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RENEWABLE SOURCES OF ENERGY: HYDRO-ELECTRICITY IN SLOVENIA

Štefan Bojnec, Drago Papler

Original scientific paper
Electricity supply in Slovenia is largely dependent on traditional non-renewable sources of electrical energy. In spite of some efforts made to change the sources of electrical energy, not significant shifts from traditional non-renewable fossil sources of electrical energy to renewable sources of electrical energy are found. Electricity supply from water resources is dependent on natural conditions, but it is particularly biased on the adverse weather conditions. The changing weather conditions between raining and sunshine periods are a reason for the needs to diversify supply of electrical energy from hydro renewable sources of energy to a combination with solar energy and co-production of energy from biomass and other renewable sources of energy. There is a need for changes in green electrical energy supply not only towards hydro resources, but particularly towards other renewable sources of electrical energy such as solar, biomass, thermal water, wind and biogas energy.

Keywords: *electricity supply, hydro-electricity, renewable sources of energy, Slovenia*

Obnovljivi izvori energije: hidro električna energija u Sloveniji

Izvorni znanstveni članak
Ponuda električne energije u Sloveniji značajno je ovisna o tradicionalnim ne-obnovljivim izvorima električne energije. Bez obzira na određene napore da se promijeni izvore ponude električne energije, nisu postignute značajnije promjene od tradicionalnih neobnovljivih fosilnih izvora električne energije na obnovljive izvore električne energije. Ponuda električne energije iz hidro izvora ovisna je o prirodnim uvjetima pa je značajno ovisna i o promjenjivim vremenskim uvjetima. Promjene u vremenskim uvjetima između kišnih i sunčanih razdoblja su razlog za potrebnu diversifikaciju ponude električne energije iz hidro obnovljivih izvora energije u kombinaciji sa solarnom energijom i koprodukciju energije iz biomase i ostalih obnovljivih izvora energije. Potrebne su promjene u ponudi zelene električne energije ne samo u pravcu hidro izvora, nego posebice u pravcu ostalih obnovljivih izvora električne energije kao što su energija sunca, biomase, termalne vode, vjetra i bio plina.

Ključne riječi: *obnovljivi izvori energije, ponuda električne energije, hidro energija, Slovenija*

1 Introduction

The implications of global warming and climate change have become one of the most crucial questions for the sustainable world energy and economic development [1]. Due to this, these subject areas have become an important research and policy question in different sciences. A body of literature has analyzed and discussed the implications of global warming and climate change and the possibility of their mitigation through increased uptake of renewable sources of energy. See for example [2, 3, 4] as recent studies towards better understanding of the problem.

The economics and management of climate change [5, 6, 7], efficient energy use and sustainable economic development [8], have become a constituent part of different documents, global and national policy agendas [9]. For example, the European Commission [10] authorizes the Austrian support measures for the promotion of green electricity supply management from renewable sources and support tariff for electricity produced in combined heat and power installations for public district heating. These state support measures aim to improve long-term environmental protection by the development of sustainable production and management of green electricity.

The subjects of climate change and its implications are associated with changes in demand and supply of energy, which motivated our research in the case of supply management of hydro electrical energy. Hydro-electricity production is considered as a green electricity production, which with electricity substitution from water resources reduces CO_2 emissions from the non-renewal sources of electrical energy such as coal. The focus of the analyses is on the reduction of losses of electrical energy in electricity distribution networks [11], on green hydro electricity supply management, and on the significance of production of green electricity production with a shift from traditional to renewable sources of energy and electrical energy for sustainable environmental and economic development [12].

The rest of the paper is organized in the following way. We first present methodology and data used followed by presentation and explanation of our empirical results and findings. The final section derives conclusions from the empirical analysis of the green hydro electricity supply management and other green electricity supply, and draws new challenges in the green energy supply management.

2 Methodology and data

Combination of the analysis on hydro-electricity supply management and the regression analysis are used as methodological approaches [13]. The importance of the renewable sources of energy in electricity consumption are analysed for Slovenia. The focus is on hydro electricity supply management in the case of Electro Gorenjska, which is one of the retailers of the electrical energy supply in Slovenia [14, 15]. The regression analysis is used to determine factors that are important for green hydro electricity production and green hydro electricity supply management. The following regression specification formula is used in the data analysis:

$$HEP = \alpha + \beta \cdot AWC + \gamma \cdot IP + \delta \cdot LRF + e,$$

where *HEP* it the annual green hydro-electricity production (in MW·h), *AWC* is the average watercourse power in the Sava River at the hydro power stations, *IP* is the installed power of generators (in kW) in the electricity power stations, *LRF* is the annual quantity in level of rainfalls, α is regression constant, β, γ and δ are regression parameters and *e* is the unexplained regression error term. The regression function is estimated in the natural logarithm form, which means that the estimated regression coefficients β, γ and δ represent at the same time the coefficients of elasticity. Time-series data for the variables used in the regression analysis are obtained from the Electro Gorenjska.

3 Results and findings

3.1 Losses in the electricity distribution networks

One of the factors for the rationalization in electricity distribution is the reduction in the losses of electrical energy in the electricity distribution networks [11]. The losses in the electrical distribution networks represent the difference between the purchased and the sold electrical energy by the electricity distribution enterprises. According to the data obtained from the five electro distribution enterprises in Slovenia (Electro Celje, Electro Gorenjska, Electro Ljubljana, Electro Maribor and Electro Primorska), the share of the losses of the electrical energy in the Slovenian distribution networks is around 5,82 % on the annual basis in the period 1980 ÷ 2010, but varies considerably between 3,98 % (1981) and 7,42 % (1982) for the Slovenian average. The variations are a bit greater across the electricity distribution enterprises over time (Tab. 1).

Table 1 Losses of electrical energy in the electricity distribution networks in Slovenia (in %)

	Electro Celje	Electro Gorenjska	Electro Ljubljana	Electro Maribor	Electro Primorska	Total
1980	4,22	8,40	7,51	9,90	5,49	7,17
1985	3,04	4,29	5,00	6,28	6,28	5,00
1990	6,02	6,36	7,07	7,53	7,15	6,90
1995	5,87	6,36	7,06	7,29	6,06	6,66
2000	3,71	5,37	5,92	5,57	5,38	5,30
2005	8,73	7,02	5,58	6,86	5,48	6,45
2010	6,67	5,69	5,23	5,63	5,72	5,69

Source: Own calculations from data of the Slovenian electro distribution enterprise.

3.2 Small hydro-electricity power stations

Production and supply of electrical energy from small hydro-electricity power distribution stations in Slovenia, which are owned by the Slovenian electricity distribution enterprises (Electro Celje, Electro Gorenjska, Electro Ljubljana and Electro Maribor, while Electro Primorska does not have own small hydro-electricity power stations), has increased due to investments in small private and new hydro-electricity capacities, changed price policy in favour of production of such electrical energy, legislation and subsidies to support hydro-electrical energy production. It is worth mentioning that since 2002 this activity of small hydro-electricity power distribution stations due to the EU regulation on liberalisation of market of electrical energy has been transferred on newly organized daughter companies of the electrical distribution enterprises. On Primorska region, this activity is conducted by the enterprise Soča electricity Nova Gorica, which owns large and small hydro-electricity power stations.

During the last quarter of the previous century, the number of hydro-electricity power stations increased from 12 in 1980 to 36 in 1995 and afterwards. The installed power of hydro-electricity power stations and total hydro-electricity production doubled during the same time period (Tab. 2).

Electricity production by private and small industrial hydro-electricity producers has increased due to the increase in the number of such electricity power stations and the installed power of these electricity producing power stations. Their market share in purchases of electrical energy by the Electro Gorenjska varied between 6 % and 8 %.

However, most recently it has been established that some capacities in other private and industrial small hydro-electricity power stations were fictive (see for the years 2000 in Tab. 3).

Table 2 Production of electrical energy in small hydro-electricity distribution power stations in Slovenia

	Production in small hydro-electricity distribution power stations (MW·h)	Installed power of small hydro-electricity distribution power stations (kW)	Number of small hydro-electricity distribution power stations
1980	44 118	8 014	12
1985	41 589	8 494	13
1990	58 680	14 940	26
1995	66 664	17 367	36
2000	73 943	18 587	36
2004	84 719	18 587	36
2005	67 270	18 587	36
2010	92 764	18 587	36

Source: Data collected by the authors from the Slovenian electro distribution enterprises.

3.3 Large hydro-electricity power stations

Large hydro-electricity power stations are defined as those which have installed technical power generated capacity greater than 10 MW. Hydro-energy potential in Slovenia for production of electrical energy is used by the following large hydro-electricity power stations: Drava hydro-electricity power stations (Dravske elektrarne Maribor) with eight hydro-electricity power stations on the Drava River, Soča hydro-electricity power stations

(Soške elektrarne Nova Gorica) with hydro-electricity power stations on the Soča River, Sava hydro-electricity power stations (Savske elektrarne Ljubljana) with hydro-electricity power stations in the upper and medium part of the Sava River in Slovenia, and Hydro-electricity power stations on lower part of the Sava River in Slovenia.

Table 3 Production of electrical energy in private and small industrial hydro-electricity power stations (qualified producers) in Slovenia

	Production in hydro-electricity power stations (MW·h)			Installed power of hydro-electricity power stations (kW)			Number of hydro-electricity power stations		
	Total	OSD	P&I	Total	OSD	P&I	Total	OSD	P&I
1980	44 118	44 118	0	8 014	8 014	0	12	12	0
1985	41 960	41 589	1	8 760	8 494	266	24	13	11
1990	71 188	58 680	12 509	20 948	14 940	6 008	112	26	84
1995	159 695	66 664	93 031	30 130	17 367	12 763	375	36	339
2000	272 756	73 943	198 812	50 436	18 587	31 849	417	36	381
2004	444 150	84 719	359 430	81 479	18 587	62 892	467	36	431
2005	350 479	67 270	283 209	81 293	18 518	62 775	458	36	422
2010				81 479*F*	18 518	62 961*F*	467*F*	36	431*F*
2010	395 853	92 764	303 089	70 275*A*	18 587	51 688	385*A*	36	349*A*

Notes: OSD – Small hydro-electricity power stations up to 10 MW installed power, which are owned and operated by the electro distribution enterprises or their daughter companies. P&I – Other private and industrial small hydro-electricity power stations. *F* – Fictive power (MW). *A* – Actual power (MW). Source: Collected by the authors for the period 1980-2005 from data of the five Slovenian electro distribution enterprises and for 2010 from [16, 17].

As can be seen from Tab. 4, electricity production from large hydro-electricity power stations has tended to increase during the last years owing to investments into the large hydro-electricity power stations in the lower part of the Sava River in Slovenia. A slightly more than 30 % of the Slovenian electricity production is generated by the large hydro-electricity power stations. Production of electrical energy from hydro-electricity power stations depends on hydrological conditions as well as on investments in construction of new large hydro-electricity power stations in the lower part of the Sava River in Slovenia.

Table 4 Production of electrical energy by large hydro-electricity power stations in Slovenia

	Electrical energy production in large hydro-electricity power stations	Total electricity production in the Republic of Slovenia*	The share of large hydro-electricity power stations in total electricity production in the Republic of Slovenia (in %)*
2002	3 313	13 319	24,87
2003	2 957	12 491	22,67
2004	4 095	13 835	29,60
2005	3 461	13 667	25,32
2006	3 591	13 643	26,32
2007	3 266	13 636	23,95
2008	4 018	15 032	26,73
2009	4 713	15 208	30,99
2010	4 696	15 260	30,77

* Without the Croatian share in the nuclear power station in Krško. Source: Own calculations from data obtained from [16, 17, 18].

3.4 Hydro-electricity in Gorenjska region

To analyze the hydro-electricity supply in more detail, we focus on hydro-electricity production and its supply by the Gorenjska electricity power station in Slovenia, which is a daughter company of the Electro Gorenjska. In the structure of primary sources of energy for the Electro Gorenjska there is prevalence of conventional sources of electrical energy. In 2006, the structure of primary sources of electrical energy for the Electro Gorenjska was as follows: conventional sources 78,8 % (coal, gas, oil derivates, and nuclear) and renewable sources 21,5 % (hydro energy, wind, solar and other renewable sources of energy) (Fig. 1). It is worth mentioning that similar structure of electrical energy sources is also in other regions of Slovenia and these structures are rather stable over time [17].

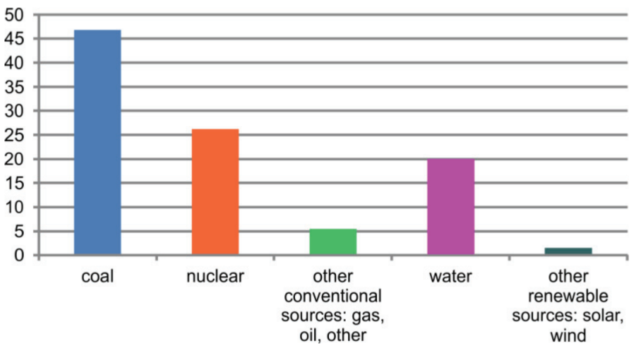

Figure 1 Structure of primary sources of electrical energy for the Electro Gorenjska, 2006 (in %); Source: Own calculations.

Within the Gorenjska electricity power stations (company Gorenjske elekrarne, d.o.o., Kranj), there are 15 small hydro-electricity power stations and seven solar electricity power stations in the Gorenjska region (Tab. 5). The type of solar electricity power stations is based on photoelectric panel.

These small hydro-electricity distribution power stations, which are owned by Electro Gorenjska, similar as in other Slovenian electro distribution enterprises, in 2002, due to the EU regulation on liberalization of markets for electrical energy, were transferred into a newly organized daughter company, Gorenjska electricity power stations (Gorenjske elektrarne, d.o.o. Kranj).

By their size of production, small hydro-electricity and solar-electricity distribution power stations cover around 6 % of electricity consumption in the Gorenjska region, which was delivered by the Electro Gorenjska. The annual production by the Gorenjska electricity power stations varies particularly depending on seasonal weather conditions. In 2005, the first solar electricity power stations entered into operation. The combination of different renewable sources of energy can contribute to a greater stability in electricity production [19], because when there is a drought weather period with a lack of water resources in rivers to produce electricity from hydro-electricity power stations, there might be favourable weather conditions for electricity production from solar electricity power stations.

3.4.1
Instabilities in hydro-electricity production by months

The seasonality in the electricity production by the Gorenjska hydro-electricity power stations is expected to be caused by the variations in the water levels of the local rivers, quantity of rainfall, and seasonally installed power capacities. We present these factors in the case of the hydro-electricity power station of Savica, in the Triglav's national park, situated in the tourism resort area of the upper part of the Sava Bohinjka River between the Waterfall Savica and the Bohinj Lake [20]. The hydro-electricity power station of Savica generates around 44 % of electricity production of the Gorenjska electricity power stations with around 2,2 % market share in the electricity consumption in the Gorenjska region. The water level in the Sava Bohinjka River is the lowest during the winter period and the water level increases during the spring and the highest level is in May and June (Fig. 2). During the summer period it is rather stable and increases during the autumn rainy period.

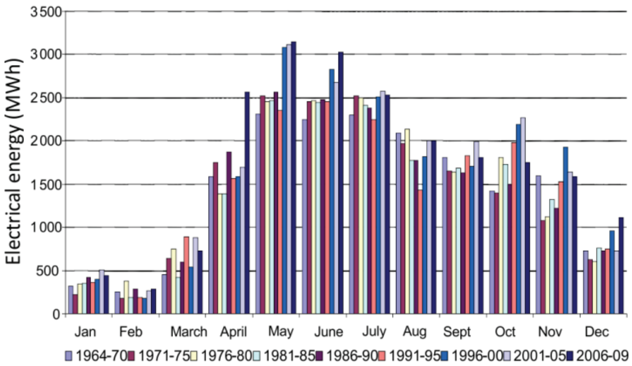

Figure 2 Monthly electricity production in hydro-electricity power station Savica (MW·h); Source: Own calculations.

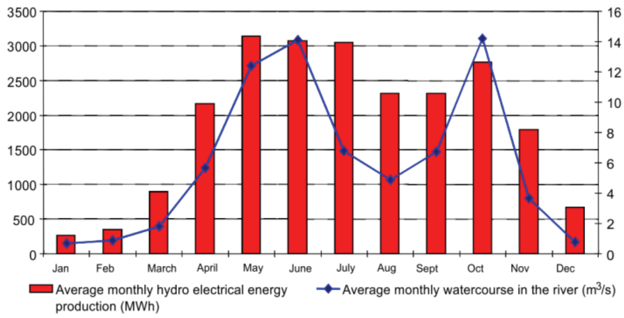

Figure 3 Association between electricity production by the hydro-electricity power station Savica and the average watercourse in the Sava Bohinjka River, 2004; Source: Own calculations.

3.4.2
Watercourse in the Sava Bohinjka River and electricity production by hydro-electricity power station Savica

Natural and technical factor endowments are important for hydro-electricity production. Among natural factor endowments are important quantity of rainfall (mm/m^2), average watercourse in the river in m^3 per second, and temperature of the air. Important among technical factor endowments is installed technical power capacity (kW) of the hydro-electricity power station. Fig. 3 presents strong correlation between the hydro-electricity production and average watercourse in the river in m^3 per second.

3.4.3
Crucial role of technical capacities and weather conditions

We employ regression analysis to estimate the association between hydro electricity production and technical capacities of hydroelectricity plants and the weather conditions in the rivers in the case of the 15 Gorenjska hydro-electricity power stations. The regression analysis has confirmed that the annual green hydro-electricity production (in MW·h) by the Gorenjska electricity producers is associated significantly with the installed power of generators (*IP* in kW) in these Gorenjska electricity power stations, but also with the annual quantities in the level of rainfall (*LRF*), the average water levels and the average watercourse power in the different parts of the Sava river (*AWC*) where the hydro-electricity power stations are located as well as with associated air temperatures. The regressions presented in Tab. 6 are estimated in natural logarithms. The parameters of the estimated regression coefficients are at the same time the coefficients of elasticity, which show the relative response of electricity production to changes in each of the explanatory variables.

Table 6 Regression analysis on determinants of electricity production by the 15 Gorenjska hydro-electricity power stations, 1993÷2005

	Dependent variable: ln (annual electrical energy production by the Gorenjska electricity power stations)	
	(1)	(2)
ln (Constant)	5,783 (1,771)	1,661 (0,379)
ln (*AWC*, average watercourse in the river Sava in m^3 per second)	0,456 (3,670)	
ln (*IP*, installed power in kW)	1,087 (3,011)	1,428 (3,187)
ln (*LRF*, level of rainfalls)		0,379 (2,071)
Adjusted R^2	0,699	0,506
F	14,9	7,1

ln: natural logarithm. t-test in parentheses. Source: Own calculations.

3.4.4
Reduction of CO_2 emissions by hydro-electricity production

Green electricity production can have significant environmental implications by substitution of the traditional non-renewable sources of energy by the renewable sources of energy for electricity and other energy production and use [21, 22]. We evaluate the impact of the hydro electricity production on environment in the case of the hydro-electricity power station Savica during the period 1950 ÷ 2009. Hydro-electricity production pollutes environment less if investment is properly constructed and built. In addition, investments in hydro-electricity power stations are long-term and operational costs are relatively low. Hydro-energy in comparison with other non-renewable fossil and nuclear sources of electrical energy is relatively cheaper and cleaner as an energy source in the long-term. As can be seen from Fig. 4, the operation of the hydro-electricity power generation station of Savica as one of the Gorenjska electricity power stations has substituted the use of coal for electricity production and thus reduced polluted materials and emissions of CO_2.

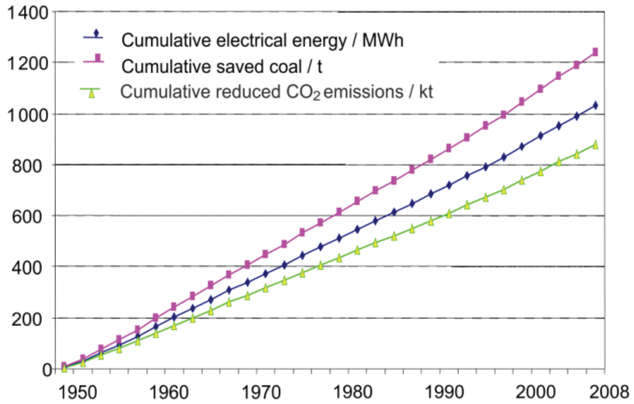

Figure 4 Cumulative electricity production from the hydro-electricity power station Savica (MW·h), saved coal consumption (in tonnes) and reduced CO_2 emissions (kt), 1949-2007. Source: Own calculations.

4 Conclusion

This paper has given an analysis of the Slovenian hydro-electric power generation infrastructure and performance over the last thirty years. The paper has offered an analysis of the assessment of greenhouse gasses reduction potential through increased integration of distributed hydro-electric power generation units.

The paper has underlined the significance of production of green electricity production from the hydro renewable sources of energy with implications for rationalization of energy supply management and environmental protection. The evidence for Slovenia confirms that the significance in the use and supply of the green hydro electricity has not followed the overall increase in electricity demands and thus a significant shift from non-renewable to renewable sources of electrical energy has not been identified. Electricity supply is still largely dependent on traditional sources of electrical energy. In spite of some efforts made to change the sources of electricity supply we have not found for Slovenia any significant shifts from traditional sources of electrical energy to renewable, green hydro sources of electrical energy. Moreover, with the construction and operation of thermo-electricity power station TEŠ-6 in Šoštanj it is unlikely to expect a significant shift from non-renewable to renewable sources of electrical energy in the near future. This can be further constrained by the economic and banking crisis in Slovenia. Some positive externalities towards investments in renewable sources of energy are thus only expected from technology developments, which will reduce costs and make investments into renewable sources of energy more profitable [23]. This can be particularly the case with solar electricity power stations [1].

Using monthly data seasonality in hydro-electricity production has been found, which is associated with seasonal weather conditions. The results imply the need for changes and new green energy supply management strategies that consider global warming, climate change and the consumer's perception [24]. They are causing changing seasonal electricity demands and availability of renewable energy factor endowments that are important for green electricity supply not only from hydro resources, but also from other renewable sources of electrical energy such as solar [1, 14]. The changing weather conditions between raining and sunshine periods are a reason for the needs to diversify supply of electrical energy from hydro renewable sources of energy to a combination with solar energy and co-production of energy from biomass, which in Slovenia is available in a large extent and other renewable sources of energy. Therefore, there is a need for changes in green electrical energy supply not only towards hydro resources, but particularly towards other renewable sources of electrical energy such as solar, biomass, thermal water and biogas energy, which are available natural potential and need a clear investment appraisal considering different interests for their efficient and sustainable long-term production and use.

Therefore, among issues for future research there are also questions of multidisciplinary nature pertaining to river water resource use and possible different interests regarding investments in large hydro-electricity power generation stations. The construction of large hydro-electricity plants often requires radical changes in the country-side landscape. Such approaches to the nature should consider natural water river endowments and water technical energy potentials and economic rationale for investment in hydro-electricity generation power stations as one of possible renewable sources of electrical energy and potential to use water. This approach requires more complex analysis in order to consider broader interests of different actors: technicians, environmentalists, cultural heritage, sport and tourism specialists among others. There can be also different interests of civil society groups and their perceptions. Sometimes this can also lead to questions about the use of the cross-border river water potentials. Such example is the river Mura with the hydro-electricity power generation stations in Austria, but not in Slovenia, Croatia or Hungary. To evaluate potential conflicts of interest in terms of costs and benefits of energy use, construction of hydro-electricity plant, sport and tourism, local cultural heritage and other actors' interests, protection of environment and cultural-ethnographical peculiarities at local, country and inter-country levels, more complex methods of analysis should be used, but this is an issue for future research in dealing with development and use of hydro energy potential and development and use of other renewable sources of electrical energy during global warming and climate change with expected greater variations in adverse weather conditions.

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Author's addresses

Prof. dr. Štefan Bojnec
University of Primorska, Faculty of Management,
Cankarjeva 5, SI-6104 Koper, Slovenia
Tel.: +386 5 610 2046, Fax: +386 5 610 2015, E-mails:
stefan.bojnec@fm-kp.si; stefan.bojnec@siol.net

Drago Papler, MSc.
Electro Gorenjska,
Mirka Vadnova 3a, SI-4000 Kranj, Slovenia
E-mails: drago.papler@gorenjske-elektrarne.si;
drago.papler@gmail.com