely that structural and technological improvements, including enhancement of energy efficiency, will reach the level which will enable gradual decrease of final consumption. In 2050 final consumption will be higher by 5.9 percent compared to 2010.

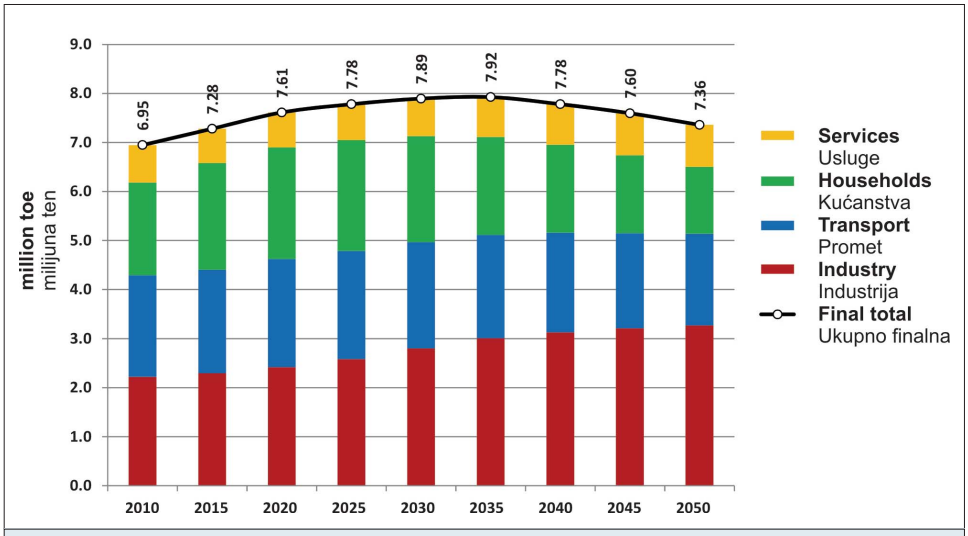


**Fig. 2. Final energy consumption in various sectors of consumption**
Sl. 2. Finalna potrošnja energije po kategorijama potrošnje

Review of final energy consumption in various sectors by 2050 indicates that final consumption will decrease in transport (from the current 2.07 million toe to 1.87 million toe, a 9.7 percent drop) and households (from the current 1.89 million toe to 1.37 million toe, a 27.8 percent drop). In the same period the final energy consumption in services sector will increase by 12.1 percent (from the current 0.76 to 0.86 million toe), with the highest increase in industry sector – 47.1 percent (from the current 2.22 to 3.27 million toe).

Hence, the structure of final consumption will change by 2050 with the industry having the highest share of 44.4 percent (up from the current 32.0 percent), followed by transport – 25.4 percent (down from the current 29.8 percent). The share of household sector is expected to decline from the current 27.2 percent to 18.5 percent, while the share of services sector is likely to remain at almost equal share (slight increase from the current 11.0 percent to 11.6 percent).

The structure of energy forms for meeting final energy demand will be also changed:

- Electricity consumption will significantly rise in all sectors; from the current 1.37 to 3.17 million toe in 2050, which represents an increase of about 130 percent or average annual increase of 2.1 percent. In combination with carbon free power generation, such a scenario would enable meeting of set targets for the decrease of total $CO_2$ emissions. In 2050 the share of electricity will rise to 43.0 percent of final energy consumption (which is significant increase from the current 19.7 percent)
- Fossil fuels consumption will decline from the current 4.84 to 2.28 million toe in 2050, which is a 52.9 percent decline. In 2050 the share of fossil fuels in final consumption is foreseen at 31.0 percent (a decrease from the current 69.6 percent)
- The share of renewables (fuel wood, modern biomass, solar and biofuels) will increase by 228 percent. The share of renewables in final consumption at the end of the observed period will be 22.2 percent. If we add electricity and heat (centralized heating systems) generated by renewable energy sources, the share of renewables in meeting total final consumption would be 55.3 percent
- Modern biomass systems will gradually replace use of fuel wood.

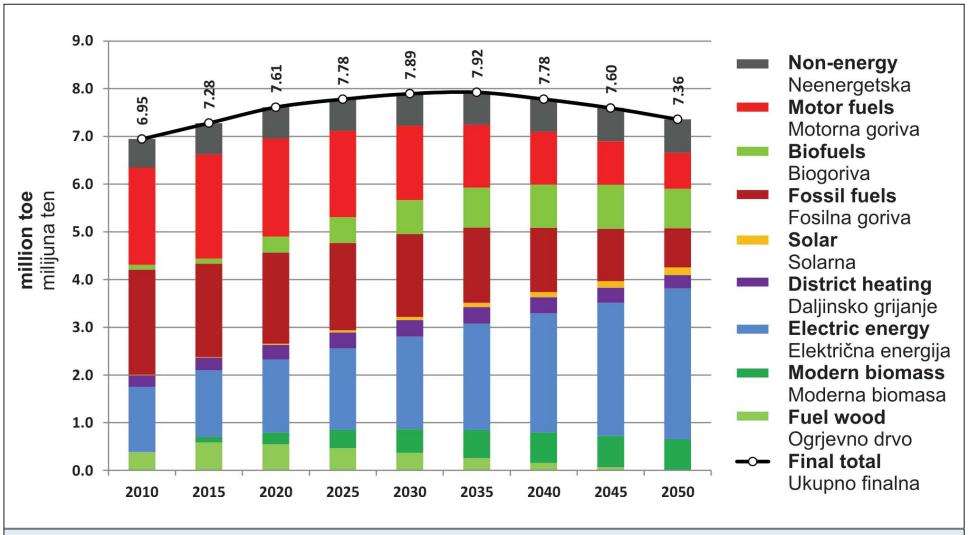


**Fig. 3. Final energy consumption according to energy form**
Sl. 3. Finalna potrošnja energije po oblicima energije

Some significant changes will have to be introduced in the power generation sector as well, particularly after 2030 when the imposed limitations of $CO_2$ emissions will growingly replace the use of old fossil fuel technologies. Natural gas has advantages in comparison with coal due to lower emissions per generated electricity unit, however, after 2030 even gas driven plants will have to be fitted with CCS facilities for sequestration and storage of $CO_2$.

It is expected that after 2030 the development of renewable sources will intensify and will include wind farms, solar thermal plants and PV solar plants. The share of electricity generated by wind farms will grow to reach 37.5 percent (16.2 TWh) in 2050. The share of power generated in solar thermal plants is 21.6 percent (9.3 TWh). Total share of power generated by renewables at the end of the period is 80.3 percent. The remaining share refers to power generation in natural gas or coal fired power plants fitted with CCS facilities. The structure of power generation is presented in Figure 4.

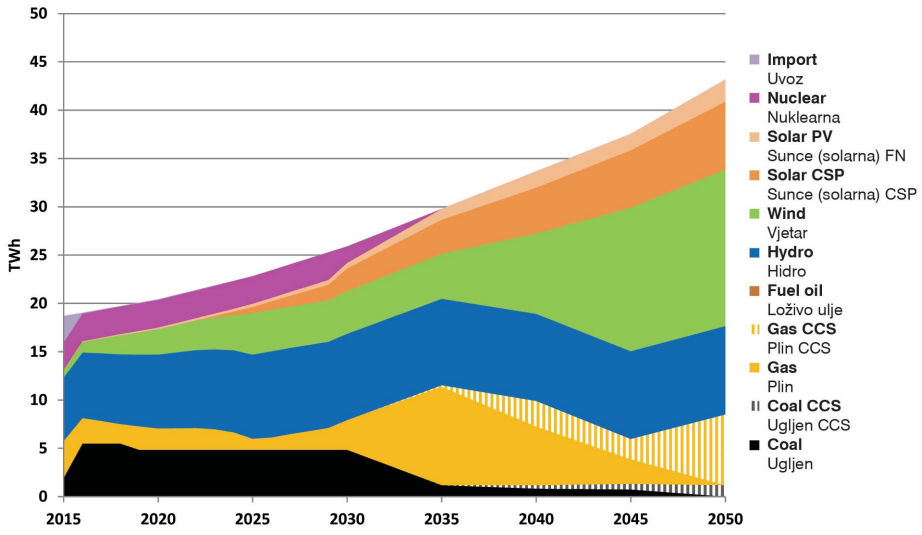


**Fig. 4. Structure of power generation**
Sl. 4. Struktura proizvodnje električne energije

At the end of the period the total installed capacity of power generation plants is expected to reach 14.3 GW with almost 100 percent spare capacity. The installed capacity of power generation from renewables will grow to 10.6 GW or 74 percent of total power generation in 2050. At the end of the observed period only one coal fired power plant 500 MW will remain in operation plus 3 200 MW generation in gas fired plants. The application of CCS systems will intensify after 2035, with accelerated speed after 2045. At the end of the period all thermal plants will be fitted with CCS systems.

Ovareall results of the simulations run indicate that it is really possible to meet the 80-percent $CO_2$ emission reduction targets by 2050. Table 2. and figure 5. show total $CO_2$ emissions in respective years and reductions of $CO_2$ emissions in individual segments of consumption.

The structure of values in acheiving overall targets differs from the EC projections at EU level. The discrepancy is explained by the fact that the structure of emissions in the reference year is significantly different in Croatia compared with the EU average. In order to meet set targets, the highest emission reductions must be achieved in industry (over 90 percent), and the lowest in transport segment (around 54 percent). In other segments the required emission reductions are about 80 percent.

Estimated total $CO_2$ emissions from all energy segments in 2050 are 4.1 million tonnes in which transport will have the highest share of 45 percent.

According to the projections, carbon intensity per capita will be 1.06 tonnes in 2050, 72 percent lower than in 1990 when it was 3.81 tonnes. Reduction in carbon intensity per capita is slightly lower than modelled $CO_2$ emission reductions by 2050 (80 percent) as a result of assumed decline in population number in Croatia.

## 5. Key messages derived from the analyses

Significant reduction of carbon dioxide emissions requires equaly significant, demanding and extensive mea-

**Table 2. $CO_2$ emissions in the Croatian energy sector and possible reductions compared to 1990**

| | $CO_2$ emissions in million tonnes | | | | | Change of emissions against 1990 in % | | |
|---|---|---|---|---|---|---|---|---|
| | 1990. | 2010. | 2020. | 2030. | 2050. | 2020. | 2030. | 2050. |
| Industry | 7.56 | 4.48 | 3.27 | 3.04 | 0.62 | -56.8 | -59.8 | -91.9 |
| Transport | 3.99 | 5.96 | 5.44 | 4.03 | 1.84 | 36.6 | 1.0 | -53.9 |
| Households | 2.00 | 2.10 | 1.87 | 1.37 | 0.42 | -6.1 | -31.1 | -79.0 |
| Services | 0.77 | 0.67 | 0.48 | 0.37 | 0.16 | -37.2 | -52.3 | -79.0 |
| Electricity & heat | 3.69 | 3.96 | 5.40 | 5.56 | 0.72 | 46.5 | 50.9 | -80.4 |
| Refineries | 2.57 | 1.47 | 0.91 | 0.69 | 0.34 | -64.3 | -72.9 | -86.9 |
| Total $CO_2$ emissions | 20.56 | 18.64 | 17.38 | 15.06 | 4.09 | -15.5 | -26.7 | -80.1 |

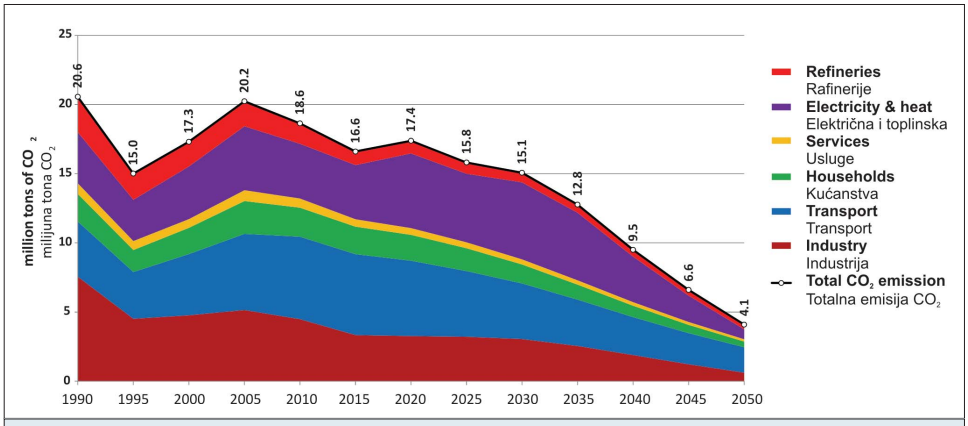


**Fig. 5. Croatian energy sector total $CO_2$ emissions 1990 - 2050**
Sl. 5. Emisije $CO_2$ iz energetskog sektora RH od 1990. do 2050. godine

sures and changes in energy generation and consumption, which stem from this analysis of Croatian energy sector development by 2050 and are described further in the text.

Acheiving of decreased heat losses of 27 kWh/m² in housing will require enforcement of strict regulations and considerable incentives. The projected 50 percent of electric cars in 2050 means that transport will go through dramatic changes, but it also assumes adjustments in electric energy system. Foreseen increase in renewables share such as modern biomass, geothermal and solar energy in direct applications in final consumption in all segments, is not possible without considerable incentives.

The share of biomass, geothermal and solar energy in remote heat systems should be increased to 80 percent in 2050. Similar development, i.e. strong penetration of biofuels (biodiesel, bioethanol and biomethane) should take place in total consumption of all motor fuels. In 2050, the share of biofuels is to reach 80 percent. Industrial production will go through significant changes as it will be necessary to increase the share of CCS tehnologies in industries that use natural gas by 80 percent up to 2050.

$CO_2$ emission reduction obligation will have significant impact on fuel refineries' strategies and market positioning; it is expected that utilised refining capacities will gradually decline to only 1.23 million tonnes of crude (i.e. only 18 percent of current refining capacity). For comparison, in 2010 the refineries in Rijeka and Sisak processed 4.18 million tonnes of crude, which represented utilisation of 61.5 percent of total refining capacity.

In 2050 all power plants will use carbon free or low carbon technologies (wind, solar, hydro and CCS technology as necessary). In order to achieve maximum possible reduction of $CO_2$ emissions, CCS technologies will be applied in all fossil fired power plants. At the end of the period, total $CO_2$ emissions from electricity and heat generation activities will be reduced by 80 percent relative to 1990 and will amount only 0.72 million tonnes. However, the dynamics of $CO_2$ reduction process that need to be achieved in power generation sector after 2030 will be exceptionally demanding from the aspect of preparatory activities, amount of investments, activities that need to be undertaken for system upgrading and particularly endeavours that need to be done in order to find sustainable model of electricity market organization that will enable fast and extensive structural changes.

Average cost of electricity generation will increase in 2050 by almost 140 percent compared to 2015. The highest part of the cost increase will be generated by 2040, after which it will be mainly affected by installation of CCS facilities in the existing gas and coal fired power plants. According to estimates, the impact of CCS tehnologies on the increase of power generation costs will be around 10 percent. Boundary cost of avoided carbon dioxide emissions in power generation will reach almost 70 EUR/t $CO_2$ in 2030 and it is to remain on this level up to the end of the observed period.

Total investments in new power plants up to 2050 are estimated at EUR 31.9 billion. About 75 percent of the above amount should be invested after 2030. Total investments in RES technologies for power generation up to 2050 are estimated to EUR 26.5 billion, about 75 percent after 2030. Investments in CCS facilities will intensify after 2030 and are estimated at about EUR 1.4 billion.

## 6. Conclusions and recommendations

As a part of international community and the EU member, Croatia will have obligation to cut significantly greenhouse gas emissions by 2050. However, it is essential that emission reduction goals are Croatia's own choice and commitment. Meeting of this target is possible through the design of a new development strategy. The new development strategy should realistically evaluate and factor in environmental protection and mitigation of climate change, and create conditions for technological and industrial development, improved energy efficiency in all economic activities, upgrading of public and personal standard of living, use of renewable energy sources which reduce negative effects on the environment and provide incentives for more intensive development of agriculture and tourism. The new development strategy should ensure conditions for economic growth and enhancement of public and personal standard of citizens by protecting the environment and climate.

One of the biggest challenges is cutting of emissions in transport sector which will require wider application of biofuels, particularly in road transport. The structure of used biofuels will depend not so much on individual country's feedstock base, but on knowhow, technology and resources that will enable development and application of such biofuels. It is expected that the production of 1st generation biofuels will be fully abandoned by 2050

because the application of this type of biofuels cannot ensure expected reduction of greenhouse gas emissions and they do not contribute to decreased dependence on oil. Production of these type of biofuels is limited by EU regulations already now. Gradual development of new fleet engines and infrastructure is paving the way for use of CNG obtained by purification of biomethane. Separation of organic components from waste, which are suitable for production of biogas, opens up prospects for wider use of this biofuel by 2050. Even today there are discussions about the 4th generation biofuels to be produced in similar processes as oil deposits were formed, advanced biotechnology or revolutionary process such as Joule's solar-to-fuel method which surpasses all former types of biofuels. However, until full commercialization of Joule's advanced technology, it is expected that production of biofuels from lignocellulosic biomass (2nd generation) will intensify, while its limited capacity could be compensated with biofuels from algae (3rd generation). It seems realistic to expect that in 2050 the combination of CNG derived from waste and versions of diesel and gasoline from the 2nd and 3rd generation biofuels will be in wide application. The size of share of the 4th generation biofuels will depend on technology competitiveness.

Large share of renewable energy sources and significant costs related to their integration into electric power system will pose a big challenge for system regulation capabilities. It is expected that forecasting techniques to determine variable renewable generation will dramatically improve in the forthcoming future along with ancillary services to support power system reliability. Although it is likely that in the mid- and long-term period regional markets of ancillary services and balancing energy will be in place, it is recommended that operators ensure sufficient support capacity within their own electric energy system.

Required level of support capacity within power system depends on renewable generation locations and load, particularly in case of wind farms. In other words, more dispersed wind farms will have less variable total production and consequently lower level of support generation. According to today's assessments, due to hourly variations in renewable generation output it is necessary to ensure support capacity of 30 to 40 percent of the wind farm installed capacity. On one hand it is expected that necessary level of support generation will decline thanks to upgraded forecasting techniques, but on the other hand it is likely that wind farms will be concentrated along the coastal belt of several hundred kilometres, which will then increase the need for support generation. Therefore it will be necessary to determine dynamically the required level of load regulation, i.e. all support services, in order to ensure optimal, timely and reliable integration of renewable energy into the system at the lowest possible costs.

The results of the analyses carried out within the framework of this paper point to the conclusion that the reduction of $CO_2$ for minimum 80 percent by 2050 relative to 1990, is possible from technical and energy aspects. However, this can only be achieved if harmonized actions for cutting $CO_2$ emissions are undertaken across Europe, or even better in all OECD countries and globally with the inclusion of undeveloped and developing countries. An integrated energy market should be established which would mean that renewable energy should be governed by market mechanisms. A precondition for functioning of market principles is to include external costs of environmental protection and climate change mitigation in actual energy price. Only in this way will market mechanisms play key role in determining operation of any power plant or impact the selection of energy source or driving fuel in transport. A new carbon free concept will dramatically change the content and structure of energy sector through the entire value chain from energy generation, selection of primary energy forms, transmission/transport, distribution and energy consumption. Hence, it is possible to reduce emissions against set targets from technological aspect, but with high financial efforts and significant changes in the energy sector, which must be preceded by changes in scientific and industrial development.

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