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The Process of Decarbonization in the Croatian Energy System

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Abstract: *This work delves into the crucial scientific research on the transition of the Croatian energy system, a process that commenced in the early 1990s. Today, the energy system confronts new challenges, including deregulation, liberalization of energy markets, heightened competition, escalating demands for supply security, and notably, the imperative to curtail CO2 emissions in line with subsequent EU regulations and standards on environmental protection. Research is also underway to establish the Environmental Kuznets Curve (EKC) between economic development and environmental pollution in Croatia. To empirically estimate the curve, data on 21 counties were scrutinized for various types of pollution. The paper also analyses the macroeconomic effects of the announced investments in renewable energy sources for electricity production. The entire energy transition process can be seen as the beginning of the renewal of industrial production capacities, i.e., reindustrialisation.*

1. INTRODUCTION

At the beginning of the early 90s, Croatia entered the process of a very deep transition, which had a substantial impact on all aspects of society. The analysis carried out in this work refers to changes within the Croatian energy sector and the impact of these changes on macroeconomic trends in Croatia. The first steps in the framework of the energy transition in Croatia were related to the decarbonization of the production sector through the production of renewable energy to reduce harmful emissions (GHG), following the recommendations of the Kyoto Protocol in 2005 (Baus & Kresic, 2024). This opened a new era of energy production from renewable energy sources (RES), which led not only to a substantial transformation within the energy sector, but also to a very strong impact on the wider aspect of economic and social changes.

The entire process of this energy transition could be analyzed through four parts: the process of building renewable energy sources, the process of closing existing energy sources that have a large GHG emission, the process of reindustrialization in Croatia due to the construction of RES and the process of a new approach to protection environment.

The objectives of the paper are to:
1. Analyze the potential natural resources needed for the production of renewable (solar) energy
2. Analyze the economic correlation, as well as the emission of greenhouse gases GHG, between 1MWh of energy produced in the Plomin coal-fired thermal power plant and in the 1MW solar power plant.
3. Analyze if Croatia can rely on its own electricity, derived from renewable sources and from sources with low CO_2 emissions that use natural gas.

All research is carried out through descriptive analysis of publicly available foreign and domestic relevant literature and data from appropriate reliable sources. This refers to the study of several scientific papers on this topic, annual reports, books, and especially to the input-output tables, from which numerous data were used in this paper.

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2. THE PROCESS OF DECARBONIZATION OF THE ENERGY SECTOR IN CROATIA

At the beginning of 2020, the Strategy of the Republic of Croatia until 2030 with an outlook to 2050 was adopted. The Strategy analyzes two energy transition scenarios, the accelerated energy transition and the moderate energy transition. The Strategy is guided and defined by goals set out by the European Union (EU), which primarily states to decrease greenhouse gas emissions and increase the share of renewable energy sources. To reach these goals, it is necessary to substitute fossil fuel capacities with new capacities to produce electricity from renewable sources.

Consumption of fossil fuels harms the environment and is the leading cause of climate change. This fact influenced energy to become one of the essential areas of common interest to all EU member states within the common energy and climate policies. Today, the EU, guided by the common energy policy, leads the process of decarbonizing economic activity and focuses on transformation toward a low carbon economy according to the Paris Agreement. All member states are following the common energy and climate policies by achieving the set goals. After the 2020 goals were met, 2030 goals were defined.

The capacity of renewables in Croatia in 2020 was 1060 MW. The largest portion came from the wind, with almost 70% of the total capacity. The next largest share was in cogeneration and biomass power plants with 10%. Solar and biogas plants generated 5% each. Around 1% came from landfill gas. The trend is expected to follow the current pattern in the next decade, given the energy and climate policies of the EU.

The Croatian parliament accepted the Energy Strategy in 2020 which aims to decrease greenhouse gas emissions, increase the share of renewables, increase energy efficiency, security and quality of supply, development of the EU energy market, energy infrastructure, and competitive economy and the energy sector. The Strategy analyzes two energy transition scenarios, scenario 1 (S1- accelerated energy transition) and scenario 2 (S2 - moderate energy transition). According to S1, decarbonization of electricity production aims to increase the share of renewables to 66%, and according to S2, to 61% until 2030. According to both scenarios, the share of renewables in total energy consumption is set to 32%. Scenarios encompass 12 activities where investments are considered to reach the goal. Electricity production is one of 12 activities analyzed for both scenarios in the Strategy. This paper focuses on the macroeconomic effects of investments in the production of electricity only. Table 1 exhibits the production structure of electricity given the defined scenarios (Energy Institute, 2018.).

Table 1. Expected electricity production and its structure according to the production technology for S1 and S2 scenarios

in GWh Production Technology	**2017 (Base Year)**	**Share %**	**S1 2030**	**Share %**	**Change 2030/2017**	**S2 2030**	**Share %**	**Change 2030/2017**
Industrial cogeneration	414	3	320	2	77%	320	2	77%
Public cogeneration	3383	28	3316	19	98%	3508	21	104%
Thermal plants	1397	12	720	4	52%	800	5	57%
Geothermal plants	0	0	129	1	-	129	1	-
Solar plants	79	1	1371	8	1742%	1013	6	1288%
Wind plants	1204	10	4332	25	360%	3549	21	295%
Hydro plants	5508	46	7307	42	133%	7319	44	133%
TOTAL	11,985	100	17,495	100	146%	16,638	100	139%

Source: Author; Energy Institute (2018)

Within the energy transition framework, renewables are expected to increase along with the greater diversification of energy sources. In S1 until 2030, the use of renewables would increase to 42%, while in S2, it goes to 49%. The most significant changes are in considerable increases in the share of wind and solar. Electricity production from wind and solar should increase from 1.3 TWh in 2017 to 5.7 TWh in 2030 in S1 and 4.6 TWh in 2030 in S2. The share of wind and solar should grow from 11% in 2017 to 33% in 2030 in S1, and 27% according to S2. To achieve these projections, considerable investments are needed in renewables. Table 2 shows investment in electricity production and its structure according to technology and scenario for the period 2021–2030.

Table 2. Investment in production of electricity according to S1 and S2, 2021–2030.

Billion EUR		**2021-2030**		
Production Capacity	**S1**	**%**	**S2**	**%**
Wind	0.84	32.9	0.67	30.7
Solar	0.68	26.8	0.54	24.7
Hydro	0.58	22.6	0.51	23.5
Gas	0.3	11.8	0.03	13.3
Biomass	0.12	4.8	0.13	5.9
Energy storage	0.007	03	0.015	0.7
Geothermal	0.012	0.5	0.02	0.9
Heat pumps and electric boilers	0.008	0.3	0.01	0.4
TOTAL	2.55	100.0	2.18	100.0

Source: Author; Energy Institute (2018)

According to S1, total expected investments amount to EUR 2.55 billion in the ten-year period, which means annually on average EUR 0.25 billion. That amount of 11% of expected investments in all 12 activities for energy transition for the period 2021–2030 amounted to EUR 22.5 billion (around EUR 2.25 billion annually). The greatest share goes towards investment in the refurbishment of old or construction of new buildings (44%). Investment in solar and wind plants is scheduled at 60% of investments in renewables, which is EUR 0.15 billion. The hydro potential is in third place, followed by gas power plants. Gas plants are not a renewable source but are needed given their flexibility in the power system with many other renewables. In the S2 case, 15% less investment is scheduled for 2.18 billion EUR in the ten years (EUR 0.22 billion annually). This amounts to 11.5% of total scheduled investment in 12 activities which amounts to EUR 18.86 billion (EUR 1.93 billion annually). The share in this scenario is led by investment into wind and solar plants, which amount to 55% or EUR 1.2 billion. It is assumed that the investment in both scenarios is linearly distributed in the ten years. For estimates of effects, energy scenarios of the moderate and accelerated energy transition were used.

Conducted input–output analysis and associated results point to weak macroeconomic effects of an investment in renewables in the period 2021–2030 according to the Energy Strategy of the Republic of Croatia for the Croatian economy. The results are shown through GDP and employment, both total and by sector. We estimate that for every EUR 1 million of investment in capacities for electricity production from renewables, the Croatian economy creates, directly and indirectly, only EUR 0.336 million of value added and EUR 0.410 million of GDP. Investment in renewables significantly increases imports which is more than double of newly created GDP. At the same time, EUR 1 million investment creates 14 new jobs (out of which 46% in industry, 32% in construction, and 22% in services). Given the results presented here, and data from previous studies on Croatia, it can be concluded that our estimates are expectedly lower because we have not included induced effects, but the average of all renewables investment, and the previous studies included the separate investment of each respective renewables on macroeconomic variables. Thus, our results show the impact of 14 new jobs created per EUR 1 million investment, while other studies show the range of 15–27 jobs created, with the highest impact of bioenergy in the range (Mikulić et al., 2018).

3. GLOBAL VALUE CHAINS (GVC) FOR ELECTRICAL POWER SYSTEMS

Economic analysts view electricity and heat as commodities with market prices, quantities, quality, delivery time, etc., like any other commodity, which can be analysed through GVC. The specificity of this exchange, in relation to other exchanges of goods and services in GVC, is that this exchange lasts continuously, 24 hours a day, 365 days a year, which results from the phenomenology of the power system itself and its interconnection with several such correspondent systems of other countries. In this way, several countries merge into one power system, and thus, a single, common electricity market governed by all market laws and other goods and services. Therefore, every electrical power system of each country is already in the international GVC system, including the Croatian national electrical power system.

More recently, the economic development of a developing country, such as Croatia, undergoing a process of intensive reindustrialization, is the fastest possible through the international division of labor. By switching to a market economy, the Republic of Croatia has undergone premature and indiscriminate deindustrialization, which has decreased the number of employees in the industry. This transition has had a substantial consensus on Croatia's positioning on the GVC scale (Kersan-Škabić, 2019).

The economic analysis found that Croatia achieves worse results than other EU member states, with a high share of domestic value added in total exports. According to the GVC participation index, Croatia did not experience significant changes in 1995-2011 and is in the GVC position in the downstream part of the scale, meaning that higher imports of intermediate products prevail compared to exports (Kersan-Škabić, 2019).

Better positioning on the GVC scale requires different strategies, which allow the realization of higher added value in the final product. This is achieved in practice using advanced technologies and employing a highly skilled workforce. The economic analysis of RESC and its positioning on the GVC scale can be carried out at the local, national, regional, or global level regarding participation in electricity generation. It is also possible to examine the positioning of RESC on the GVC scale through manufactured or imported technical equipment required for RESC. The implementation of this analysis provides insight into the decomposition of the production process to the lowest microeconomic level, entering the production capacities and financial results, if necessary, of the lowest production organizational units and their interaction.

This fragmentation of internationalization of production and exchange of goods and services enables companies to be more competitive in the market but also reduces business risks. In previous scientific papers in Croatia, the analysis of Croatia's involvement and positioning in the field of electric power engineering in the GVC has not been sufficiently investigated. However, according to many scientists in this field, this is crucial for the development of one country.

However, this constant trend of economic growth in industrially developed countries leads to conflict with many current constraints related to sustainable development. These are primarily energy conversion in accordance with environmental protection. In recent years, it has been particularly emphasized through European recommendations, which have a legislative character, the construction of clean, renewable energy sources, which have little or almost no adverse effect on the environment.

Accordingly, energy production trends are changing, where the production of "green" and "clean" energy and its placement in the electricity consumption network, goat (RESC), is increasingly represented. This crucial global change also results in a substantive shift in energy production sources, i.e. the application of entirely different modern energy technologies (Notton et al., 2018). New energy trends have multiple meanings for Croatia, as follows:

1. use of renewable energy are developing in line with EU recommendations;
2. significantly contributes to better positioning of Croatia in GVC by creating a domestic newly created added value;
3. significantly contributes to the protection of the environment;
4. the positive implications for society's economic and social aspects are significantly strengthened.

One of the main goals of Croatia's energy policy is to increase the participation of renewable energy sources in total energy consumption. Accordingly, the fundamental indicators for monitoring the share of renewable energy sources are defined as follows:

1. the share of renewable energy sources in gross final energy consumption (RES);
2. the share of renewable energy sources in gross final electricity consumption (RES-E);
3. the share of renewable energy sources in gross final consumption of energy for heating and cooling (RES);
4. the share of renewable energy sources in final energy consumption in transport (RES-T).

4. BASIC CORRESPONDENT FEATURES (RESC) AND (GVC)

With the arrival of new renewable energy technologies, the equipment of the entire supply chain is significantly changed, which requires completely different device production, servicing, operational maintenance and much more recent knowledge and skills of the employed personnel. Exceptionally high demands have been placed on the supply chain regarding decarbonization, reliability, and plant safety (Ahmad & Zabri, 2018).

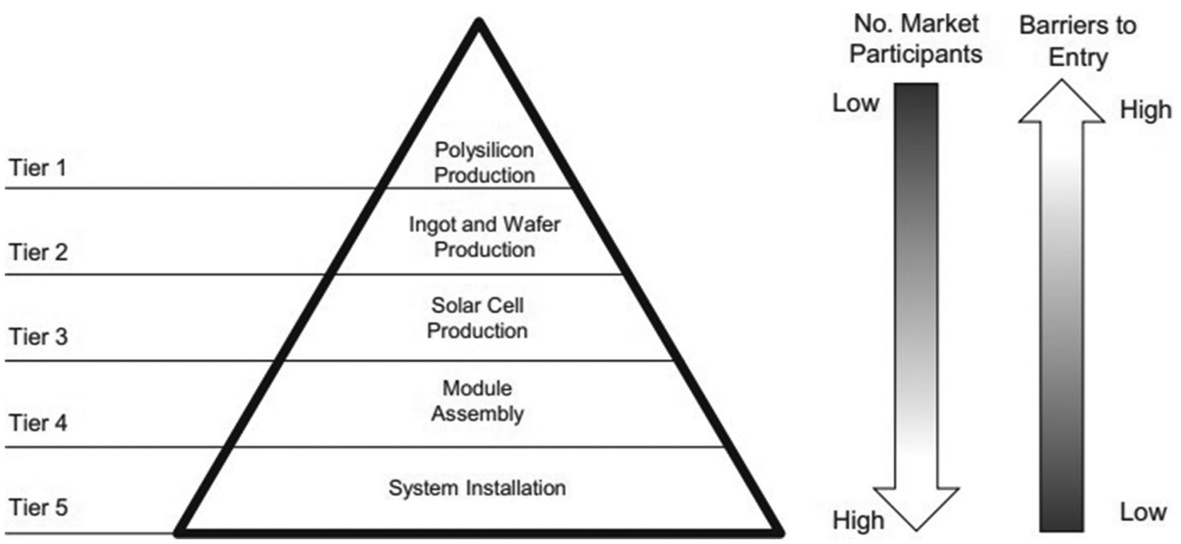

Figure 1. The RESC - The PV supply chain

Source: Own illustration

An essential part of RESC should be the so-called "smart grid", which allows optimal use of electricity and heat. In this way, considerable energy savings can be achieved. In addition, this gives the entire supply chain much greater working flexibility. Because of this, the energy transition process is very complex and will last for decades because traditional technologies are based on fossil fuels, deeply rooted in existing energy systems. Of all renewable sources, photoelectric (PV) is the most widespread. In addition, in the construction and organization of this supply chain, it is possible to increase the participation of domestic production entities. Therefore, it is explained below it in more detail.

As seen in Figure 1, the PV supply chain can be presented through five levels, as follows: 1- Tier 1 – the production of the polysilicon material; Tier 2 – production of ingots and wafers; Tier 3 – production of solar cells; Tier 4 – module assembly; and Tier 5 system installation.

By analyzing the levels of the organizational pyramid, we see that the PV supply chain's structure is such that almost all its levels, except for the 1st level, can be successfully realized by domestic companies in Croatia.

Level 1 products are made mainly by Asian companies, which account for about 86% of the world's production of this equipment (Grubler et al., 2012).

For performing work at level two of the organizational pyramid, there are two large domestic companies that, with their production capacities, can fully cover the domestic market but also place about 20% of their annual production on the foreign market. At all other levels: 3, 4, and 5, Croatia has a lot of domestic companies with highly specialized and well-trained personnel who can build and commission the PV supply chain in a relatively short time. This example shows that domestic companies have a share of more than 90% of the total random engagement for the construction and commissioning of the PV energy supply chain, which defines the new value-added. Furthermore, this is, in fact, a perfect example, which gives a clear picture of the interaction between the supply chain (RESC) and the global chain GVC.

On the one hand, it inevitably follows that a larger share in domestic companies' production of equipment and services in (RESC) automatically gives a better position to the Croatian economy in GVC. Likewise, a detailed recursive analysis of the previous example shows that GVC significantly impacts RESC. As seen in Figure 1, imported equipment, which financially amounts to less than 10%, is located only at level 1, the organizational pyramid of the supply chain. Although this imported technical equipment participates so little in the entire supply chain, this supply chain could not be realised without it. This indicates how big and significant the role of GVC is in the international exchange of goods and services and the interconnection with RESC.

In other words, this means that here, when organizing the RESC, we have a two-way movement process on the GVC scale, Downstream when importing equipment at levels 1 and Upstream for other levels, 2, 3, 4, and 5.

$$BackGVC = \frac{foreign\ added\ value\ in\ exports\ of\ the\ country}{total\ added\ value\ \ in\ exports\ of\ the\ country} \times 100$$

$$ForwGVC = \frac{domestic\ added\ value\ in\ exports\ of\ other\ country}{total\ added\ value\ \ in\ exports\ of\ the\ country} \times 100$$

Here, BackGVC shows the foreign-added value contained in the exports of the analysed country, expressed as the share of foreign-added value in the total value of that country's exports (Mikulić, 2018).

ForwGVC defines "forward links" and represents a country's added value in exporting to other countries. It is necessary to measure the indirect export of a country's added value contained in the export of all other countries in the model. Then, the share of the calculated total value added (included in the export of all other countries in the model) in the total value added of the exports of the analyzed country is calculated.

Inclusion in GVCs is the sum of two of the following indicators:

$$GVCinclusion = BackGVC + ForwGVC$$

If the result is positive, it means that "forward connections" prevail in the analyzed industry, and if it is negative, it means that "backward links" prevail in the analyzed industry. A microeconomic analysis of the inter-impact between industrial manufacturing sectors to produce technical equipment for renewables could be carried out in further research.

Different renewable energy sources (wind, solar, geothermal, biomass) are complex and heterogeneous, so they cannot be classified into one industrial sector. Economic analysis is carried out at the microeconomic level by monitoring the interdependence of production sectors by applying fundamental indicators and multipliers in input-output analysis.

However, this method has certain drawbacks. Namely, grouping the entire economy into only a few sectors makes it easier to monitor the calculation of different indicators. Still, it reduces the analytical strength of the model since such production sectors are very heterogeneous, and the cross-sectoral dependence between more homogeneous sectors remains hidden.

5. FUTURE RESEARCH DIRECTIONS

Renewable energy sources are built for well-known reasons: cost-effective energy production, cessation of fossil fuel use, ecology, etc. It is important to point out here that it is not only about the construction of new renewable sources but also about the closure of existing energy sources that are major polluters of the environment. These are primarily coal-fired thermal power plants, then heavy oil derivatives, then light oil derivatives and finally natural gas, and propane. Thus, it is a very complex process of energy transition, which is reflected through the substitution of outdated technology to reduce CO_2 emissions and decarbonization.

The transition process should be integral, and comprehensive, which means that every closed power plant should be adequately replaced with renewable energy sources. Furthermore, some of the questions arising from the current consideration of the Croatian electric power system are presented:

1) Can Croatia produce enough electricity for its own needs in the coming period of 5 years, including all energy sources (primary and renewable)?
2) Can this new production capacity refer only to renewable energy sources?
3) Can Croatia, and in what timeline, close the coal-fired thermal power plant TE Plomin with a capacity of 350 MW (the biggest polluter of the environment) and replace it with RS energy?
4) Can Croatia reduce the emission of harmful gases (CO_2 and NO_x) compared to the current situation and in what period and to what extent in the future?

5) Can Croatia export electricity derived from RS? In which months of the year and in what quantities? What is the economic benefit of that export?
6) Does Croatia have the opportunity for greater participation in technological innovations and the development of new technologies during the construction of RS? Can this analysis be carried out using global value chains (GVCs)?
7) How does the increased development and construction of the RS affect the overall development of industry and economy, and thus the GDP?
8) What are all the barriers and to what extent do they affect the faster development and construction of RS?

The answers to these questions are not simple and require a deep dive into the topic but could be a modest scientific contribution to the creation of initial guidelines for the implementation of the short- and medium-term Strategy for the development of renewable energy sources in the Republic of Croatia.

6. CONCLUSION

This analysis aimed to estimate the macroeconomic effects of an investment in electricity production according to the approved and accepted Energy Strategy of the Republic of Croatia. Croatia freely exchanges electricity, not only with neighbouring countries but also with countries such as Bulgaria, Germany, Switzerland, etc., and thus is a member of the global electricity market in the exchange of electricity. Economic analysts view electricity and heat as commodities with market prices, quantities, quality, delivery time, etc., like any other commodity, which can be analyzed through GVC.

The specificity of this exchange, compared to other exchanges of goods and services in GVC, is that this exchange lasts continuously during the year, which stems from the phenomenology of the standard power system for several countries. On the other hand, looking at the changes at the local level of the power system, in recent years, the production of renewable electricity and heat following global trends and recommendations of the European Union to maintain environmental ecological standards has been intensified.

As a result of this process, energy production and placement in the public consumer electricity network is generated through activity, first private entrepreneurship, and then public-private partnerships, thus establishing the first RESCs in Croatia, which are interpolated into a standard power system and thus into GVC. The result of this interpolation is an integral part of the global energy diffuse, creeping transition, very ambitiously planned, that by 2050, Croatia should have in RESC installed capacity in the amount of 50% of the total installed energy capacity of the entire country.

The final analysis concludes that the interaction of RESC and GVC greatly accelerates the energy transition process and achieves multiple positive effects essential for Croatia's better energy, socio-economic and general cultural development perspective. The topic of this paper is very complex. It requires a lot of theoretical and practical knowledge from various scientific, technical and social disciplines and goes beyond the framework of this paper.

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