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Novejše energetske tehnologije

Nekaj novejših energetskih tehnologij je zelo zanimivih tudi za širšo komercialno rabo. Prva novost prihaja s področja koriščenja sončnega sevanja z namenom direktnega pridobivanja električne energije. Nov pristop bazira na principu pretvorbe svetlobe kot elektromagnetnega valovanja z anteno v nano-velikostnem razredu. Hkrati se koristi tudi infrardeči spekter svetlobe oz. toplote. Z razrešitvijo tiskanja množice anten v obliki kvadratne spirale na tanki polimerni film je ta rešitev zaživela tudi v praksi. Vsaka spiralna antena je širine 1/25 debeline človeškega lasu. Le-te so postavljene v polje spiralnih anten, ki absorbirajo tudi infra rdeči svetlobni spekter, ki ga sonce največ izseva. Ta del svetlobnega spektra je zanimiv tudi zaradi tega, ker ga seva tudi zemeljska površina (segreta površina zemljine), in sicer še približno štiri ure po sončnem zahodu. To seveda pomeni, da lahko pridobivamo električno energijo tudi do štiri ure po sončnem zahodu, kar seveda znatno poveča produkcijo električne energije. Zato lahko nano-antene koristijo tako sončno sevalno energijo, kot tudi sevalni del toplote, ki jo sprošča zemeljska skorja v nočnem času. Tudi izkoristek je bistveno višji kot pri dosedanjih foto-voltaičnih modulih.

Druga novost je energetska raba termočlenskega principa za proizvodnjo električne energije. Pri višjih temperaturah uporabljamo kovinske stike dveh različnih kovin, pri nižjih temperaturah pa uporabljamo pol-prevodniško tehniko oz. diode.

Tretja novost pa prihaja iz sveta jedrske energetike iz Livermore, Kalifornija, ZDA, kjer se ob ITER tehnologiji, ki bazira na TOKAMAK-principu, vzpostavlja nova tehnologija, ki bazira na laserskem principu vzpostavljanja pogojev za zlitje jeder (fuzijo).

Newer energy technologies

Some newer energy technologies are very promising for large-scale commercial use. The first innovation I would like to mention is the utilization of solar radiation for the direct production of electricity. A new approach is based on the principle of the conversion of light as an electromagnetic oscillation, with a nano-size antenna. Benefits can be found by using the infrared spectrum of light (and heat). This solution is workable in practice with antennas printed in a square spiral shape on a thin polymer film. Each spiral antenna has a width of 1/25 of the thickness of a human hair. They are placed in an array, which also absorbs the infra-red light emitted by the sun. This part of the light spectrum is also interesting, because it continues for about four hours after sunset, meaning that electricity can be obtained up to four hours after sunset, thereby significantly increasing the production of electricity. Therefore, nano-antennas can use both solar radiant energy and the radiant heat released by the Earth's crust during the night. Furthermore, the efficiency is significantly higher than in previous photo-voltaic modules.

Another innovation is the use of the energy thermocouple principle for the generation of electricity. At higher temperatures, metallic contacts using two different metals at low temperatures are used as semi-conductors or diodes.

The third innovation comes from the world of nuclear energy, from Livermore, California, USA, where the ITER technology based on the TOKAMAK-principle is being challenged by technology based on a new laser technology that ensures conditions for the fusion of nuclei.

Krško, November, 2011

Andrej PREDIN

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BIOGAS — A SUSTAINABLE ENERGY SOURCE: NEW POSSIBILITIES AND MEASURES FOR SLOVENIA

BIOPLIN — TRAJNOSTNI VIR ENERGIJE: NOVE MOŽNOSTI IN UKREPI ZA SLOVENIJO

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Keywords: Biogas, renewables, sustainable energy technologies, Slovenia

Abstract

In this paper, biogas as a sustainable energy source is examined from economic, environmental and socio-politic points of view. The pros and cons of biogas and the compatibility of biogas as a sustainable energy source within EU directions and goals were examined using a SWOT analysis.

Because new technologies for the exploitation of biogas are being rapidly developed and improved, technologies for the exploitation of biogas are identified, analysed and cross-compared.

New possibilities, potentials and options for the development of the biogas industry in Slovenia are presented, and the possibilities for biogas exploitation and biogas potential are examined. Measures for the faster and more efficient development of biogas industry and for encouraging biogas exploitation are proposed.

Proposals are also made on the basis of comparison of current state of the biogas industry in Slovenia, with current state of the biogas industry in Austria (predominantly Styria) and Sweden (predominantly Östergötland County). Proven effective measures from Austria are analysed and the implementation of the most appropriate and effective measures from Austria is proposed.

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Povzetek

V prispevku preučujemo bioplin kot trajnostni vir energije iz ekonomskega, okoljskega in družbeno-političnega vidika. Prav tako preučujemo prednosti in slabosti bioplina s SWOT analizo in testiramo kompatibilnost bioplina, kot trajnostnega vira energije, z smernicami in cilji EU.

Ker se nove tehnologije za koriščenje bioplina zelo hitro razvijajo in izboljšujejo, smo identificirali, analizirali in primerjali tehnologije za koriščenje bioplina.

Dodatno predstavljamo nove možnosti in potenciale za razvoj industrije bioplina v Sloveniji. Preučene so možnosti za izkoriščanje bioplina in potencial bioplina v Sloveniji. Predlagani so tudi ukrepi za vzpodbujanje rabe bioplina ter za hitrejši in učinkovitejši razvoj industrije bioplina.

Predlogi so podani na temelju primerjave stanja na področju bioplina v Sloveniji z stanjem, ukrepi in primeri dobre prakse iz Avstrije (pretežno Štajerske) in Švedske (pretežno okrožja Östergötland). Dokazano učinkovite in uspešne ukrepe iz Avstrije smo analizirali in predlagali njihovo implementacijo v slovenskem prostoru.

1 INTRODUCTION

Environmental pollution, greenhouse gas emissions (GHG), increasing quantities of waste, increasing energy demand and high energy import dependency represent the essential problems that are addressed in this paper.

Increased quantities of waste are the most problematic in urban areas, where they are generated, because locations for landfills are scarce and waste disposal is expensive, and does not represent a sufficient solution of abovementioned problems. Landfills are also environmentally controversial, because of GHG emissions and emissions in water and soil. The solution is found in minimizing waste quantities, reuse of waste, separate waste collection and recycling. At present in Slovenia, only the separating and recycling different types of waste are required. However, the quota of collected and recycled/reused organic waste and the demand for recycling are increasing, because of raised environmental awareness, resource depletion and a tightening of environmental legislation that prohibits the deposit of waste on persistent landfills in the near future. Consequently, the profitability of recycling bio-waste is increasing. In the EU and especially in Slovenia, there are not enough capacities for the efficient recycling of biological waste.

Increasing energy demand and global oil depletion are also promoting the development and use of alternatives, such as biogas plants. In the 20th century, a dramatic 20-fold increase of energy consumption occurred. It is expected that the energy consumption will also rise in the future. The forecast of the International Energy Agency (IEA) in its reference scenario estimate is that global energy demand from 2005 to 2030 will rise by approximately 52% [1], while the predictions of the World Energy Council estimate that energy demand will double by 2050, which is comparable to IEA's prediction. Fossil fuels will remain the major energy source, covering approximately three quarters of elevated world energy needs.

The IEA noted that the predicted increase of energy demand in the next twenty years will have a simultaneous influence on increased prices of energy sources and increased GHG emissions. That is why the IEA is drawing attention to the problems of fossil fuels consumption and is calling for an international climate agreement to cut GHG emissions. The continuous increases of energy consumption in Slovenia in the past and future expectations are not sustainable.

Slovenia's energy import dependency is approximately 55% and energy-related emissions are already around 80% of all GHG emissions in Slovenia [2].

That is why renewable energy sources (RES), which include biogas, are seen as a long-term solution and a short-term reduction of the above-stated problems. The EU is aware of the issues related to conventional energy sources and supports the development of RES and sustainable energy. Sustainable energy comprises two key components: energy efficiency (EE) and RES. The investments in EE and RES are highly important, since these cause less pollution, enable the use of local resources, lower import dependency and energy demand, and simultaneously increase EU competitiveness.

That is why biogas as a RES enables the production of electricity and heat from local sources (especially biological waste and landfill gas) thereby contributing to the development of suburban areas, lowers energy import dependency and contributes to greater socio-political stability, lowers environmental impacts and reduces the need for new landfills, thereby contributing to a cleaner environment.

2 METHODOLOGY

The data presented in the study are gathered on the basis of a compilation method. Different independent sources (statistical offices, national, international and private studies and analysis, scientific papers and national energy balances) were used. The data on energy consumption; RES and biogas share, total, technical and economic biogas potentials (exploited and unexploited); biogas technologies; possibilities and barriers of biogas exploitation and all others data are statistically analyzed, evaluated and cross-compared.

Our contribution is the identification and combination of data, since individual data from different sources are not completely comparable, because they were obtained with different methodologies. On this basis, the actual similarities and differences of biogas statistics were then examined and cross-compared. For evaluating biogas potentials in Slovenia, we examined and critically evaluated many existing studies, evaluations, legislation and strategic documents.

With a SWOT analysis, we evaluated the Strengths, Weaknesses, Opportunities and Threats of biogas as an energy source in Slovenia. The data presented are syntheses and combinations of many different studies, upgraded with our own findings, based on national specificities and previous studies.

Sustainability analysis is typically based on environmental, social or socio-politic and economic perspectives; however, we also included a technological perspective, because we estimate that it is also important for the process of transition in the sustainable energy industry. Sustainability analysis is general and is not attached on Slovenia.

Finally, we also analyzed the current state of biogas in Slovenia. The research also includes finding the reasons for the scarcity of biogas plants in Slovenia on the basis of comments and the opinions of biogas plant planning participants (owners, investors, municipality, neighbors, farmers, etc.) and on a review of institutional restrictions. Measures for more efficient biogas industry development in Slovenia are provided on the basis of potential solutions for problems and on the basis of proven effective measures from the Austrian and Swedish biogas industries. Implementation of the most appropriate and effective measures from Austria is proposed.

The survey and analysis of Slovenian biogas potential, sustainability analysis and SWOT analysis are performed on the basis of currently established levels of economical, technological and environmental acceptability. We assume that technological and economic biogas potential will increase in the future due to technological development, internalized external costs and increased prices of fossil fuels, but the environmental potential will be reduced because of stricter environmental requirements, partial depletion of biomass and (hopefully) increasing food self-sufficiency.

3 RESULTS AND DISCUSSION

3.1 Sustainability analysis of biogas

A sustainability analysis of biogas is very important for the planning of a future policy for biogas development. Future energy policy development must be consistent from technological, environmental, economic and socio-political perspectives.

From the technological perspective, biogas is very interesting, because biogas technologies are already fully developed and are being continually improved. Especially important are cogeneration (or even three-generation) technology and technologies for the exploitation of landfill gas. Biogas can contribute to covering peak energy consumption, because energy produced from biogas can be managed with the amount of biogas supplied in the energy generator, and is not directly dependent from primary RES (wind, sun, water flow, geothermal energy, biomass) [3].

The exploitation of landfill gas and cogeneration technology are also very appropriate from the environmental perspective, because they contribute to lower environmental impact per produced unit of energy and reduced GHG emissions, specially from landfills, which also reduces unpleasant odors. That is very important when landfills are close to urban areas. Biogas plants also use biological waste as a fuel. Bio-waste is transformed into useful energy in biogas plants, thus avoiding GHG emissions caused by decay. Using local resources in biogas plants is also environmentally preferable.

The socio-political perspective indicates that biogas plants contribute to rural development, create new jobs and new possibilities for farmers and local communities, and enable the decentralization of the energy supply. Landfill gas-stations also enable a healthier living environment, because they minimize unpleasant odors and GHG emissions, and (because landfills are usually close to cities) energy distribution is simpler and more effective [4].

The EU energy policy is a pro-RES policy and sets ambitious RES goals for the future. The first ambitious goal was set in 2001 for the EU Member States: a 12% share of RES in 2010 (which was not reached throughout the EU). The second goal is represented in the 20/20/20 objectives that require 20% of RES in EU by 2020. The specific target for Slovenia is 25% of RES. Achieving this objective is also encouraged with the Renewable Energy Directive (2009/28/EC) that required a National Renewable Energy Action Plan (NREAP) submitted by each Member State by 30 June 2010. These plans had to be prepared in accordance with the template published by the Commission, and provide detailed roadmaps of how each Member State expected to reach its legally binding 2020 target for the share of RES in their final energy consumption. Member States had to set out the sectoral targets, the technology mix they are expecting to use, the

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trajectory they will follow and the measures and reforms they will undertake. Regulations that prohibit bio-waste also contribute to biogas industry development [5].

From this perspective, biogas as a RES that (re)uses bio-waste is an attractive energy source for the future.

From the economic perspective biogas is not yet very interesting. Biogas stations are usually profitable only with feed-in tariffs, because external costs are not yet fully included and because the price of energy and the profitability of energy plants is still more favourable for conventional energy sources. Additional income could be achieved by selling heat and fertilizer (a by-product of biogas plants). That is however questionable, because biogas plants are usually in suburban or rural areas, where there are not many households or industrial facilities that could use the extra heat produced; the transport or distribution of it over a longer distance is not profitable. The use of fertilizers is also limited, because biomass used in biogas production is often environmentally problematic (e.g. heavy metals like zinc in animal manure) [4].

The investment required in a biogas plant is approximately €3–5 million per installed MW of power. Because investment costs are declining, external costs are increasingly being considered and a ban on bio-waste disposal is planned in the future, biogas plants will become economically feasible without feed-in tariffs.

3.2 SWOT analysis of biogas

A SWOT analysis is very appropriate for the evaluation of energy sources; such analyses are performed on the basis of internal Strengths and Weaknesses and external Opportunities and Threats.

Strengths:	Weaknesses:
-developed technology -cogeneration/three-generation (high efficiency) -lower environmental impact -lower GHG emissions -renewability -bio-waste reuse/recycle -sustainable energy -usable by-product: fertilizer -stench reduction -improved hygiene -(re)use of landfills	-high investment -unprofitable without feed-in tariffs -geographic limitations -lack of skilled labour -lack of knowledge and experience (especially small biogas plants) -high maintenance costs
Opportunities: -to become leading/important alternative for oil -possibility of use of existing infrastructure -broad range of applications -environmental legislation of EU and member states -waste legislation and requirements -regional/rural development -decentralization -raising environmental awareness -high unexploited potential -reduction of landfills -20/20/20 objectives – NREAP -covering peak energy consumption	**Threats:** -subsidies (feed-in tariffs) only for electricity, not heat -Other RES -legal restrictions on fertilizers, permit -suitability of biological wastes for biogas plants -contraction of agricultural land for food -seasonal/annual price and volatility of commodities

Figure 1: *SWOT analysis of energy from biogas [4, 5, 7, 8, 9 and 10]*

As can be seen in Figure 1, positive features, especially opportunities, dominate. Therefore, we are assessing biogas as a perspective RES and a good alternative for transition in the sustainable energy industry. The essential weakness of biogas is the rather high investment in the biogas plant, approximately €3.6 million per installed MW of power (presented calculation is the average for Styria, [5].

However, the biggest problem is not the investment, but the contraction of agricultural land intended for food production. Slovenia is not self-sufficient in food, producing only approximately 60% of the food that it consumes [6]. It also has the lowest rate of agricultural land per capita in the EU. We believe that food self-sufficiency is more important than energy self-sufficiency and that energy crops must not force out food crops. Biogas in Slovenia should be exploited mainly on landfills and on the basis of biological wastes, sewage and animal manure.

3.3 Biogas technologies

Biogas is mainly extracted with anaerobic digestion in four stages. In first stage (hydrolysis), bacteria decommission complex organic molecules (fats, proteins and carbohydrates) and produce sugars, fatty acids and amino acids. In the second stage (acidogenesis), simple molecules are decommissioned and carbonic acids, alcohols, hydrogen, carbon dioxide and ammonia are produced. New technologies also enable capturing alcohol. In the third stage

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(acetogenesis), hydrogen, acetic acids and carbon dioxide occur. These are used in the last stage (methanogenesis), where methane and carbon dioxide (biogas) are produced.

Basic biogas production technology uses a batch reactor, where bio-wastes are only added and fermented mass is not removed [11]. Batch reactor technology is used on landfills.

Unlike batch reactors, biogas plants use continuous procedure technologies (flow reactors) that are divided into three groups, according to the containment times of microorganisms, substrate and liquid [12].

The containment times of all three inputs are the same as in the first group technologies (e.g. flow reactor and reactor with process of complete mixing). With the second group, represented by a bioreactor with a sludge bed and suspended activated sludge process, the containment time of liquid (water) is shorter than the containment time of microorganisms and the substrate. The third group are reactors with fixed active biomass, where the containment time of microorganisms is longer that containment time of the liquid and substrate. The same microorganisms that are fixed in the reactor are used more times [11, 13, 14].

Another interesting, technologically and cost-effective and simple technology for biogas extraction is floatation technology, which divides two different components with an injection of microscopic air bubbles in the water that is used as a media and continually mixed with air under high pressure [4].

Biogas capture usually takes place in stretching storage tanks, because they store biogas for utilization in times of peak consumption.

Hybrid technologies that combine more than one biogas extraction technology have also been developed but remain quite uneconomical because they are less efficient. Most of them are not widely used.

The most widespread technology is a reactor with a process of complete mixing. Its strengths are its simple and stable operation process, the technology is well tested and suitable for processing biological waste and other biomass from the market (with dry matter content from 4–12%). Its weakness is the long containment time of biomass, which means a long process of biogas production.

The second group of biogas technologies are technologies for the production of energy from biogas, which are similar to those used for the exploitation of conventional energy sources. The most widespread technology is the internal combustion engine. Smaller biogas plants can also use modified car engines (e.g. the Semriach biogas plant in Austria). The other technologies are Stirling engine technology, turbines, and modern steam engine technology, which have efficiencies of over 80% [3]. Furthermore, fuel cells can be powered with hydrogen extracted from biogas [3, 15].

Biogas extraction technologies and technologies for energy production from biogas are presented on Figure 2.

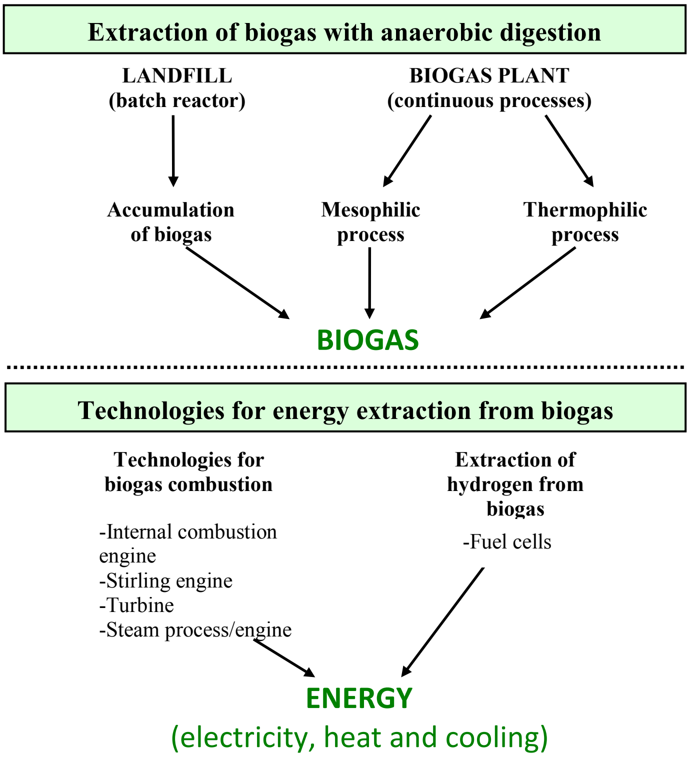

Figure 2: *Production of biogas and energy from biogas [3]*

The production and utilization of heat from biogas plants is also very important. There are also some cases in which only heat is produced in biogas plants. Heat is usually extracted by cooling the engine for energy production, but is also generated in the anaerobic and aerobic digestion process.

When producing electricity and heat simultaneously, we are referring to cogeneration technology (CHP). CHP is also proposed and supported by the EU. As a low carbon and high efficiency solution for electricity and heat supply with tens of thousands of installations across Europe, cogeneration is already saving Europe a minimum of 35 Mtoe per year while providing 11% of its electricity and heat (in the entire energy sector).

Cogeneration is a key technology especially for industry. It allows companies to be competitive and to decarbonise industrial heat now and in the foreseeable future. The EU forecasts that cogeneration will be saving a minimum of 70 Mtoe of primary energy per year by 2030 (and 80 Mtoe by 2050) and contributing to 170 million tones of CO_2 savings every year to Europe by 2030.

Even more advanced is the technology of three-generation, where electricity, heat and cooling are produced from one energy source at the same time.

In Slovenia, approximately 7.2% of energy is produced by cogeneration. In the EU, the percentage is a bit higher and is approximately 10.9% [16].

3.4 Biogas potential, possibilities and measures for Slovenia

The examination of the current state of biogas exploitation in Slovenia has shown that the biogas potential in Slovenia is relatively unexploited, but the growth of exploitation from 2008 to 2009 was a considerable 117%. The production of electricity from biogas at the end of 2009 was approximately 40 GWh. At the end of 2010, there were 17 biogas plants with approximately 17 MW of installed capacity [17].

However, studies and strategic documents, (e.g. NREAP) have concluded that the biogas potential in Slovenia is very high. The technical potential estimated in these studies, considered in the NEP preparation, differ significantly: from 222 to 2755 GWh/year. The maximum technical biogas potential of Slovenia seems to be a bit overestimated and the minimal a bit underestimated. Despite that, NREAP foresees production of approximately 367 GWh/year of energy in biogas plants with a total installed capacity of 61 MW by 2020 (58 MW by 2015) [10, 18].

In similar studies, which were not included in the preparation of NREAP and NEP (such as the study of BigEast), the estimated technical and total potential is much smaller. However, the NREAP goal is not too ambitiously set, because the study made by the Agricultural and Forestry chamber, which was also not included in the preparation of NREAP and NEP, estimates that the biogas potential by 2020 is 927 GWh/year [19], which is almost three times more than the NREAP goal for 2020.

Surprisingly, great potential is also indicated in biological wastes that are exported from Slovenia. Slovenia is currently exporting most of its bio-waste to neighbouring countries [2].

The examination of potential raw materials/waste for biogas production also showed that biogas potential is highly unexploited. In 2007, biogas plants in Slovenia used approximately 2,800 tons of biological wastes. At the same time, Slovenia produced more than 25,000 tons of biological waste. From 1 kg of decommissioned kitchen bio-waste, 0.45 m^3 of biogas can be obtained. The price for collecting biological waste from households is approximately €70 per ton [20].

There are around 563,000 ha of agricultural land in Slovenia (approximately 50% fields and 50% pastures) [6]. Rutz [21] predicts that approximately 10% of fields (resulting in 168,000 tons of corn silage) and 20% of pastures (resulting in 308,000 tons of grass silage) can be used for biogas extraction. We believe that this evaluation is overestimated, because Slovenia is not self-sufficient in food. That is why we believe Slovenia should sacrifice only fields and pastures, necessary for the production of a technical minimum. That means an amount of silage that is necessary for biogas production, according to the use of bio-waste quantities.

Annual production of agricultural waste in Slovenia, appropriate for biogas production was approximately 214,000 tons [16]. This data excludes waste used for fertilization directly by farmers.

The total amount of annual animal manure in Slovenia is approximately 900,000 tons [6, 20]. With the reuse of animal manure, we further contribute to environmental protection, because manure itself cause high GHG emissions.

The collected annual amount of municipal bio-waste in Slovenia is approximately 30,000 tons which represent 3.6% of all municipal waste [6]; 64% of which is used in Slovenian biogas plants for biogas production [2].

The goal is actually to reduce landfilled biodegradable waste from 47% (base year is 1995) to 16% by 2015 [22].

For biogas productions, waste water is also appropriate, because of the high content of methane. Biogas production is feasible and frequently also very cost-effective with the upgrading of existing wastewater treatment plants into biogas plants (e.g. the biogas plant Ilirska Bistrica).

Because regulations require that all settlements with less than 2,000 inhabitants (85% of all settlements in Slovenia) must have regulated sewage systems by 2015, and prohibit the use of permeable septic tanks after 2017, we believe small settlements and their private sewage systems could also be seen as an appropriate source for production of biogas and energy from biogas.

3.5 Comparison of biogas industry with Austria and Sweden and proposals for more efficient development of biogas industry in Slovenia

The biogas industry in Austria is much better developed than in Slovenia; there are approximately 350 biogas plants there [23]. Austria's success is also a result of the implementation of public/private partnerships: a special cooperation between local communities, farmers and investors. However, the current state of biogas industry in Austria is not optimal: 50% of all biogas plants lost money in 2008, because the guaranteed electricity purchase price was low and because of very poor use of heat; 60% of all biogas plant owners said they would not invest again in biogas plants [23]. Despite that, Austria has almost five times more biogas plants per capita and per square km than Slovenia. The concentration of biogas plants can be seen especially close to Austrian borders with neighboring countries, like Styria, which borders to Slovenia.

Despite a recent decline in bio-waste exporting, Slovenia currently still exports a great deal of biological waste to neighbouring countries, especially Austria [2]. We believe that Slovenia should search for options for bigger domestic exploitation of biological waste and implement measures for that. The cooperation of local communities, farmers and investors in Austria contributes to rural development, creating new jobs, and additional motivation because of profit-sharing. Instead of this, measures for the local conversion of bio-waste must be developed and applied, because this could contribute to social (new jobs, rural development, development of local communities), economic (profit from conversion of bio-waste in energy and other development) and environmental (less pollution because of exclusion of transport) benefits.

A similar but still slightly different pro-biogas industry oriented situation can also be found in Sweden, in Östergötland County, where biogas generation is organized in some form of social entrepreneurship, with an objective of encouraging the development of RES and the municipality. A municipally-owned company operates the biogas plants. Therefore, the profit generated by this company is not distributed to stakeholders but is reinvested in new socially useful projects like kindergartens and schools.

The use of biogas is also very advanced. Because the added value of a product is higher when producing liquefied biogas as a fuel for cars, they do not use biogas for electricity production or CHP but they rather produce only fuel for cars. The biggest problem at the beginning of the

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project was existing infrastructure which did not support any “oil alternatives”. So they installed their own biogas pump stations. Today, most of the buses and a few thousand cars in Linköping, the capital of Östergötland County in Sweden, are powered by liquefied biogas.

Another important thing is the production and use of by-product: fertilizer. Because they know the origin of their inputs/raw materials, they are producing environmentally friendly bio-fertilizer, which farmers can access 24 hours a day. This fertilizer is also very cheap, because farmers must only cover transport costs and do not have to pay any extra for the fertilizer. A continuous, economical and reliable supply of fertilizer is very important for farmers, because their yield depends on fertilizers, which should be available at the right time.

There is also one more significant difference, when comparing Sweden and Slovenia: the supply of raw materials. In Slovenia, the biological wastes appropriate for biogas production are often exported, mainly to Austria. The situation in Sweden is the opposite. They are aware of the scarcity of their resources and importance of controlling raw materials, including biological wastes for biogas production. Therefore, they are already searching for new sources, appropriate for biogas production, because the demand for biogas is rising.

We believe that an important emphasis in Slovenia must be made especially on cogeneration of heat and electricity and the more extended use of landfill gas, because the investment in infrastructure and production process for producing liquefied gas as in Sweden is much higher. However, cogeneration also brings some problems. Especially problematic is the use of heat from biogas plants, because they are mainly in the areas where not many heat consumers live. The problems presented are similar to those in Austria.

The most important measure that is proven effective in Austria and should be implemented in Slovenia is public/private/local partnership. Slovenia should support and promote the cooperation between local farmers and local communities that should become partners in biogas plant investments. This kind of partnership is very appropriate for rural development and for preserving jobs in rural areas. That means that local positive effects of biogas as a RES are not just a matter of national energy policy, but must be implemented in strategic national energy plans.

Social entrepreneurship and municipally owned biogas plants, as described in the Swedish case, are also a good example; especially because municipalities usually dispose with biological wastes and can more easily ensure adequate quantities of raw material for biogas production.

We also propose the thoughtful positioning of biogas plants, especially to locations that also allow the use of produced heat. The use of heat increases energy efficiency and the profitability of biogas plants.

The promotion and education about RES (including biogas) is also very important. Presentation and education about new possibilities, the reuse of bio-waste, manure and fertilizers is especially important for farmers, who are the core element for the operation of biogas plants, but also for municipalities, which are the biggest producers of bio-wastes.

More efficient development of biogas industry in Slovenia could also be achieved with the simplification of bureaucratic procedures, more extended use of landfill gas and improved collection of separated waste. Landfills are major polluters, but pollution can be minimized with biogas exploitation. Biodegradable wastes are also a major environmental problem, because their digestion causes GHG emissions. That is why reuse of bio-waste is environmentally and economically sound.

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4 CONCLUSION

The study of biogas and energy from biogas has revealed that biogas is sustainable energy source, because the technology needed has already been developed, it is environmentally more appropriate than fossil fuels, has positive social effects and will also become economically attractive. With a SWOT analysis, we examined the pros and cons of biogas and we discovered that biogas has many more strengths than weaknesses and many more opportunities than threats. Because of that and because the exploitation of biogas has strong growth, good potential and (at least in principle) policy support, we believe future developmental measures are appropriate for Slovenia.

However, we also believe that reduced and efficient energy use is the only solution that leads to a totally sustainable society. That is why it is most important that efficient technologies will be used, regardless of the RES, and that measures regarding RES and EE will be combined and implemented. Even the NREAP goals for biogas are ambitiously set, but our opinion is that achieving these goals will be the most problematic.

Despite the specified measures, the main problem of biomass exploitation (whether to exploit rural areas for food or for energy corps supply) remains the same. The exploitation of rural areas for biogas production must be minimized and bio-waste and manure must be considered as the main input.

References

[1] **International Energy Agency (IEA):** *World Energy Outlook 2010 Factsheet*, IEA, 2010.

[2] **ARSO:** E*nvironmental indicators of Slovenia*, available on: http://kazalci.arso.gov.si/, [10.02.2011], 2010, (in the Slovenian language).

[3] **M. Pehnt and L. Schneider:** *The future heating market and the potential for micro cogeneration*, 2006, available at: http://han.ukm.si/han/SpringerLink/springerlink.com/content/r558540160870054/?p=6f339e13805b4ef295a8dd69afaefd40π=0 [26.3.2011].

[4] **M. Obrecht:** *Possibilities for exploitation of energy from biogas in Slovenia* (in the Slovenian language), Research study, University of Maribor, 2009.

[5] **M. Obrecht et al.:** *Evaluation and Analysis of Renewable Energy Sources Potential in Slovenia and its Compatibility Examination with Slovenian National Renewable Energy Action Plan*, World Renewable Energy Congress 2011 Lynköping Sweden, 2011.

[6] **SURS Statistical Office of Republic of Slovenia:** *National Statistic*, 2011, (in the Slovenian language).

[7] **M. Obrecht, M. Denac:** *Evaluation of potential and options of renewables for development of sustainable energy in Slovenia*, Facing the Challenges of the Future: Excellence in Business and Commodity Science, 17th IGWT Symposium and 2010 International Conference on Commerce, 2010.

[8] **S. Rasi, A. Veijanen and J. Rintala:** *Trace compounds of biogas from different biogas production plants*, Energy, vol. 32, no. 8, pp. 1375–1380, 2007.

----

[9] **G. Teleghani and A. Kia Shabani:** *Technical-economical analysis of the Saveh biogas power plant*, Renewable Energy, vol. 30, no. 3, pp. 441–446, 2005.

[10] **NREAP:** *National Renewable Energy Action Plan*, Ministry of the Economy, 2010.

[11] **T. Kurbus:** *Development of high efficient procedure for wastewater treatment in batch bio-reactor*. Doctoral thesis, University of Ljubljana, 2008 (in the Slovenian language).

[12] **FV. Nekrep:** *Anaerobic procedures for wastewater treatment* University of Ljubljana, 2004 (in the Slovenian language).

[13] **M. Stražar et al:** *Wastewater treatment procedure MBBR with PVA-gel carriers*. Simposium "Vodni dnevi 2006", 18–19 October 2006, Portorož, Slovenia, 2006 (in the Slovenian language).

[14] **Environmental engineering**, *Wastewater threatment procedures* – presentation, 2006, available on: http://www.fs.uni-lj.si/lvts/okoljsko%20inzenirstvo%20MB/voda3.pdf [12.3.2011] (in the Slovenian language).

[15] **ST. Neumann and C. Myren:** *Fuel processing of biogas for small fuel cell power plants*, Journal of power sources, no. 56, pp. 45–49, 1995.

[16] **EUROSTAT:** *Energy statistics* – main indicators and quantities, EUROSTAT, 2010.

[17] Energy Agency of the Republic of Slovenia: *Register of declarations for the production facilities of electricity from renewable sources and high-efficiency cogeneration*, 2010, (in the Slovenian language).

[18] **Jožef Štefan Institute:** *National energy program (NEP) 2010 Long-term energy balance 2010 to 2030*, Ministry of the Economy, 2010, (in the Slovenian language).

[19] **Agricultural and forestry chamber**, *Data about wood biomass and biogas in Slovenia*, available at: http://www.kgzs.si/gv/gozd/les-in-biomasa.aspx, [25.11.2010], 2010.

[20] **Biofutura:** *Presentation of biogas plant Ilirska Bistrica*, Internal data, 2009 (in the Slovenian language).

[21] **D. Rutz:** *Impact of biogas production in Bulgaria, Croatia, Greece, Latvia, Romania and Slovenia*, available on: http://www.big-east.eu/downloads/IR-reports/ANNEX%202-8_WP2_Task_2.7-impacts-WIP.pdf [21.4.2011], pp. 38–52, 2009.

[22] **OPOO:** *The operational program for waste disposal with the aim of reducing the quantities of biodegradable waste*, UL RS št. 83/99, 1999 (in the Slovenian language).

[23] **R. Braun:** *Short report – status Austria 2009*, available on: http://www.iea-biogas.net/_download/publications/country-reports/apr2009/austria_report4-09.pdf [21.4.2011], 2009.

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THE ENERGY CONSUMPTION CHALLENGE OF SUSTAINABLE TOURISM

TRAJNOSTNI TURIZEM JE IZZIV RABI ENERGIJE

Milan Ambrož ℜ

Keywords: tourism, energy consumption, sustainability, culture change

Abstract

This research paper identifies a unique model of culture change to a more sustainable model of energy consumption. Further study suggests strategies to implement cultural changes toward sustainable tourism using cultural traits proposed by researchers of culture change as a vantage point to master the impact of energy consumption on the environment.

Povzetek

Ta študija predstavlja izvirni model kulturnih sprememb k bolj trajnostni rabi energije. Poleg tega, študija predlaga strategije za vpeljavo kulturnih sprememb k trajnostnemu turizmu, ki temeljijo na faktorjih kulturnih sprememb, ki jih predlagajo raziskovalci kulturnih sprememb kot izhodišče za obvladovanje negativnih vplivov energije na okolje.

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1 INTRODUCTION

Despite the economic crisis, tourism remains one of the fastest growing industries in the world. It is a very valuable source of income and employs millions of people. Tourism, like other industries, fosters intense competition for common goods and often negatively impacts local natural and social environments, [1]. There is no doubt that tourism substantially increases local income, but it also leads to a focus on individual benefits. Socially, tourism fosters intercultural communication, while simultaneously dissolving kinship relationships and removing traditional resource-use strategies. At the level of the local community, non-sustainable tourism fundamentally disrupts the local socio-economic system and fosters the degradation of the ecosystem. It commoditises natural resources and replaces them with imports. Large-scale global environmental and climate problems are produced by tourism's pressure on all human activities, which raises the question of the future of tourism development on the level of the global community, [2]. Gössling, [3], warned that some impacts, such as the use of energy and its global consequences, have essentially been excluded from the discussion of sustainability. Sofield, [4], added that tourism should be governed as a part of overall sustainable human development. Its development and adaptability are closely related to continuity and change. Sustainability factors address many public, business and private areas of life and form a sustainable way of seeing and doing things. They cannot be maintained, or sustained without considering their social, economic, cultural, and environmental contexts. Sustainable tourism is a complex phenomenon and many different factors and circumstances should be considered in the process of its implementation at the level of local communities, [4]. Sustainable tourism can be defined as a set of policies, practices and programmes that take into account the expectations of tourists and the needs of communities, [5]. It strives to be more energy efficient by using renewable energy, reducing water consumption and waste. On the local level, it plays an active role in conserving biodiversity, cultural heritage and traditional values, and supporting intercultural understanding and tolerance. Economically, it generates local income and integrates local communities.

Using sustainable principles makes tourism more sustainable, benefits local communities and raises awareness and support for the sustainable use of natural resources. On the human level, it aims to improve livelihoods and reducing poverty. Through implementing sustainable principles, all forms of tourism should become more sustainable, [6].

In this paper, we concentrate on the creation of consumption culture change processes towards the greener tourism, which is the solid foundation for sustainable tourism development. Energy consummation is at the core of our interest, as we propose strategies leading to the model of effective use of energy in tourism.

2 CULTURE CHANGE AND SUSTAINABLE TOURISM

The sustainable way of life is closely linked to the culture that is one of the core factors that generates sustainable behavior in all aspects of social life including tourism. Culture is complex and multilevel phenomenon that includes individual, group and national levels defining a set of attitudes, values and norms, [7]. Culture comprises a set of values and communicative means that describe the relationship to environment. In a very narrow sense we understand culture as an organisational phenomenon, which has several dimensions. The first dimension consists of two traits: involvement and adaptability; these are indicators of flexibility, openness, and

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responsiveness. They are strong predictors of growth. The second dimension is comprised of another two dimensions: consistency and mission; these are indicators of integration, direction, and vision. They are strong predictors of profitability.

In implementing changes toward the sustainable use of energy in tourism, only improved understanding of the complex nature of tourism, and of its connections to the environment, can help to implement culture changes and establish a new form of symbiotic relationship, [8]. Farrell and Ward, [9], even thought that new approaches are needed to address complex cultural changes. They proposed a retreat from reductionism, allowing for an extensive integration of human and natural systems that could form new interpretations of sustainability. Tourism development as a vehicle of cultural change is nevertheless perceived as positive and sustainable, because changes are complex and damage becomes perceptible only in the medium or long-term future. The tourism industry tends to shift its impact to remote areas, and villages become centres of resource allocation. Gössling, [9], added that imports compensate for the losses in the local ecosystem capacity. This is the area where Becken and Simmons, [10], saw a serious threat to the sustainability of tourism. It becomes very evident that global tourism requires more and more energy to produce its products and services, and visitor experiences, [11]. Energy is needed for the transportation of travellers. Accommodation facilities offer more comfort and need more energy. Supply chains become longer and energy-and time-consuming. Formerly peripheral changes to tourism resorts are only possible with new energy inputs from the external environment. As a consequence of the accelerated consumption of energy, natural resources are depleted and the threat to the global climate is heightened. From the ecological perspective, the “natural” is often seen as fragile and vulnerable; natural resource mobilisation, when not properly managed, has unseen effects on natural and social environment. It is only justified when conditions for sustainable and ecologically sensitive development are created based on sustainable principles. In this process, the role of local community is irreplaceable. It must manage resources, interact with local cultures, and redistribute ecological benefits through the community, [12], [1].

This is the reason the mobilisation of nature as a resource for tourism must be done very carefully. It is justified when the conditions of tourism development are set on the level of the local community. D’Amore's, [12], case study of Canada's approach to minimising negative tourism impacts is a good example of the active community role. Canadian authorities developed and implemented a code of ethics and guidelines for sustainable tourism for local residents and tourists that yielded very positive results. Hughes, [13], saw these efforts to implement sustainable principles as tentative strategies for the tourism culture change. When supported by technical, rational and scientific strategies, sustainable principles can be successfully implemented.

3 GREEN ENERGY CULTURE APPROACH

The main drivers towards the sustainable tourism investment are culturally bound and realised through the attitudes and behaviour of tourists who create tourism demand. Tourism demand in a sustainable tourism environment is followed by business actions to reduce operational costs and increase competitiveness. These activities are supported by coherent policies and regulations for environmental protection and technological improvements. However, private efforts for environmental and social responsibility represent the major input in the process of change of energy usage behavior and resource conservation, [14].

The sustainable way of life is closely linked to the culture that is one of the core factors that generates sustainable behavior in all aspects of social life including tourism. Culture is a complex and multilevel phenomenon that includes individual, group and national levels defining a set of attitudes, values and norms, [15]. In relation to the environment, culture comprises a set of values and communicative means that describe the relationship to environment. According to Denison and Mishra, [16], organisational culture, in a very narrow sense, has two dimensions. The first dimension consists of two traits: involvement and adaptability, which are indicators of flexibility, openness, and responsiveness. They are strong predictors of growth. The second dimension is comprised of another two traits: consistency and mission, which are indicators of integration, direction, and vision. They are strong predictors of profitability. These two dimensions allow for more a subtle analysis of the role of a culture in shaping sustainable attitudes and behavior: (a) an action or growth approach allows them to analyse behavior practices and environmental lifestyles, and (b) a structural or profitability approach allows researchers to analyse attitudes toward environment, [16], [17].

Building on these two dimensions, we conclude that sustainable tourism depends on the attitudes and behaviour of local residents, government bodies and municipalities, and tourists. They pave the ways to the involvement of the local community to the process of customer satisfaction, the preservation of natural and cultural heritage, the improvement of living conditions, and poverty reduction in tourist destinations. This can only be realised through a commitment to long-term strategies. These strategies, as a tool for cultural change, largely depend upon the quality of the design of local tourism policies and activities, [18].

Butler, [8], pointed out that cultural change can be implemented only when an awareness of the limitations of growth and the education of all parties in the change process is involved. Halme, [19], supported this idea by stating that multi-stakeholder public-private networks should play the crucial role in the culture change and the developing of sustainable behavior. The main goal of networks aimed at sustainability is to develop and establish a profitable and ecologically sustainable tourism industry. In this context, it is very important to emphasise that the satisfying experience for visitors and quality life for local residents can be preserved and sustained through the actions of the tourism management, [20]. Carter, [23], argued that in the process of change to more sustainable tourism culture, many interests, including the role of host population, tourists as guests, tourism-organising activities and the relationship to the natural environment, should be considered. Additionally, the prevailing lack of knowledge, responsibility and long-term planning, where these interests are neglected, often results in environmentally and culturally unaccepted development.

McKercher, [22], proposed two specific sources of external threat provoked by the sloppy implementation of culture change. The first is economically sustainable development that can be used as a tool of incompatible urban and industrial activities into tourism areas. The other is ecologically sustainable development being used as a means of policies that restrict tourism access to and use of public land.

4 ENERGY FOOTPRINT OF TOURISM

Given the pervasive character of energy consumption, assessing the relative effects of attitudes, policies and behavior strategies in tourism represents a valuable step in positive change towards sustainable tourism. In many cases, these change policies and strategies involve the

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implementation of innovative planning and management. Change practices are associated with transport, accommodation, building construction and design, and energy supply structure, employees' commuting and geography, [12]. However, before such initiatives are implemented, it is important to understand the structure of energy consumption and the behavior of tourists and local residents with regards to energy consumption.

Some researchers, including Hunter, [5], Gössling et al., [23], and Williams and Kelly, [12], emphasise the importance of ecological footprint analysis to understand the tourism demands upon the biosphere. An ecological footprint reveals the wider and profound impacts of consumerist lifestyles on local environment that have been so long neglected. Furthermore, ecological footprints for individual tourism products can be used to clarify the theoretical aspects of sustainable tourism and to inventory the key drivers of energy use. The detailed examination of the energy use pattern of an operator can reveal the pattern of energy use and paves the way to develop strategies to improve energy efficiency.

The consequences of the tourism sector's growing consumption of energy are by no means global GHG emissions. This trend is especially seen in travel and accommodation. It is an indisputable fact that dependence of tourism sector on fossil fuels is very high. Several elements contribute to this situation. Growth rates in international tourist arrivals and domestic travel are high, and tourists tend to travel for a shorter periods of time. According to Peeters et al., [24], tourists prefer energy-intense transportation like aircraft and car travel. Many tourism products, like scenic flights, scenic travelling and jet-boating consume much more energy than activities that are not associated with travelling by means using carbon fuel.

Geographic distance plays important role in the consumption of energy. Some distant tourism destinations are heavily weighted by the energy consumed to reach them. Scott [25] shows that transport subsectors such as air transport, car transport and other transport, add 75% of CO_2 emissions. Transportation of tourists accounts for 75% of transport subsector emissions. Non-CO_2 emissions are not included. The global tourism sector adds 5% of all emissions. A projection to 2035 shows that tourism CO_2 emissions in air transportation will increase from 40% to 52%, and car transport CO_2 emissions will decrease from 32% to 16%. It is estimated that tourism will grow faster than other industries in the next decades. Without green investments, there will be much higher impacts on environment.

Transportation is still the principal emitter (0.7 Gt) in tourism. Aviation and cars will account for 74% and 24% of reductions, respectively. Accommodation will account for 0.58 Gt of emissions in 2050. Other tourism activities will account for 98 Mt of CO_2 emissions. Because tourism is highly sensitive to the impacts of climate change, there is no alternative other than the strengthening the capacities of tourist destinations to adapt to unfavourable climatic conditions, [7]

Accommodation is the second most energy-intensive component of the tourism industry. The study of Becken et al. [11] of the tourism accommodation energy consumers revealed that hotels are the largest energy consumers in the accommodation sector. About 67% of total energy in accommodation sector is consumed by hotels. There is a large demand for heating or cooling, lighting, cooking, cleaning and other activities. More luxury in hotels requires more energy. The study of Peeters et al. [24] of energy use in hotels shows a range between 25 and 284 MJ/guest/night. Table 1 presents the costs of the BAU scenario up to 2050.

***Table 1:** Source *International Energy Agency, available at http://data.iea.org/ieastore/default.asp.*

Consumption	Value
Average international tourist trip/per person - shorter and less activity-oriented business trip	50MJ
Visiting Friends and Relatives (VFR) per trip	100 MJ
Weighted global average of energy consumption for activities of international tourists – excluding transport and accommodation	170 MJ
World daily energy consumption per capita	135 MJ*

5 BAU SCENARIO ENERGY CONSUMPTION IMPACT

The potential costs of economic, social and environmental activities that are generated by the "business-as-usual" (BAU) scenario of tourism are often neglected when the evaluating cost of investments toward sustainability, [7]. Classic tourism is in a mature stage, and new, more responsible energy and resources forms of tourism are emerging. These new forms of tourism are worth investing in because they will be leading transformations in the future tourism industry and will determine the returns on investment.

The green investment scenario is expected to undercut the expected BAU scenario by 18% for water consumption, 44% for energy supply and demand, and 52% for CO_2 emissions [16].

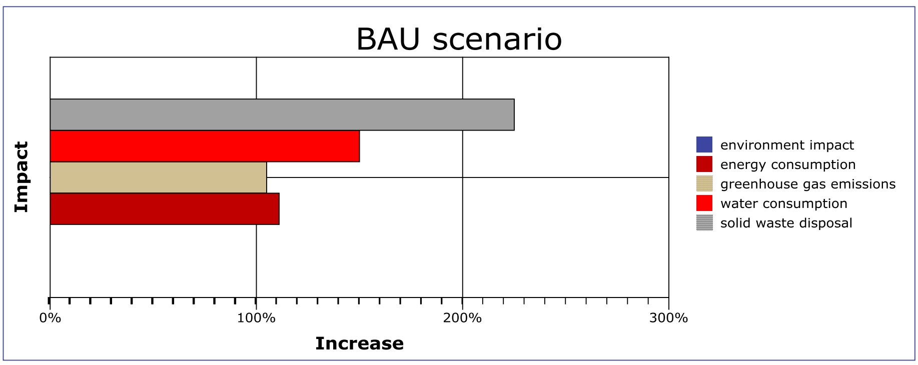

***Figure 1:** BAU scenario of resources consumption*

Energy for tourist destinations is supplied from different sources. Some of it is derived from local systems (micro-hydro, local wind, or photovoltaic cells, thermo-electric plants). These sources are not evenly distributed, while each source is not available in every region. In most cases, energy is imported from outside the destination. In Slovenia, this is the case with fossil fuels and (to some extent) natural gas.

The problem is the disproportional use of energy. Kelly and Williams [12] calculated that 65% of internal energy consumption and GHG emissions in the Resort Municipality of Whistler in Canada is attributed to tourism. The direct uses of energy for the functioning of tourism

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facilities is accompanied by the use of energy for importing food and other material goods and disposing of waste [23].

The largest proportion of energy is consumed by travelling to host destinations. It is estimated that 90% of all energy used in tourism is spent on travelling activities (10). As previously mentioned, air travel accounts for a major share of tourism-related energy use.

The major energy challenge is its structure. The majority of it comes from fossil fuels (natural gas, coal, and oil). Many energy transformation processes produce potentially harmful substances, like CO_2, CO, NO_X, SO_X, and PM. The environmental effects in some tourist destinations are devastating [26]. The potential cumulative effects of energy-related emissions make the situation worse and damage the natural environment. The effects of tourism energy requirements extend well beyond the destination where they are consumed [12].

The operation of accommodation facilities is the second largest consumer of energy. Energy is vital to the hotel industry. It powers the engineering systems, equipment, appliances and devices that provide services and the level of comfort of tourists and visitors. Hotels usually consume the largest proportion of energy used for accommodation because they require more energy per visitor (bars, laundries, swimming pools, restaurants). The situation is the same with facilities for seasonal residents and tourists that stay with friends and family. Hotels are often located in areas where access to energy is unlimited. They tend to operate with few restrictions on energy consumption, so their actions have little or no effect on the immediate availability and reliability of their energy sources.

Tourist attractions and activities are the third largest intensive consumer of energy (Becken & Simmons, 2002). The recreational part of the product contributes considerably to the heightened energy consumption, [12]. Mechanised tourists activities are at the top of the consumption chain. Boat cruises, jet boat rides, charter fishing operations, scenic flights and water skiing are the most evident examples [11].

6 METHODOLOGY

In this paper, we concentrate on creation of the consumption culture change processes towards greener tourism, which is the solid foundation for sustainable tourism development. Energy consumption is at the core of our interest, when we propose strategies leading to the model of effective use of energy in tourism.

Energy has an exceptionally strong impact on the global environment and affects tourism destination sustainability and endangers future tourism development. In response, the need for planners to develop proactive energy management strategies has become a necessity. However, the unique characteristics of energy consumption attitudes and behavior in the local community are the result of local cultural attitudes and behavior based on sustainable principles.

Quantitative research of culture change toward the sustainable use of energy in Slovenian local communities will show how they implement change toward sustainable tourism regarding energy consumption.

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7 RESULTS

Cultural change is based on the attitudes of all stakeholders towards energy consumption, and on the quality of behavioural strategies in this domain. Change of attitudes towards the development of sustainable tourism firstly influences the expectations of customers, and secondly increased energy costs. Successful cultural change requires the involvement of all stakeholders in the change process toward sustainability.

The most important role in this process is held by the local community, by creating a comprehensive customer database, [27], to set proper changes, to implement sustainable tourism, and to set improvement processes in motion. Additionally, the community role includes setting strategic direction and the intent for sustainability changes, to define clear goals and objectives, and to establish the clear vision how to implement changes.

The second, but no less important role of the local community is to establish and strengthen the core sustainability values, achieving the agreement of all stakeholders toward planned actions, and coordinating and integrating these actions, [1]. The final, but not the last stage of the change process consists of setting common actions of all social groups involved, empowering all stakeholders to initiate and accept changes, and building and maintaining sustainability competences, [28], [29].

When "dirty" energies are surcharged and eco-labels are in extensive use, tourism managers should try to use clean energy. Regulations and legislation on energy and government incentives support the constructing and renovation of facilities that are more energy efficient. When low cost renewable energy technologies are included, technology changes are put in place. Scott [25] argues that there is no alternative, and that tourism must adapt businesses and destinations to climate conditions and apply new technologies to improve energy efficiency.

Figure 2 shows the sustainable energy model that should be applied in the future to preserve the competitiveness of the tourism industry and to develop new behavior patterns based on sustainability.

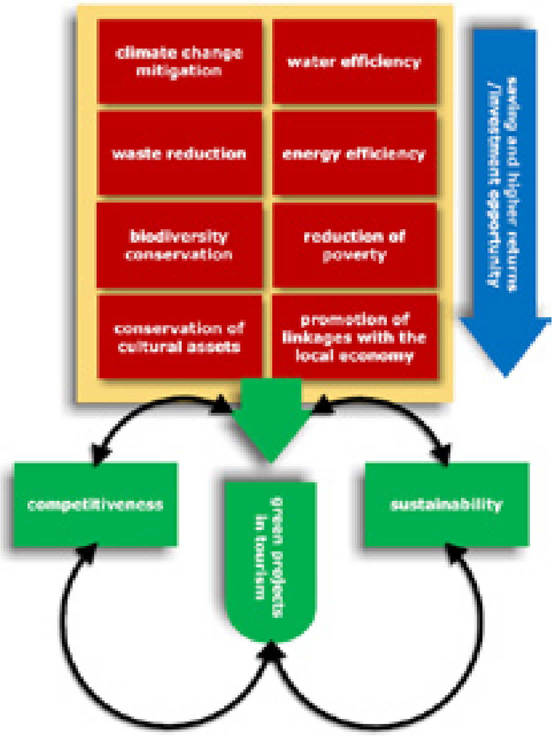

Figure 2: *Green energy consumption model*

Leading airlines can explore alternative fuel strategies and change in routing, aircraft and flight policies, [7]. Strong taxation and trade of CO_2 certificates of air transport can redirect mid-haul and low cost airlines to long-haul airlines, [30]. Several short tourism trips consume substantially more energy than one long one. Tourist operators will have to convince tourists to travel once and stay longer at one destination. To achieve this goal, new attractions should be developed to keep tourists' attention for a long time. An effectively organised railroad network, like in Europe, could play a "green" alternative to air travel. For example, a network of high speed and energy efficient trains, especially in Europe, would support the development of the sustainable tourism transport in the future. The travel and tour-operating industry will have to offer progressively less carbon intensive products to remain "green" and efficient. Hammerl, [30], argued that only 1% of tourism products are environmentally and socially acceptable.

Soft mobility products are very rare. Strong information and awareness at the European, global and destination levels are needed. Cultural change should support new attitudes toward travel. Hyper-mobility should be reduced, slow tourism should develop, and stays must be substantially longer at the tourist destination. Better housing conditions and daily environment, proximity leisure, and cultural and sport activities in vicinity should push people to travel less.
The development of new attitudes and sustainable behavior in the field of transport can be supported by educating and raising awareness among tourists about the impact of global environmental change on the main European destinations. These activities must be supported by wide awareness campaign using all ways of communication and attractive messages, [30].

Tourist operators can maintain or reduce operating costs through investment in continuous improvements strategies of energy efficiency, [31]. They can manage efficiency through the use of retrofits and with investment in new energy-efficient stock. They can improve efficiency through innovation of services, [29], and through energy-efficient equipment and appliances, e.g. refrigeration, television and video systems, air conditioning and heating, and laundry machines, [32].

To reduce energy consumption, the tourism industry must develop products with increased lengths of stay, and develop and implement soft mobility products: e.g., bicycle infrastructure and products, canoeing, walking, visiting libraries, outdoor recreation and strolling through urban areas consume substantially less energy, [25].

On the SME level, successful organisation and management is a key to business sustainability, [29]. By and Dale, [28], were convinced that management of change on SMEs level on political, economic, social and technological levels is crucial for the survival and success of tourism SMEs. Denison and Mishra, [18], argued that the culture of sustainability in the form of organisational culture has an important influence on effectiveness regarding some severe limitations that must be considered. Horobin and Long's, [33], study reveals that many owners of the small firms that could contribute to low energy tourism are not informed about the challenges to reduce the energy consumption related to tourism products. Such circumstances call for the systematic involvement of public agencies that can substantially contribute to the sustainable development of the region. Kyriakidou and Gore's, [34], work suggested that five main cultural dimensions (organisational performance, teamwork, building the future together, building the ability to learn, and collaborative setting of strategies) in tourism, hospitality and leisure SMEs are linked to the effectiveness and support of the sustainable tourism concept.

References

[1] **Ambrož, M.**: *Attitudes of local residents towards the development of tourism in Slovenia: the case of the Primorska, Dolenjska, Gorenjska and Ljubljana regions*. *Anthropol. noteb.*, 2008, year 14, no. 1, pp. 63–79.

[2] **Neto, F.**: *A new approach to sustainable tourism development: Moving beyond environmental protection*. Natural Resources Forum, 2003, Vol. 27, no. 1, pp. 212–222.

[3] **Gössling, S.**: *Tourism – Sustainable development option?* Environmental Conservation, 2002, vol. 27, pp. 223–224.

[4] **Sofield, T. H. B.**: *Empowerment for Sustainable tourism: the role of the "small firm"*, international Journal of Contemporary Hospitality Management, 2006, Vol. 8, no. 5, pp. 15–19.

[5] **Hunter, C.**: *Sustainable tourism as an adaptive paradigm*, Annals of Tourism Research, 1997, Vol. 24, no.4, pp. 850–867.

[6] **ILO**: *Developments and challenges in the hospitality and tourism sector. Sectorial Activities Programme*. Issues paper for discussion at the Global Dialogue Forum for the Hotels, Catering, and Tourism Sector (23–24 November 2010).

[7] **Pratt**, *Tourism: investing in energy and resource efficiency*. 2011, United Nations Environment Programme.

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[8] **Butler, R. W.**: *Tourism, Environment, and Sustainable Development*. Environmental conservation, 1991, No 18, pp. 201–209.

[9] **Farrell, B. H., and Twining-Ward, L.**: *Reconceptualizing tourism*. Annals of tourism research, Vol. 31, Issue 2, 2004, pp. 274–295.

[10] **Gössling, S.**: *Market Integration and Ecosystem Degradation: Is Sustainable Tourism Development in Rural Communities a Contradiction in Terms?* Environment, Development, and Sustainability, 2003, Vol. 5, pp. 383–400.

[11] **Becken, S., Simmons, D. G.**: *Understanding energy consumption patterns of tourist attractions and activities in New Zealand Tourism Management*, 2002, Vol. 23, Issue 4, pp. 343–354.

[12] **Kelly, J. and Williams P. W.**: *Modelling tourism destination energy consumption and greenhouse gas emissions: Whistler*, British Columbia, Canada. Journal of Sustainable Tourism, 2007, Vol.15 (1), pp. 67–90.

[13] **Robinson, M.; Picard, D.**: *Tourism,* Culture and Sustainable Development, 2006, UNESCO.

[14] **D'Amore, L. J.**: *Promoting sustainable tourism: The Canadian approach*. Tourism Management. 1992, Vol. 13(3), pp.258–262.

[15] **Hughes, G.**: *The cultural construction of sustainable tourism*. Tourism Management, 1995, Vol. 16, Issue 1, pp. 49–59.

[16] *Tourism and the Millennium Development Goals*, 2010, Madrid: World Tourism Organization.

[17] **Ambrož, M.**: *Viharnost organizacije*. 2009, Kranj, B & B.

[18] **Denison, D. R., and Mishra, A. K.**: *Toward a Theory of Organizational Culture and Effectiveness.* Organization Science, 1995, Vol.6 No 2, pp. 204–222.

[19] **Ermoaleva, P.**: *College Students' Green Culture: Reflecting on the ideal Types of Environmental Awareness and behavior Practices*. Research and Discussion, 2010, Vol. 3, No. 3, pp. 49–73.

[20] **Robinson, M.; Picard, D.**: *Tourism, Culture and Sustainable Development*, 2006, UNESCO.

[21] **Halme, M.** (2001). *Learning for sustainable development in tourism networks. Business Strategy and the Environment:* Special Issue: Networks, Environmental Management and Sustainable Development, 2001, Volume 10, Issue 2, pp. 100–114.

[22] **Lim, C., McAleer, M.** *Ecologically sustainable tourism management*. Environmental Modelling & Software, Volume 20, Issue 11, 2005, pp. 1431–1438.

[23] **Cater, E.**: *Environmental Contradictions in Sustainable Tourism*. The Geographical Journal, 1995, Vol. 161, Issue 1, pp. 21–28.

[24] **McKercher, B.**: *The unrecognized threat to tourism: Can tourism survive 'sustainability'?* Tourism Management, 2002, Volume 14, Issue 2, pp. 131–136.

[25] **Gössling, S., Borgström, C. H. Hörstmeier, O., Saggel, S.**: *Ecological footprint analysis as a tool to assess tourism sustainability*. Ecological Economics, Volume 43, Issues 2–3, December 2002, pp. 199–211.

----

[26] **Peeters, P.S.; Gössling, S., and Scott, A.**: *Background Report (Tourism patterns and associated energy consumption) prepared for the tourism chapter of the UNEP* Green Economy Report, 2010.

[27] **Scott, D.**: *Climate Change and Tourism: Responding to Global Challenges CTO/CRSTDP* Regional Workshop, The Bahams, 2008, pp. 18–19.

[28] **Gössling, S.** (2000). *Tourism – sustainable development option?* Environmental Conservation, 27: 223–224.

[29] **Veljković B., Ambrož, M.**: *Towards the sustainable concept of tourism development in Posavje region in Slovenia*. Innovative issues and approaches in social sciences, 2010, Vol. 3, No. 1, pp. 36–59.

[30] **By, R. and Dale, C.**: *The successful management of organisational change in tourism SMEs: initial findings in UK visitor attractions.* The International Journal of Tourism *Research*, 2008, 10(4), pp. 305–313.

[31] **Ambrož, M., Praprotnik, M.**: *Organisational effectiveness and customer satisfaction*. Organizacija (Kranj), 2008, Vol. 41, No. 5, pp. 161–173.

[32] **Hammerl, M.**: *A challenge for the Sustainable Tourism? ECOTRANS*, EU Parliament, Brussels, 2011, available: 30.3.2011 at: http://www.ecotrans.de

[33] **Hamele, H.; Echhardt, S.**: *Environmental Initiatives by European Tourism Businesses. Instruments, indicators and practical examples. A contribution to the development of sustainable tourism in Europe.* Saarbrücken: SUTOUR, TourBench, DBU, ECOTRANS, 2006.

[34] **Baldinger, P.**: *Energy and Sustainable Tourism –Energy Supply and Use in Off-Grid Ecotourism Facilities*, 2006, USAID.

[35] **Horobin, H., Long, J.**: (1996) *Sustainable tourism: the role of the small firm.* International Journal of Contemporary Hospitality Management, 1996, Vol. 8 Issue: 5, pp. 15–19.

[36] **Kyriakidou, O., Gore, J.**: *Learning by example: Benchmarking organizational culture in hospitality, tourism and leisure* SMEs. 2005, *Benchmarking,* 12 (3), pp. 192–206.

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ENERGY INFRASTRUCTURE AND THE DEVELOPMENT OF TOURISM IN POSAVJE

ENERGIJSKI OBJEKTI IN RAZVOJ TURIZMA V POSAVJU

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Keywords: energetic objects, tourism development, tourist products, tourist destination, sustainability

Abstract

One strategy of Slovenian tourism development is based on the development of the Posavje region. Our aim was to discover how new energy infrastructure in Posavje will add to the development of new tourism products. We conducted the study in the Posavje using correspondence analysis. The study of the attitudes of the local residents toward tourism products shows that products are evenly distributed in the region, and that there are new opportunities for the development of new tourism products associated with water spaces. These new products are the basis for the development more integrated and varied tourism in the Posavje region.

Povzetek

V strategiji gospodarskega razvoja Slovenije in regije Posavje, razvoj energetike in turizma zasedata prioritetni poziciji. Najin raziskovalni cilj je bil ugotoviti, kako bo gradnja novih energetskih objektov vplivala na razvoj novih turističnih produktov. Izpeljala sva študijo stališč lokalnih prebivalcev do turizma v Regiji Posavje. Anketiranci so ocenjevali tip turista v povezavi s kraji v Posavju. S pomočjo korespondenčne analize sva ugotovila, da so ti produkti enakomerno razporejeni po Posavju. Z gradnjo novih energetskih objektov se pojavljajo priložnosti za razvoj novih bazičnih turističnih produktov, ki jih je mogoče povezati v združene produkte in tako popestriti turistično ponudbo s produkti, ki so povezani z novimi urjenimi vodnimi površinami.

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1 INTRODUCTION

Energy infrastructure is a core competitive factor of business success in the Posavje region. Furthermore, the region has a great tourism potential that has not been fully exploited. Regarding energy and tourism, the Posavje region is a very important element of the Slovenian development strategy. On the Regional Development Agency Posavje (RRA) web site, a vivid and argumentative debate reveals the priorities of the Posavje region, [1]. Respondents prioritise energy and tourism. The tourism development program of RRA is based on natural resources, which could be damaged by the construction of new power plants.

Some serious questions have emerged in the environment in which the new power plants are to be built. One of the most important questions is how the new power plants will influence the future development and performance of tourism in Posavje. The second question is how the tourism landscape will change. In the environmental impact report on new energy infrastructure, there is no comment regarding this. Furthermore, there have been no research studies on this topic.

It is well known that the Slovenian tourism strategy is inclined toward the development of soft, environmentally friendly tourism that benefits all tourism stakeholders: tourists, local residents, the local community and businesses, [2]. The orientation toward green tourism is the major success factor of tourism development when the environment is endangered and when all resources are scarce. As a tourist destination, Posavje especially emphasises tourism with special regard to the environment and responsibility to the local community. Bramwell defines sustainable tourism as a positive approach that tends to minimise tensions that are the result of complex interactions between the tourism industry, visitors, environment and the local community. Sustainable tourism is the aim of the current generation to protect the environment for the future generations, [3]. The European white paper on sustainability tourism in protected areas gives recognition to all activities that make long-term contributions to the protection of all resources, that stimulate sustainable ways of business growth and that contribute to the satisfaction of the individual, [4].

2 IMPACT OF A NEW ENERGY INFRASTRUCTURE ON TOURISM DEVELOPMENT

The landscape, the political governance and the usage of resources will definitely change when new power infrastructure will be built in the Posavje region. Tourist products and management of tourist resources will also change. Many amenities could be endangered of even cease to exist. The entire water chain from Vrhovo to Mokrice will change when the flow of the Sava River will be regulated. We can observe this impact when we compare the landscape before and after the power infrastructure is built. The Sava River is cleaner and many pollution refineries were built in the areas of Sevnica, Krško, Brežice, and Obrežje. Many affluxes of the river Sava were regulated. From the tourism perspective, these facilities and activities give new added value to tourism. They preserve fauna and flora, and connect the modern landscape with the natural landscape. Every new power plant is a new opportunity for the development of the nearby cities and landscape. With the construction of HE Brežice in Vrbina, about four hundred meters above the old railroad bridge over the Sava River, the town of Brežice has an opportunity for a new development to the west. The regulation of the space between the HE Brežice reservoir lakes and the west side of the town will open the opportunity to build many

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new spaces for recreation and sport activities. New water spaces will facilitate the development of new water sports, e.g. new kayak runaway. HESS d.o.o. as a concessionaire will pay concessions to the municipality of Brežice: 60% of the 10% from the produced power. This will yield the amount of few thousands euros per year, [5].

Sustainable tourism is not a special form of tourism: it is the principle of the future tourism development. Its aim is to preserve the natural and other resources for current and for future generations. The sustainable approach improves ecological and economic conditions, and levels the inequalities in the overall development. Furthermore, it is development that levels the economic, cultural, corporate and natural components of development. Sustainable tourism as an enriched form of leisure activity connects space with people. As a result of the active involvement of the local residents in the tourism activities, new opportunities for their economic gain emerge. Sustainable tourism is an act of sustainable consumption aimed at levelling of all resources that develop the overall quality of life of all stakeholders.

Five new power plants in the Posavje region have had an overwhelming impact on the preservation of the original nature environment and on the enrichment of the tourism products. It is of utmost importance that the equilibrium between the artificial and natural environment be constantly maintained. This inevitably adds to the recognition of the tourism destination.

In this context, we have to point out that the interaction between the natural environment and tourism is based on the irreversibility and the mutual influence of all factors. Tourism builds new conditions and new environments, and has many positive and negative impacts on the natural and social environment. Some of these impacts are traffic congestion, water consumption and pollution, the usage of resources, the quality of life of local residents, new jobs, facilitated criminal activities and others.

Tourism can be defined as a network of relationships and phenomena that is based on the migration of the people from their place of residence to other places for some time for the purpose of leisure, [6]. To bring tourists to an area means to bring local residents the opportunities to build local markets for new products and services. On the cultural level, this results in the preservation of the natural and cultural inheritance and social welfare, [7].

The local community has an important role in this process. This is evident in the effort to link global development with local opportunities regarding tourism. Local development can be realised through a clear mission and vision. The tourist destination of Posavje has significant local conditions to become a part of the global tourism story. The combination of energy infrastructure and tourism enables unique competitive advantages on the global market. Tourism management is faced with the challenge of using the combination of energy and tourism resources in building an attractive and sustainable tourism destination.

All power plants in Posavje have a good impact on climate change and on the efficient use of water resources. Their role is indispensable in protecting the towns, fields and farms, and villages from floods and droughts. They enable the navigability of the Sava River to Brežice, and have a positive impact on the continuous betterment of the local environment.[1] Newly established conditions are the quality basis for the development of sustainable tourism products and services. Water sports without the use of engines, the development of spiritual

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[1] Okoljsko poročilo (DPN) za Hidroelektrarno Brežice

refuges for mental healing and wellness and new ways of exploring the natural environment are some of the new opportunities in this field. New water surfaces can be used in many new ways to enrich the tourism product. Other tourism products and services will be linked to the new ones and an integrated and unique offer of tourism services and facilities will be established. New sport facilities can be built along newly the regulated Sava River. Some good examples in Slovenia show that this could be realised in the near future (Dravinja near Ptuj, Maribor (Kobler Bay, Pristan) and in the Lavamunda region (swimming pools near Drava, rafting on the HE Lake). In Austria, very good sport products were developed in the region Völkermarkt (Velikovec) (boating on Lake Wörthersee).

The image of a tourist destination is changed with new infrastructure. Tourism becomes more dynamic and suits to the modern lifestyle. Reservoir lakes' new water surfaces are available, giving a new way of life of local residents and tourists. The Posavje region has a unique opportunity to reduce the gap between static and dynamic tourism. Only 10% of tourists are engaged in sport activities during their holidays. New forms of tourism emerge, and this paper attempts to illuminate the relationship between the impact of new energy infrastructure in the Posavje region and the conditions of tourism development in the region.

3 METHODOLOGY

To analyse the space distribution of the tourism products in Posavje, a correspondence analysis was used. Correspondence analysis is an *exploratory data analytic* technique designed to analyse simple two-way and multi-way tables containing some measure of correspondence between the rows and columns. As opposed to traditional hypothesis testing designed to verify *a priori* hypotheses about relations between variables, exploratory data analysis is used to identify systematic relations between variables when there are no (or rather incomplete) *a priori* expectations as to the nature of those relations. Correspondence analysis is also a (*multivariate*) *descriptive data analytic* technique. Even the most commonly used statistics for the simplification of data may not be adequate for description or understanding of the data. Simplification of data provides useful information about the data, but that should not be at the expense of valuable information. Correspondence analysis remarkably simplifies complex data and provides a detailed description of practically every bit of information in the data, yielding a simple, yet exhaustive analysis.

3.1 Sample

The data came from the survey which was administered to a sample of 170 local residents from Brežice, Krško, Brestnica, Kostanjevica, Cerklje near Krka, Senovo, Dobova, Raka, Jesenice, Bizeljsko, Šentjernej (Table 1). The resultant data were examined using correspondence analysis.

Table 1: *Features of the sample*

1	gender		Men Women	88 (51.76%) 81 (47.65%)	
2	age		average in years range in years	34 17–70	
3	time of residence		average in years		30
4	employment in tourist organisation		average in % 7.5%		
5	education		secondary school high school bachelor/university degree master degree Doctorate	89 24 54 3 1	51.76% 14.12% 31.76% 1.76% 0.59%

Table 1 one shows demographic variables included in the questionnaire. Men and women are equally represented in the survey sample, and the age distribution is within working age. The average time of residence of local residents' is long enough to clarify the attitudes of local residents about tourism development. Only 7.5% of respondents work in a tourist organisation.

3.2 Instrument

According to the purpose of this study, the overall process of developing the instrument for the study of tourism development was divided into three separate parts. Part One generated sample of items by a literature research. In Part Two, data were drawn from a survey originally administered to respondents (local residents) in the Posavje region in 2009. Respondents were asked to rank their opinions on Likert-type scales and coded as 1 (totally disagree) to 5 (totally agree). Participants were asked to respond to a range of questions relating to their views on the tourism development in Posavje region in Slovenia. Respondents were assured that their individual responses would be treated as confidential.

For the space analysis the following questionnaire was used and distributed to the places in the Posavje region.

Table 2: *Initial instrument*

Assess the develop-ment of the tourism category (in % from 0% to 100%)	S – Sport
	PC - Leisure activities (walking, sight-seeing, visiting thematic parks and events.
	ZT – Health resort tourism
	KT - Event tourism
	TK – Farm tourism
	ZT1 Cottage tourism
	Other

The results of the correspondence analysis, including the weighted Euclidean distance, are used to measure and thereby depict the distances between profile points. Here, the weighting refers to differential weighting of the dimensions of the space and not to the weighting of the profiles.

The Chi-square distance differs from the usual Euclidean distance in that each square is weighted by the inverse of the frequency corresponding to each term.

Table 3 shows the relationship between columns and rows in two-dimensional space. In this case, Euclidean distances were calculated between six columns (tourism products) and 37 rows (places in region Posavje). The columns and rows are in an independent relationship.

Table 3: *The relationship between columns and rows*

Place	Sport	Leisure time	Health resort tourism	Event tourism	Farm tourism	Cottage tourism
BS	50	15	5	30	50	20
BI	73	68	80	80	65	55
BL	55	30	50	60	70	70
BO	65	30	20	40	80	75

BR	63	80	60	57	71	70
B	54	57	75	53	58	55
BU	7	90	50	40	80	100
BŠ	31	77	47	37	67	97
C	55	55	82	58	71	58
D	66	67	68	54	64	56
DV	10	20	20	10	20	30
G	10	20	80	70	65	60
J	58	50	78	63	55	43
K	18	10	50	15	20	43
KO	60	58	75	60	66	66
KR	70	60	100	10	100	100
KV	20	10	30	20	10	10
K	51	59	50	38	44	41
M	90	80	100	90	70	70
NM	50	10	80	5	60	100
P	15	15	50	20	60	0
PI	60	0	100	80	50	50
PO	70	75	30	30	65	55
R	55	60	51	44	71	84
S	60	63	64	58	75	71
SE	48	55	61	50	56	67
SR	100	70	100	80	80	50
SG	100	70	100	80	80	50
Š	65	70	60	55	75	95
ŠJ	30	50	80	70	40	50
ŠU	100	50	70	0	60	100
VP	50	30	20	30	30	30
VK	80	85	70	85	90	95
VV	50	20	20	10	10	50
Z	80	80	100	90	90	90
ZP	10	10	40	30	5	5
ZZ	60	90	100	50	60	90

Table 4 shows that input table of rows and columns (6×37) shows total inertia = 0, 104, Chi^2 = 1277, 0, and DF = 180 with p = 0.000. We can conclude from the Table 4 that the quality of presentation of the two dimensions in the two-dimensional space is satisfying. The two dimensions together explain 59% of inertia (ideal inertia is 100%).

Table 4: *Eigenvalues and Inertia for all Dimensions*

	Singular - Values	Eigenvalues	Percent of - Inertia	Cumulative Percent	Chi - Squares
1	***0.20***	***0.04***	***37.13***	***37.13***	***474.10****
2	***0.15***	***0.02***	***22.06***	***59.19***	***281.71****
3	0.14	0.02	20.08	79.26	256.36
4	0.11	0.01	11.79	91.05	150.60

5	0.10	0.01	8.95	100.00	114.23

For places BL, P, BO and BU, inertia does not meet the quality criteria.

Table 5: *Column Coordinates and Contributions to Inertia: Input Table (Rows x Columns): 6×37 Standardisation: Row and column profiles*

	Column - Number	Coordinate - Dim.1	Coordinate. - Dim.2	Mass	Quality
BS	1.00	-0.05	0.40	0.01	0.44
BI	2.00	0.15	0.11	0.03	0.95
BL	***3.00***	***0.02***	***-0.01***	***0.03***	***0.01****
BO	***4.00***	***-0.23***	***0.10***	***0.03***	***0.37****
BR	5.00	-0.06	0.11	0.03	0.57
B	6.00	0.07	0.00	0.03	0.49
BU	***7.00***	***-0.26***	***-0.12***	***0.03***	***0.31****
BŠ	8.00	-0.26	-0.06	0.03	0.54
C	9.00	0.09	-0.02	0.03	0.73
D	10.00	0.02	0.09	0.03	0.65
DV	11.00	-0.21	-0.17	0.01	0.74
G	12.00	0.28	-0.30	0.02	0.71
J	13.00	0.19	0.04	0.03	0.94
K	14.00	0.02	-0.45	0.01	0.88
KO	15.00	0.05	0.01	0.03	0.84
KR	16.00	-0.23	-0.20	0.04	0.67
KV	17.00	0.36	-0.03	0.01	0.70
K	18.00	-0.01	0.14	0.02	0.49
M	19.00	0.13	0.09	0.04	0.79
NM	20.00	-0.26	-0.45	0.02	0.78
P	***21.00***	***0.33***	***-0.13***	***0.01***	***0.24***
PI	22.00	0.41	-0.18	0.03	0.70
PO	23.00	-0.24	0.26	0.03	0.93
R	24.00	-0.16	0.00	0.03	0.79
S	25.00	-0.02	0.04	0.03	0.35
SE	26.00	-0.02	-0.01	0.03	0.07
SR	27.00	0.16	0.12	0.04	0.73
SG	28.00	0.16	0.12	0.04	0.73
Š	29.00	-0.13	0.02	0.03	0.72
ŠJ	30.00	0.26	-0.08	0.03	0.66
ŠU	31.00	-0.36	-0.07	0.03	0.55
VP	32.00	-0.05	0.28	0.02	0.76
VK	33.00	-0.02	0.09	0.04	0.47
VV	34.00	-0.36	0.06	0.01	0.36
Z	35.00	0.07	0.02	0.04	0.70
ZP	36.00	0.74	-0.17	0.01	0.90
ZZ	***37.00***	***-0.05***	***-0.07***	***0.04***	***0.15****

In Figure 1, the positions of tourism products are distributed near places in the region Posavje.

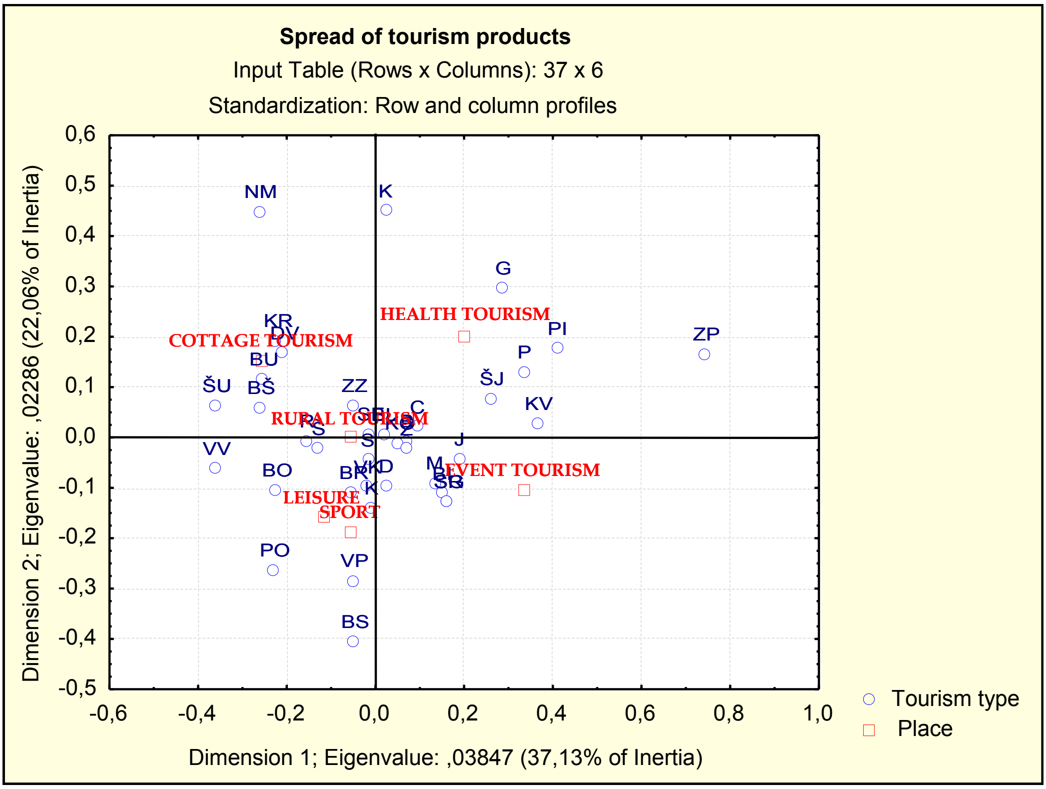

__Figure 1:__ Space distribution of tourism products in the region Posavje

The places are divided in two groups: on the left, we can see the places VV, ŠU, BŠ, DV, KR, NM, PO, BS and VP, which reside in the same space as tourism products of sport, leisure activities, farm tourism, and cottage tourism. On the left, of the dimension are distributed the places ZP, PI, G, P, ŠJ, KV, SP, BP and M, which reside in the same space as health resort tourism and event tourism. A full list of places is in the annex of this article. The space distribution of tourism products shows that sport tourism, leisure activities, and recreational tourism are located around the town Brežice. Health resort tourism and recreational tourism are located in the Čatež spaces.

__Table 6:__ Structure of tourism products in the destination of Posavje

Tourism	**Structure**
Sport	16.13%
Leisure activities	14.92%
Health resort tourism	18.77%
Event tourism	14.21%
Farm tourism	17.72%
Cottage tourism	18.25%
SUMMARY:	**100.00**

The percentages of total of tourism products in the tourist destination of Posavje are shown in Table 6 (Input Table (Rows × Columns): 6 × 37 Total Inertia=104 Chi2=1277. 0 DF=180 p=0.0000). Health resort tourism and cottage tourism represent the majority of the structure of the tourism products. Tourism products are quite evenly distributed according to tourist destination. This is a good vantage point to develop new tourist products enabled by the construction of new energy infrastructure.

The results of our study show that the construction of the new power plants can stimulate the development of new tourism products associated with new water spaces. There is a real opportunity to develop sports that are sustainable and add to the overall effort to make tourism in Posavje greener.

4 DISCUSSION

Energy and tourism are the core factors for tourism development in Posavje. In some aspects, the energy infrastructure damages the environment. However, it also produces new tourism development opportunities. Our research on tourist typology shows that there are many tourism products, including sport tourism, event tourism, adventure tourism, farm tourism, cottage tourism, and health resort tourism, [8]. In the area where new energy infrastructure is built, new basic tourism products emerge, including rowing, surfing, sailing, walking and trekking. Many passive forms of tourism will be added to the existing tourism services, such as sport and cultural events on local and on international levels. Newly regulated river banks are a great opportunity to develop parks and events associated with cultural heritage.

These products will be merged with the existing products found in our study, and very diverse and dynamic products will be constantly combined according to tourism demand, [9].

References

[1] http://www.rra-posavje.si/index.php?lg=0&mf=4&mc=135&pg=191.

[2] **Ambrož M.**: *"A third way" of tourism planning: case of Slovenia.* Destination management. Frankfurt am Main [etc.]: 2006. P. Lang. str. 2.

[3] **Bakić. O.**: *Marketing menadžment turističke destinacije*. Beograd: 2005. Čigoja štampa. pp. 308.

[4] *Evropska listina o vzdržnem turizmu na varovanih območjih:* Listina je sprejeta leta 1991 na predlog Federacije naravnih in nacionalnih parkov Evrope (FNNPE).

[5] *Okoljsko poročilo Državnega prostorskega načrta za Hidroelektrarno Brežice*.

[6] **Unković S.**: *Ekonomika turizma.* Beograd: Savremena administracija. 2001. pp. 2.

[7] **Ambrož. M.**: Attitudes of local residents towards the development of tourism in Slovenia: the case of the Primorska. Dolenjska. Gorenjska and Ljubljana regions. *Anthropol. noteb*. 2008. year 14. no. 1. pp. 63–79.

[8] **Gursoy. D. Jurowski. C. Uysal. M.**: (2002). Resident Attitudes. A Structural Modelling Approach. *Annals of Tourism Research*. 29. pp. 79–105

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[9] **Hunter. C.**: Sustainable tourism as an adaptive paradigm. *Annals of Tourism Research*. 1997. Vol. 24. no. 4. pp. 850–867.

Nomenclature

Bistrica ob S.	BS	Mostec	M
Bizeljsko	BI	N. Mesto	NM
Blanca	BL	Pečice	P
Boštanj	BO	Pišece	PI
Brestanica	BR	Podbočje	PO
Brestnica	BR	Raka	R
Brežice	B	Senovo	S
Bukošek	BU	Sevnica	SE
Buše	BŠ	Sromlje	SR
Cerklje ob K.	C	Stari Grad	SG
Dobova	D	Šentjernej	Š
Dvor	DV	Šentjanž	ŠJ
Globoko	G	Šutna	ŠU
Jesenice	J	V. Podog	VP
Kapele	K	Vel. Kamen	VK
Kostanjevica	KO	Vel. Vas	VV
Križe	KR	Zdole	Z
Krška vas	KV	Zg. Poha	ZP
Krško	K	Žejno	ZZ

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PERSPECTIVES ON RENEWABLE ENERGY IN SLOVENIA

PRESPEKTIVA OBNOVLJIVIH VIROV ENERGIJE V SLOVENIJI

Fouad Al-Mansour[ℜ]

Keywords: Renewable energy sources, energy policy and measures

Abstract

The main strategic goals of the European Union (EU) and Slovenian energy strategies are the reduction of the emissions of greenhouses gases, an increase of the share of electricity production from renewable energy sources (RES) and a decrease of energy dependency.

The overall targets of the EU climate and energy package, known as “20-20-20”, are a 20% increase in energy efficiency, a 20% reduction in greenhouse gas (GHG) emissions, a 20% share of renewable energy sources in overall EU final energy consumption, and a 10% share of renewable energy sources in transport by 2020.

Individual targets for each Member State have to be determined as fairly as possible. The obligation of Slovenia is to increase the share of RES in final energy consumption from 15.1% in 2005 to 25% in 2020. Another obligation of Slovenia is to increase the share of electricity production from RES to 33.6% of the 2010 level total electricity consumption.

The priority to increase the share of RES in the energy supplies in the EU-27 has continued more intensively to avoid the rapid impacts on environment (climate change) and to increase the security and sustainability of energy supply.

In 2008, the share of renewable energy in primary energy was less than 11%, and it was 15.1% in gross final energy consumption. The share of electricity production from renewable energy sources represents 30% of gross electricity consumption in Slovenia.

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The development of renewable energy sources in Slovenia as well as an analysis of the Slovenian energy policy will be presented in this paper. Special focus will be given to the actual programs (RES action plan) and the potential of future development.

Povzetek

Glavni strateški cilji Evropske unije (EU) in Slovenenske energetske strategije so zmanjšanje emisije toplgrednih plinov, povečanje deleža obnovljivih virov energije (OVE) in znižanje energetske odvisnosti.

Glavni cilji EU podnebnega in energetskega svežnja "20-20-20" so 20% povečanje energetske učinkovitosti, 20% zmanjšanje emisije toplogrednih plinov (TGP), 20 % povečanje deleža obnovljivih virov energije v celotni porabi končne energije v EU in 10% deleža obnovljivih virov v rabi energije prometu do 2020.

Cilji za posamezno državo članico naj bi bili določeni čimbolj pravično. Obveznosti za Slovenijo je povečanje deleža OVE v končni rabi energije od 15,1% v 2005 na 25% v 2020. Druga obveznost Slovenije je povečanje deleža proizvedene električne energije iz OVE na 33,6% celotne porabljene električne energije v 2010.

Prioritetno povečanje deleža OVE v oskrbi z energijo v EU je bilo bolj intenzivno pri izogibanju hitrih vplivov na okolje (podnebne spremembe) in povečanju varnosti in trajnostni oskrbi z energijo.

Delež obnovljivih virov v primarni energiji je manjši od 11% in 15,1% v bruto rabi končne energije. Delež električne energije proizvedene iz OVE predstavljala 30% od bruto porabe v Sloveniji.

Razvoj obnovljivih virov energije v Sloveniji tako kot analiza slovenske energetske politke bo predstavljena v članku. Posebna pozornost bo dana sedanjemu programu »Akcijski načrt za obnovljive vire energije za obdobje 2010 - 2020 (AN OVE)« in potencialu razvoja v prihodnosti.

1 INTRODUCTION

The serious impacts of climate change on the quality of life have great influence on the decisions made in prioritising of the main goals of strategy development. Sustainable development is the goal of all countries' development strategies.

The priority to increase the share of RES in energy supply in the EU-27 has continued more intensively to avoid the rapid impacts on environment (climate change) and increase the security and sustainability of energy supply.

The main strategic goals of the European Union (EU) and Slovenian energy strategy are a decrease of greenhouse gas emissions, an increase of the share from renewable energy sources (RES) in the energy supply and a decrease of energy dependency. The overall targets of the EU-27 to 2020, as defined in the climate and energy package known as "20-20-20", are: a 20% increase in energy efficiency, a 20% reduction in greenhouse gas (GHG) emissions and a 20% share of renewable energy sources in overall EU final energy consumption, [1].

The targets of the new EU Directive on the promotion of the use of energy from renewable sources (RES Directive) adopted by the European Parliament in March 2009 [4] under the EU's "20-20-20" climate and energy package by 2020 is a 20% share of renewable energy sources in the overall EU final energy consumption and 10% biofuel component in vehicle fuel by 2020. Individual targets for each Member State have to be determined as fairly as possible. The Slovenian obligation target as is defined in Annex I of the Directive [4] is 25% share of renewable energy sources in gross final consumption of energy by 2020.

The target share of RES by 2020 as is defined in the RES Directive for all member countries, is shown in Figure 1.

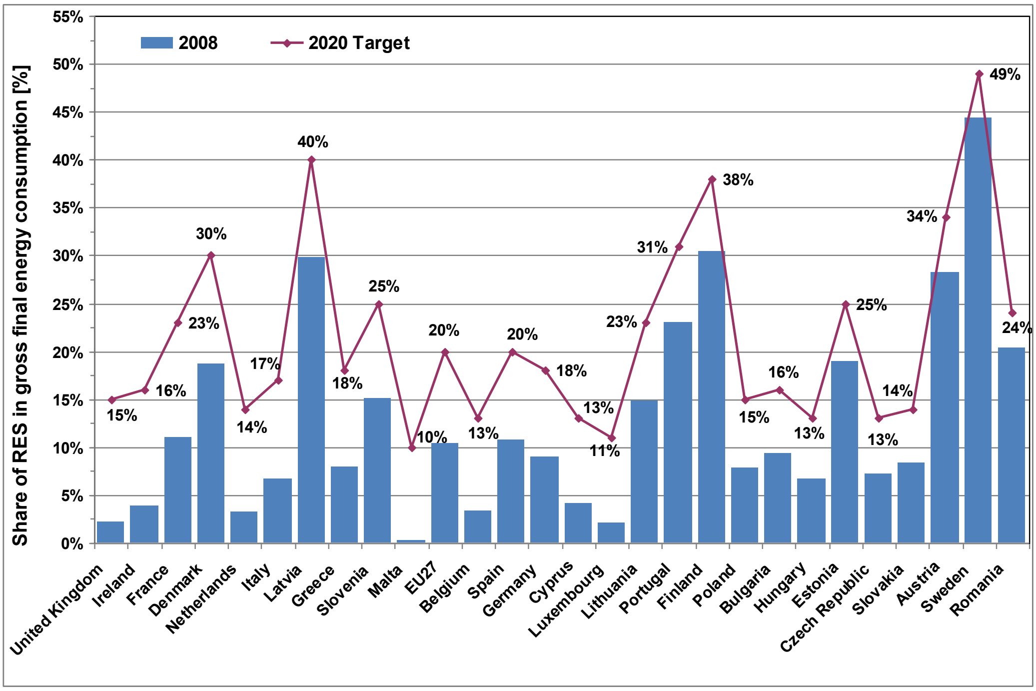

Figure 1: *The share (2008) and target of RES in gross final energy consumption by 2020*

Fossil fuel consumption in transport is relentlessly increasing in all EU countries and presents a major challenge for the EU policy and its activities to decrease emissions of greenhouse gases. In different adopted directives, the EU has focused on increasing the share of renewables fuels in transport. Directive 2003/30/EC of 8 May 2003 on the promotion of the use of biofuels or other renewable fuels for transport aims "…at promoting the use of biofuels or other renewable fuels to replace diesel or petrol for transport purposes in each Member State", [2]. The target of this directive is to achieve a 5.75% share of renewable fuels, calculated on the basis of energy content, of all petrol and diesel for transport purposes placed on their markets by 31 December 2010.

Furthermore, the increase of the share of electricity produced from renewable energy was the aim of EU Directive 2001/77/EC on the promotion of electricity from RES, [2]. The target of this directive is to achieve a 22.1% share of electricity produced from RES in total electricity consumption by 2010, [3].

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2 ENERGY SUPPLY

The total primary energy consumption in Slovenia in 2009 was 292.6 PJ (7.0 mtoe), [2], and the main domestic energy sources are coal with a 20% share of the energy supply, hydroelectricity with 6% and wood biomass with 7% in 2009 (Figure 2).

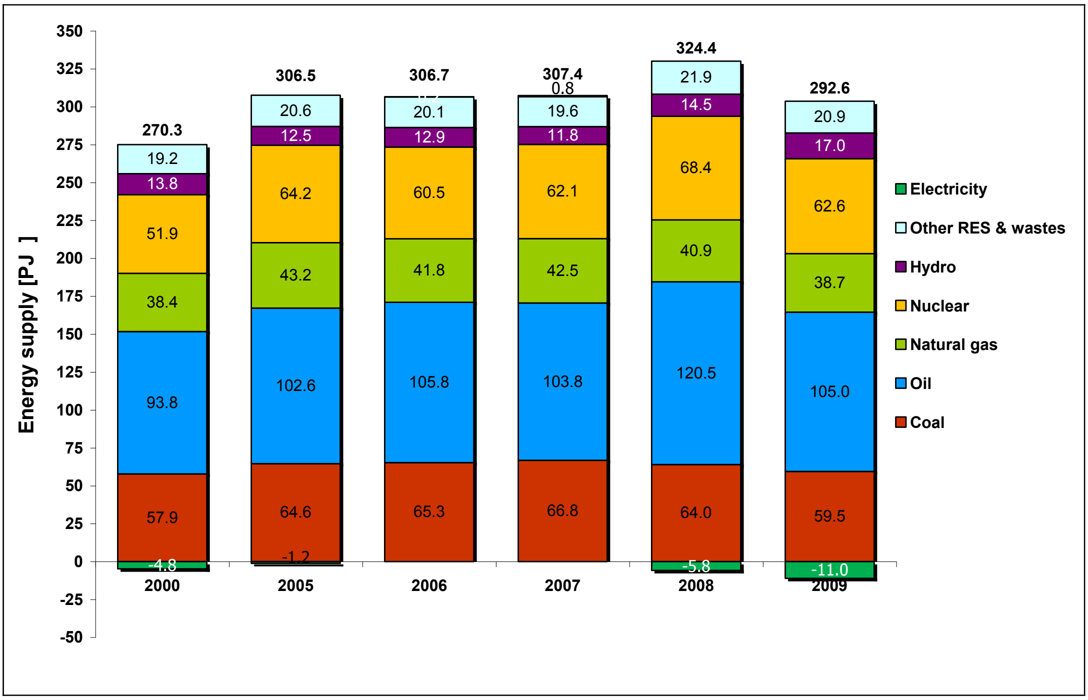

Figure 2: *The structure of primary energy supply in Slovenia*

Slovenia imports about half of its primary energy, including all of its petroleum products and natural gas. In 2008 and 2009, Slovenia exported electricity (negative value of electricity), as shown in Figure 2. The share of renewable energy sources (without waste) was 12.7% of the primary energy supply and 18% of final energy consumption in 2009.

2.1 Renewable energy sources

According to EU Directive 2001/77/EC, Slovenia is obligated to increase the share of RES in final energy consumption to 25% by 2020.

The total use of renewable energy sources (RES) in Slovenia was 37 PJ or 885 ktoe, which represents an 18.1% share of primary energy supply in 2009 (Figure 3). The two main renewable energy sources are hydropower with a 5.6% share in primary energy or 17 PJ (405 ktoe) and wood with a 6.9% share in primary energy or 20 PJ (480 ktoe).

The other renewable sources used are biogas (from agriculture and wastes from households, restaurants, the food and paper industries and sewage, landfill), biofuels, solar energy

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(photovoltaic and thermal solar) and geothermal energy (Figure 3). There are no published statistical data about geothermal energy.

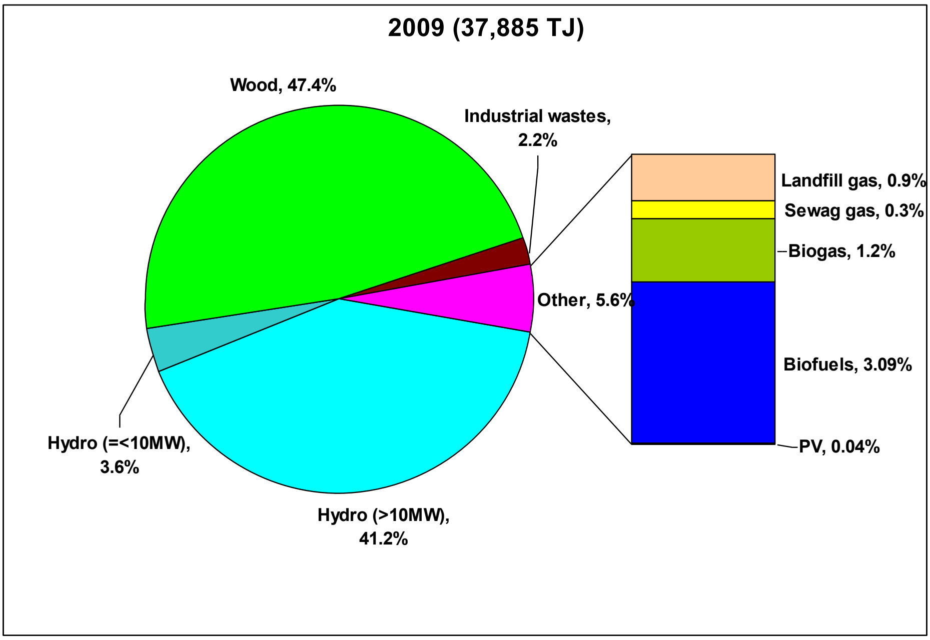

Figure 3*: Structure of renewable energy consumption in Slovenia in 2009*

2.2 Electricity production from RES

According to EU Directive 2001/77/EC, Slovenia is obligated to achieve a 33.6% share of electricity production from RES in total electricity consumption in 2010, [2].

The share of electricity production from RES was increased from 29.1% in 2008 to 36.8% in 2009 of gross electricity consumption, which is higher than the target in 2010. The index of electricity production from RES increased in the last two years, while the index of electricity consumption was decreased, as shown in Figure 4.

The main electricity production from RES is from hydropower, followed by wood and biogas.

Changes in electricity production from RES are dependent on the hydrology situation in the country, because almost all of the electricity production is coming from hydropower stations, as shown in Figure 4.

There is also electricity production from wood biomass, biogas, landfill gas and sewage gas (Figure 4). There is also a very small share of electricity production from solar energy (Photovoltaic-PV), but to date there is not any production from wind or geothermal sources.

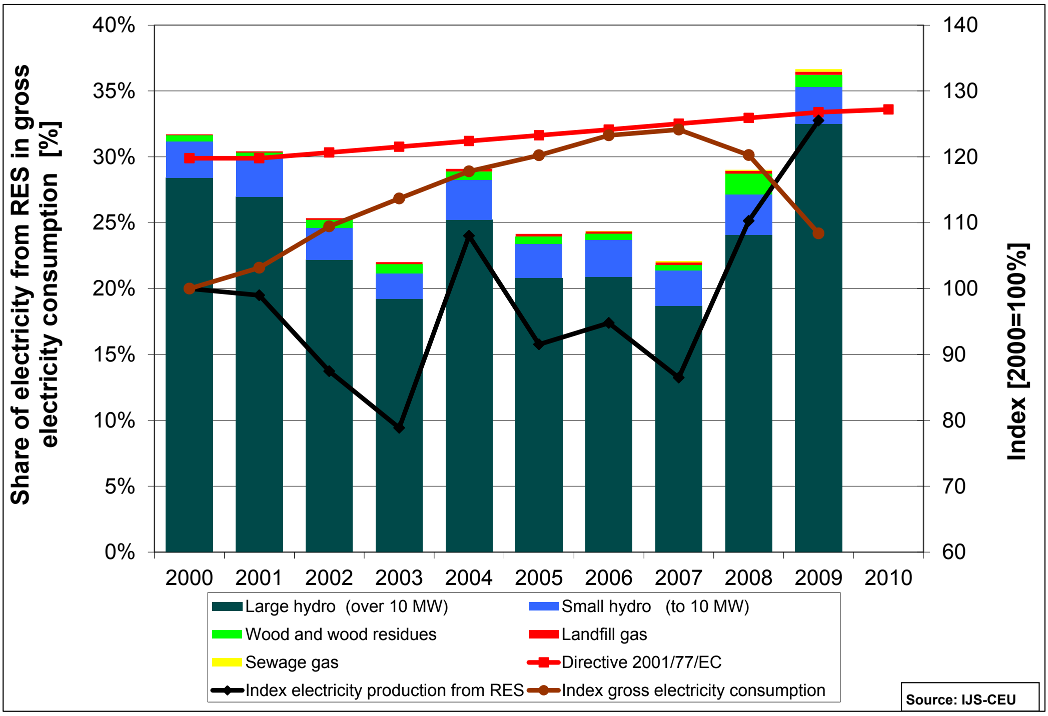

Figure 4: *Structure and index of electricity production of RES and index gross electricity consumption in Slovenia*

3 ENERGY POLICY

Slovenian energy policy gives priority to the use of renewable energy resources and energy efficiency in all adopted strategic documents after 1990, [6], [7], [8].

The first strategic document, the "Resolution on the Strategy of Energy Use and Supply of Slovenia", adopted by the National Assembly (Slovenian Parliament) in February 1996, [6], summarised the government policy for renewable energy sources as follows: "In the long run, renewable energy sources are the most important sources of primary energy for Slovenia, and are national strategic reserves. The long-term objective of Slovenian policy is to substantially increase the share of renewable sources within the primary energy balance."

The current Energy Act, [8], adopted by the National Assembly (September 1999) gives special emphasis to the promotion of the use of renewable energy resources and priority to the utilisation of renewable resources before supplying energy from non-renewable resources. The Energy Act states that the efficient use of energy, and encouraging of the use of RES are constituent parts of the energy policy.

The target of Slovenian policy was defined in the Resolution on the National Energy Programme (ReNEP), [7], adopted by the National Assembly in May 2004; the long-term development goals, orientation of energy supply, energy systems and mechanisms for stimulation of the use of RES

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are all defined in detail. The target of the Resolution ReNEP, [7], was to increase the share of RES in the primary energy balance to 12% in 2010:

- increasing heat supply from RES from 22% in 2002 to 25% in 2010,
- increasing electricity from RES from 32% in 2002 to 33.6% in 2010,
- achieving a 2% share of biofuels for transport at the end of 2005.

3.1 National Renewable Energy Action Plan

In 2010, the Slovenian government adopted the 2010-2020 National Renewable Energy Action Plan (NREAP), [9], following EU Directive 2009/28/EC on the promotion of the use of energy from renewable sources for Slovenia, [4]. The target of the Slovenian policy for renewable energy sources is to increase the share of RES in gross energy consumption from 16.2% to 25.0% in 2020.

The NREAP gives a detailed review of all current Slovenian policy and measures (legalisation and financing) supporting the use and exploitation of RES, and meeting the directive on renewable energy sources.

Based on the review and analysis of the current policy and measures, additional policies and measures necessary to achieve the objectives from the RES Directive are designed and proposed.

The policies and measures to promote RES (current and planned) in NREAP are defined in respect of:

- the anticipated results of modified behaviour, installed capacities (MW, t/year), energy produced (ktoe) and similar quantified goals,
- target groups (investors, end users, public administration, planners, architects, installation contractors, etc.) and target activities (production of biofuels, use of animal manure to generate energy, biodegradable waste management),
- duration of measure and start of implementation programs.

The NREAP gives also a review and analysis of specific measures to fulfil the requirements of Directive 2009/28/EC.

The NREAP gives assessments of the expected contribution of each technology for obtaining energy from renewable sources to target in 2020 in the sectors of electricity, heating, cooling and transport.

The measures in the NREAP are formulated on the basis of targets regarding the share of energy from renewable sources for 2020 in the following sectors:

(a) electricity,

(b) heating and cooling,

(c) transport.

3.1.1 Electricity from RES

The assessment of expected installed capacity (in MW) and annual generation (GWh) in the 2010 to 2020 period are specified by technology as shown in Table 1. The assessment is made of the contribution of the individual technology: hydro (small to 10 MW, large over 10MW), solar (photovoltaic), wind, wood, and biogas (including sewage and landfill gas), power plants (Table 1, Figure 5).

Table 1: *Assessment of expected electricity produced from RES*

	2005		2010		2015		2020	
	[MW]	[GWh]	[MW]	[GWh]	[MW]	[GWh]	[MW]	[GWh]
Hydro energy	981	4.099	1.071	4.198	1.193	4.559	1.354	5.121
< 1 MW	108	451	118	262	120	270	120	270
1 MW – 10 MW	37	155	37	192	52	247	57	270
> 10 MW	836	3.493	916	3.744	1.021	4.042	1.176	4.581
Solar energy (PV)	0	0	12	12	37	37	139	139
Wind energy	0	0	2	2	60	109	106	191
Biomass	18	114	51	298	83	623	96	676
Wood	15	82	22	150	24	272	34	309
Biogas	3	32	30	148	58	351	61	367
Total	**999**	**4.213**	**1.136**	**4.51**	**1.373**	**5.328**	**1.693**	**6.126**
Of which CHP	18	114	51	298	83	623	96	676

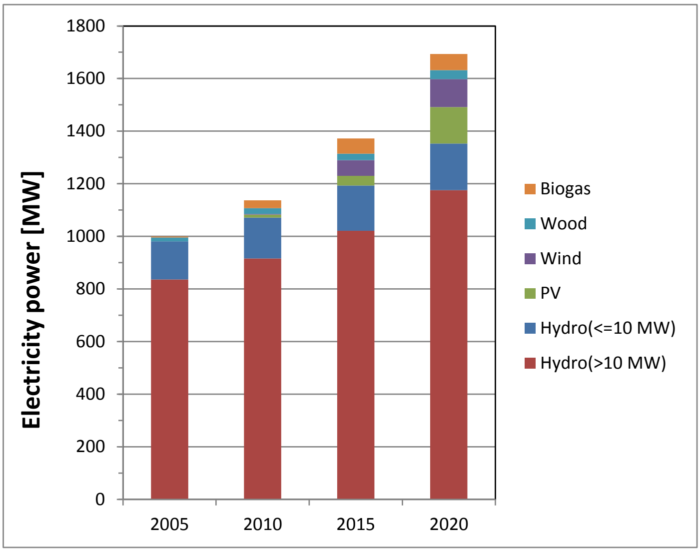

Figure 5: *Expected installed capacities of power plants from RES by technology to 2020*

3.1.2 Heating and cooling from RES

The assessment of contribution of RES technology for heating and cooling is made based on the installed capacity and production for technologies exploiting geothermal and solar energy, heat pumps and biomass, where biomass is separated into solid (wood and wood wastes), bio gaseous (biogas, sewage gas, landfill gas and gas from wastes) and liquid biomass (Table 1). An estimate is given of the contribution of district heating systems using RES and the consumption of RES for heating and cooling in households.

Table 2: *Assessment of contribution of RES technology for heating and cooling*

[ktoe]	2005	2010	2015	2020
Geothermal energy	16	18	19	20
Solar energy	3	5	10	21
Biomass	445	415	495	526
Wood	401	415	483	497
Biogas	0	0	0	0
Biofuels	43	0	12	28
RES from heat pumps	2	8	37	58
Aerothermal	0	1	7	14
Geothermal	0	4	26	38
Hydrothermal	0	2	5	5
TOTAL	465	445	561	625
District heating	8	17	34	48
In households	329	332	387	394

3.1.3 Use of RES in Transport

The contribution of RES of different technologies to achieve a 10% share of consumption in transport is estimated with an indication of standard biofuels (bioethanol and biodiesel), and electricity from RES as shown in Table 3.

Table 3: *Assessment of expected contribution of RES technology in transport*

[ktoe]	2005	2010	2015	2020
Bioethanol/bio-ETBE	0.0	3.9	7.6	18.5
Biodiesel	0.0	36.6	71.6	173.7
Renewable electricity	3.9	5.4	7.0	10.5
Of which road transport	0.0	0.0	0.1	1.1
Of which non-road transport	3.9	5.4	6.8	9.4
TOTAL	**3.9**	**45.9**	**86.2**	**202.7**

3.2 Financial support for the use of renewable energy sources

The financial supporting mechanisms in Slovenia for the use of renewable energy source is available in form of subsidies and soft loans for investments in heating systems using RES and guaranteed purchase price or operation support for electricity produced from RES.

The government (through the Ministry of Economy — Sector for Efficient Use and Renewable Sources of Energy and Eco-Fund) supports the investments and the use of renewable energy sources through its public competition programme with which it promotes energy efficiency and renewable energy investments and programmes for the increase of their use.

Direct financial support (subsidies) is available for investments in individual heating-cooling systems using renewable energy sources (boilers using wood biomass, geothermal energy, solar energy, heat pumps).

The amount of financial support or subsidy for households is 30–40% of the eligible investment costs in accordance with the regulation on the promotion of efficient energy use and use of renewable energy sources, [10]

The financial support (subsidy) for investments in large and micro district heating systems is determined in accordance with the rules of state aid, amounting to 30–50% of the eligible investment costs.

One of the more effected measures to support the utilisation of RES in electricity production is a financial support scheme for the electricity produced from RES or the “feed-in tariffs”.

3.2.1 Financial support for electricity production from RES

The first financial support for electricity production from RES was in 2002 when the government adopted its “Decree on the Price and Premium for the Purchased Electricity from the Qualified Producers” (or feed-in tariff), [11], [12]. The decree defines a fixed purchase price and premium for the purchased electricity from qualified producers (QP) of electricity from renewable energy

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resources (small hydro, biomass, wind, geothermal, solar, waste and all other RES for power plants with capacities up to 10 MW).

The government adopted in 2009 “Decree on Support for Electricity Generated from Renewable Energy Sources”, [13], in accordance with the amendments to the Energy Act (Official Gazette of the Republic of Slovenia, No 70/08) and EU regulation (Directive 2001/77/EC on the promotion of electricity produced from renewable energy sources in the internal electricity market, Community Guidelines on State Aid for Environmental Protection - 2008/C82/01).

The decree defines the support for electricity produced in RES in forms of methodologies for financial support in the form of guaranteed purchase of electricity (guaranteed purchase price) and financial aid for current operations (operation support).

The determination of the guaranteed purchase price and operation support is based on the reference costs of producing electricity in RES-generating plants (reference costs).

The decree includes the methodology for determination of the reference costs based on published professional data on investments and operating costs for individual energy technologies and sizes of RES-generating plants, the economic and financial parameters of investing and operating, the prices of fuels and other costs associated with electricity generation in Slovenia, and reduced by all other benefits obtained through the operation of the plant, [13]

The guaranteed purchase prices for electricity are determined as the reference costs for the individual production technologies and size categories.

Operating support is the difference between the reference cost of electricity-generating plants using various renewable energy sources and the reference market price of electricity.

The power plants on RES with a nominal electrical capacity of up to 5 MW may decide that instead of a guaranteed purchase price, they may independently sell electricity on the market, and that they will receive support in the form of operating support. The power plants on RES with nominal capacity of 5 MW and more may only receive operation support.

The current (2011) guaranteed purchase prices and operation supports for the electricity from renewable energy sources are shown in Table 4 for electricity generated from hydro, solar and wind energy) and in Table 5 for electricity generated from biomass (wood, biogas) in Slovenia, [14].

Table 4: *The current (2011) guaranteed purchase price and operation support for the electricity from RES (hydro, solar and wind energy) in Slovenia*

	Capacity	Guaranteed purchase price (EUR/MWh)	Operation support (EUR/MWh)
Small hydro power	less than 50kW	105.47	59.78
	>50 kW<1MW	92.61	46.92
	From 1MW to 10MW	82.34	34.52
	over 10MW to 125MW	/	28.75
Wind PP	less than 50kW	95.38	52.88
	>50 kW<1MW	95.38	52.88
	From 1MW to 10MW	95.38	52.88
	over 10MW to 125MW	86.74	40.81
Solar energy-on buildings or civil constructions	less than 50kW	332.37	285.62
	>50 kW<1MW	304.02	257.27
	From 1MW to 10MW	252.29	203.94
	over 10MW to 125MW	/	171.44
Solar energy-installed as free-standing structures	less than 50kW	312.34	265.59
	>50 kW<1MW	287.77	241.02
	From 1MW to 10MW	231.98	183.63
	over 10MW to 125MW	/	162.25

Source: Borzen

***Table 5:** The current (2011) guaranteed purchase price and operation support for the electricity from biomass (wood, biogas) in Slovenia*

2011	Capacity	Guaranteed purchase price (EUR/MWh)	Operation support (EUR/MWh)
Wood (over 90%)	less than 50kW	(individual case)	(individual case)
	>50 kW<1MW	233.79	185.44
	From 1MW to 10MW	175.30	126.42
	over 10MW to 125MW	(individual case)	(individual case)
Wood - co-firing (over 5% from biomass)	less than 50kW		63.54
	>50 kW<1MW	/	61.94
	From 1MW to 10MW	/	61.41
	over 10MW to 125MW	/	(individual case)
Biogas produced from biomass	less than 50kW	160.56	113.81
	>50 kW<1MW	156.31	107.96
	From 1MW to 10MW	141.42	92.54
	over 10MW to 125MW	/	/
Biogas produced from biodegradable waste	less than 50kW	139.23	92.48
	>50 kW<1MW	139.23	90.88
	From 1MW to 10MW	129.15	80.27
	over 10MW to 125MW	/	/
Sewage gas	less than 50kW	85.84	36.96
	>50 kW<1MW	74.42	25.54
	From 1MW to 10MW	66.09	17.21
	over 10MW to 125MW	/	/
Landfill gas	less than 50kW	99.33	50.45
	>50 kW<1MW	67.47	18.59
	From 1MW to 10MW	61.67	12.79
	over 10MW to 125MW	/	/
Biogas produced from communal biodegradable waste	less than 50kW	/	/
	>50 kW<1MW	77.44	28.56
	From 1MW to 10MW	74.34	25.46
	over 10MW to 125MW	(individual case)	(individual case)

Source: Borzen

3.2.2 Other support

The Act on Forests[1], [16], (adopted by the Slovenian Parliament in May 1993) includes a financial supporting of the investment in wood production process (machine), such as wood chips and co-financing of other activities.

The Ministry of Agriculture, Forestry and Food also decided to subsidise the production of cereals, canola and some other crops.

The government supports the biofuel with the exchange of Excise Law, [15], to discharge the biofuel of excise and other taxes (in force from 1.5.2004).

[1] The act manages the protection, cultivation, utilisation and use of forests.

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4 CONCLUSIONS

Renewable energy sources play an important role in sustainable development in all developed economies. The exploitation of renewable energy sources is one of the important measures to replace fossil fuels and to mitigate greenhouse gas emissions and the global climate changes.

Long-term strategy development is in principle based on the development of a low-carbon society, which means more use of renewable sources and the efficient use of energy. The age of fossil fuels is declining, and oil and natural gas will be exhausted in the relatively nearly future.

The Slovenian government has adopted different regulations to promote and stimulate the use of renewable sources for energy proposes; these include subsidised investment in systems for heating, cooling and hot (sanitary) water, financial support for electricity produced from renewable sources, discharge of excise and other taxes biofuels and other support, [16], [18].

There has been significant growth in the last two years in solar (photovoltaic) and biogas plants, mainly using corn silage.

In Slovenia, there is significant potential for investments in technologies for the exploitation of wood biomass, wind, solar, geothermal, hydropower potential in the future.

In particular, the focus should be on the increase of the use of wood biomass from forests and agriculture for energy purposes.

References

[1] *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions* - 20 20 by 2020 - Europe's climate change opportunity, COM(2008) 30 final

[2] *Directive 2003/30/EC of the European Parliament And of the Council*, of 8 May 2003 on the promotion of the use of biofuels or other renewable fuels for transport, Official Journal of the European Communities, L 123/42

[3] *Directive 2001/77/EC of the European Parliament And of the Council*, of 27 September 2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market, Official Journal of the European Communities, L 283/33

[4] *Directive 2009/28/EC of the European Parliament and of the Council* of 23 April 2009 n the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC

[5] *Directive 2001/77/EC of the European Parliament of the Council* of 27 September 2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market, Official Journal of the European Communities, L 283/33, 27.10.2001

[6] *Resolution on the Strategy of Energy Use and Supply of Slovenia*, Official Journal of the Republic of Slovenia No 9/1996

[7] *The resolution on national energy program* (ReNEP), Official Journal of the Republic of Slovenia No 57/2004(http://www.uradni-list.si/1/objava.jsp?urlid=200457&stevilka=2669)

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[8] *Energy Act*. Official gazette of the Republic of Slovenia, No. 79/1999, 51/2004, 27/2007, 70/2008 (http://www.uradni-list.si/1/objava.jsp?urlid=199979&stevilka=3757, http://www.uradni-list.si/1/objava.jsp?urlid=200870&stevilka=3025)

[9] *The National Renewable Energy Action Plan 2010-2020* (NREAP), July 2010

[10] *Regulation on the promotion of efficient energy use and use of renewable energy sources*, Official Journal of the Republic of Slovenia No 89/08 and No 25/09

[11] *Decree on the Rules for Setting prices and for purchasing electricity from qualified electricity producers:* Official Journal of the Republic of Slovenia No 25/2002

[12] *Decision on prices and premiums for the purchase of electricity from qualified electricity producers*, Official Journal of the Republic of Slovenia No 75/2006

[13] *Decree on supports for the electricity generated from renewable energy sources*, Official Journal of the Republic of Slovenia No 37/2009, last amendment 43/2011

[14] Borzen, *Določanje višine podpor električni energiji proizvedeni iz OVE in SPTE in višine podpor v letu 2011*, Ljubljana, 21. 1. 2011 (http://www.borzen.si/slo/centerzapodpore/dokumenti)

[15] *Excise law:* Official Journal of the Republic of Slovenia No 84/1998 and 42/2004

[16] *Forest Act,* Official Journal of the Republic of Slovenia No 30/1993

[17] *Government of the Republic of Slovenia*: National Energy Efficiency Action Plan 2008–2016 (NEEAP), Ljubljana, 31.01.2008

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PROJECT-ORIENTED TEACHING OF POWER ELECTRONICS DURING UNDERGRADUATE STUDY

PROJEKTNO ORIENTIRANO UČENJE MOČNOSTNE ELEKTRONIKE NA DODIPLOMSKEM ŠTUDIJU

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Keywords: project-oriented teaching, power electronics, boost converter, electromagnetics, inductor, control

Abstract

This paper presents the results and acquired experience from the Project-Oriented Teaching (POT) of the undergraduate students in Power Electronics course at the Faculty of Electrical Engineering and Computer Science in Maribor, based on using a boost converter test-board. In the project task, the students are asked to calculate the main boost converter circuit parameters capacitor C and inductor L; they are additionally required to design the inductor L in order to meet the project goals. The whole project design is based on the ideas from the CDIO (Conceive, Design, Implement, Operate) framework in which the students are encouraged to consider the whole system process to obtain hands-on experience. Finally, students have to design a PI-voltage controller to connect their newly obtained knowledge with their prior knowledge.

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Povzetek

V prispevku so predstavljeni rezultati in pridobljene izkušnje pri projektno orientiranem učenju z dodiplomskimi študenti, ki so pri izbirnem predmetu Energetska elektronika na Fakulteti za elektrotehniko, računalništvo in informatiko v Mariboru načrtovali in izdelali pretvornik navzgor na osnovi preizkusne plošče. Projektna naloga vsebuje izračun glavnih energijskih komponent pretvornika navzgor: kondenzatorja in dušilke, s posebnim poudarkom na izdelavi dušilke. Celoten postopek načrtovanja projekta temelji na t.i. CDIO idejah (Conceive – zamisliti, Design – načrtovanje, Implement – izvedba in Operate – delovanje), kjer se študente vzpodbuja, da sodelujejo pri celotnem procesu načrtovanja in si tako pridobijo dragocene izkušnje. Na koncu študentje z načrtovanjem napetostnega PI-regulatorja povežejo novo pridobljeno znanje z znanjem iz teorije regulacij.

1 INTRODUCTION

In all power supply systems, power electronics has a central role in the control of energy flow. This paper presents the results and acquired two years of experiences from the project-oriented teaching (POT) of power electronics realized with a student design project task, based on a boost converter test-board layout. The test-board is used during the laboratory exercises in the advanced course of Power Electronics that is offered as an optional subject to the third year students of a professionally oriented undergraduate study program. In the second year of the curriculum, students participate in a basic course of Industrial Electronics that covers the basics in DC/DC, AC/DC and DC/AC converters. Applied teaching methods in this course follow the strategy described in [1], where the use of theoretical lectures together with simulations and measurements in the laboratory are proposed. In the advanced course of Power Electronics, in which the design and dynamical analysis of converters are treated along with other themes, a combination of theoretical lectures with the POT approach is used. One of the goals of the using the POT approach was to make power electronics more attractive to students, especially to those who originally preferred non-power related subjects.

Nowadays, engineers have to deal with uncertainty and solve complex problems; they need to be able to function as effective members of teams in which strong communication and problem-solving skills are required. However, it is commonly believed that today's engineering graduates lack these skills and have difficulty applying their fundamental knowledge to practical problems. Recently, many authors have reported their experiences with using more learner-centered teaching approaches, such as problem-based learning or project-oriented teaching (POT), instead of using lecture-based teaching methods in undergraduate engineering [2]–[7]. Some authors, [3], [6], reported that POT students scored slightly less on factual knowledge, but they retained more of the acquired knowledge, since their knowledge is grounded in context. The authors also argued that POT students develop more conceptual knowledge; therefore, they are able to better recall their knowledge.

Teaching students through POT is based on the philosophy that students learn fundamental laws and their applications most effectively through design practices that result in demonstrated success, [8]. Through such practice, students learn that understanding the fundamentals and attention to details are required to succeed in engineering. They also become familiar with the science/art of the iterative design process. A strong foundation consisting of a deep understanding of the fundamentals of engineering and an ability to deal with details must be provided to students to prepare them for advanced courses as well as for the challenges of

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the competitive industrial world.

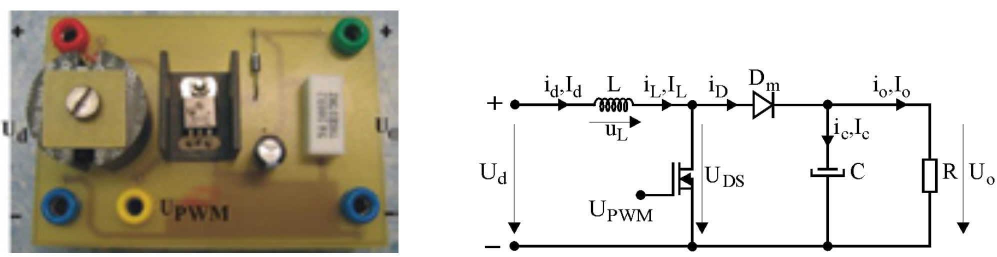
From the students' point of view, POT is learner-centered and intrinsically motivating, since the students are actively engaged in "doing" things rather then in "learning about" something and it is challenging, focusing on higher-order skills. The whole project design task is based on the ideas from the **CDIO** (Conceive, Design, Implement, Operate) framework, in which students are encouraged to consider the whole system process to obtain hands-on experience. According to the basic CDIO premise that hands-on experience is a vital foundation on which to base theory and science, [9], [10], the teaching of engineering should be arranged in following steps:

- **Conceive** - students formulate the given task into what needs to be performed to fulfilled the assignment;
- **Design** – students make adequate design/calculations;
- **Implement** – based on design, the derived construction is practically implemented;
- **Operate** – the completed construction is analyzed and evaluated.

In order to connect the new knowledge gained with POT with their prior knowledge from the control theory subject, students also have to design a PI-voltage controller for a boost converter. The implementation and verification of the boost converter control has been done within Matlab/Simulink program.

2 DESIGN PROJECT TASK SPECIFICATIONS

The design requirements should be clearly specified, although they are seldom unambiguous in the professional world, where it is left to the engineer to work out the details of the requirements. The following specifications were given to our students: using boost converter test-board layout (but, without a mounted main inductor and output capacitor, shown in Figure 1(a)), build the converter with following specifications: the input voltage U_d, the output voltage U_o, the switching frequency f_s, minimal load resistance R, maximum allowed inductor current ripple ΔI_L and maximum allowed output voltage ripple ΔU_o. An additional requirement is that the converter has to operate in continuous conduction mode (CCM).



(a) (b)

Figure 1: *(a) Boost converter test-board with mounted inductor and capacitor, and (b) boost converter circuit*

In order to fulfill the given specifications, students are required to calculate the necessary duty cycle and the main boost converter circuit parameters: the output capacitor C and the main inductor L (see Figure 1(b)). Additionally, they are also required to design and build the inductor

L in order to meet the project goals. When students have the opportunity to perform practical work with theoretical material they had been taught, their understanding of the subject increases.

In the application of boost converter, shown in Figure 1(b), in which operation in continuous conduction mode is required, the inductance's value L is usually chosen such that inductor current ripple's peak magnitude has a prescribed fraction value of the full-load inductor current DC component. Based on the calculated inductance value L, students have to design the inductor using procedure described in next sections.

2.1 Procedure of the Design Project Task

In the initial phase of the project, students have to become familiar with the boost converter test-board layout and its circuit. At this stage, is important that the relevant fundamental laws are discussed in class to prepare students for the design project. When the initial phase is completed, the design project task can be done with information given at the beginning: the supplying voltage U_d, the output voltage U_o, load resistance R and switching frequency f_S.

2.2 Calculations of the Boost Converter

Basic calculations are based on assumption that students deal with the ideal boost converter [10]. The required duty cycle D can be calculated from the converter input and output voltage transfer ratio:

$$\frac{U_o}{U_d} = \frac{1}{1-D} . \tag{2.1}$$

The converter's output power P_o and output current I_o are related to the load resistance R and the input current is available from the current transfer ratio:

$$\frac{I_o}{I_d} = (1-D) . \tag{2.2}$$

Now the necessary inductance L and capacitance C can be calculated as:

$$L = \frac{U_d t_{on}}{\Delta I_L} = \frac{U_d D}{\Delta I_L f_s} , \tag{2.3}$$

$$C = \frac{I_o t_{on}}{\Delta U_o} = \frac{U_o D}{R \Delta U_o f_s} . \tag{2.4}$$

While the converter has to operate in continuous conduction mode, it is necessary to verify whether the actual current through the inductance is always greater than zero or:

$$I_d \geq = \frac{\Delta I_L}{2} . \tag{2.5}$$

If this would not be fulfilled, then the specification about inductor current ripple ΔI_L should be corrected to the lower value, which would consequently give a larger value for the inductance L. Finally, the rated peak current through inductor can be calculated as:

$$I_{L,\max} = I_d + \frac{\Delta I_L}{2}. \tag{2.6}$$

When all basic calculations are done, students can start to build the converter. The easier task is to choose the adequate capacitor with the capacitance value at least as calculated by (2.4), while the more difficult one is to design the inductor with the inductance value at least as given by (2.3).

2.3 Design Procedure of the Inductor

In power electronic circuits, the inductive components, such as the inductors and transformers, are basic elements. Since they can not be bought off the shelf as capacitors, they have to be dimensioned, designed and built; for that, a deep understanding of electromagnetic behavior is essential. Many students lack such an understanding of the physics of inductive components, even though they successfully finished the introduction courses in basic electrical engineering. In the case of inductor design, there are a large number of design parameters to be chosen including: air-gap length, conductor area, number of turns, all of the magnetic core dimensions, and the type of magnetic material with inductance factor A_L defined as:

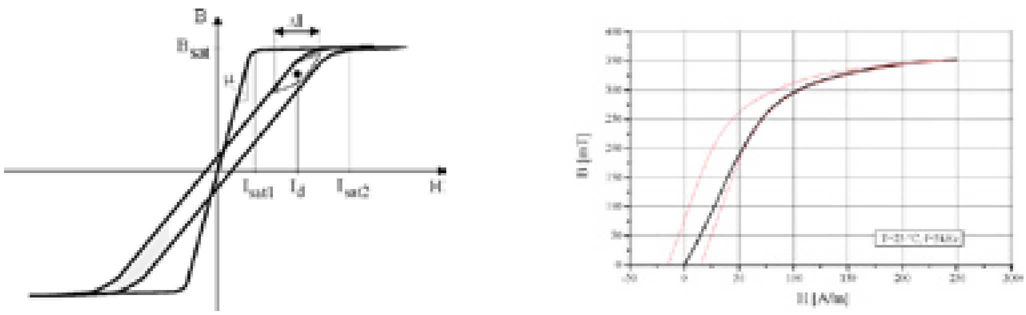
$$A_L = \frac{L}{N^2}. \tag{2.7}$$

The inductor design procedures described in literature make use of numerous equations and diagrams, and the final result is achieved through several iterations. Therefore, inductor design presents a formidable optimization problem, and there is a general perception that it is difficult task and that requires significant experience [11]–[13]. It is particularly difficult to teach inductor design to students at the undergraduate professional level, since they lack ability to comprehend difficult physics concepts.

Due to the limited supply of magnetic cores and in order to simplify the design procedure, students have been given a toroidal magnetic core, L30, with following specifications: inductance factor A_L = 2000 nH, saturated flux density B_{sat} = 350 mT, magnetic field strength H = 250 A/m, core cross-sectional area A_c = 115 mm^2 and average magnetic core path l_m = l_c = 45 mm. All calculations for the inductor design can now be performed as follows: first, it is necessary to calculate the required number of turns N for a magnetic core without air-gap from (2.7). In inductor design, it is important that the core is not driven into saturation by increasing the current, so the value of saturation current I_{sat1} for the given core has to be calculated (see Figure 2(a)). By applying Amper's law and with taking into account the distribution of flux density B in dependence on the magnetic field strength H (see Figure 2(b)), the saturation current is calculated as:

$$I_{sat1} = \frac{B_{sat} \cdot l_m}{N \cdot \mu} = \frac{l_m \cdot H}{N} \tag{2.8}$$

where l_m is the average magnetic core path and μ is the magnetic permeability of the ferromagnetic core.



(a) (b)

Figure 2: *(a) Magnetic curve of the core without- or with air-gap, and (b) distribution of flux density B in dependence on magnetic field strength H*

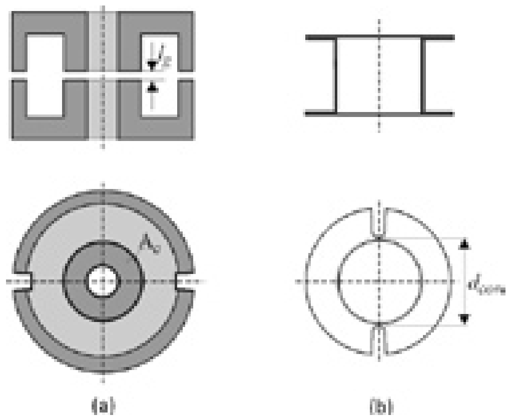


Figure 3: *(a) Structure of the toroidal core L30 with air-gap and (b) toroidal coil-bobbin*

When the peak value of inductor current $I_{L,max}$ in (2.6) is close to the calculated value of saturated current I_{sat1} in (2.8), it can then be assumed that the core will be saturated during the operation of boost converter. Consequently, the amount of the energy stored in the inductor will be lower, which will result in lower current and lower converter output power. The temperature in the core will increase, as well as core losses, which will result in the decreased efficiency of the converter. Thus, the decision whether the core with an air-gap should be used must be accepted. If the core with air-gap is used (see Figure 3(a)), then the value of the saturated current is higher (see Figure 2(a)) and can be calculated as:

$$I_{sat2} = \frac{B_{sat} \cdot A_c}{N}\left(\frac{l_c}{\mu \cdot A_c} + \frac{l_g}{\mu_0 \cdot A_c}\right) = \frac{B_{sat}}{N}\left(\frac{l_c H}{B_{sat}} + \frac{l_g}{\mu_0}\right) \tag{2.9}$$

where l_c is the average magnetic core path, l_g is the length of air-gap and μ_0 is the magnetic permeability in the air. It is assumed that the core and air-gap have the same cross-sectional areas; in practice, the permeability $\mu >> \mu_0$, then the above equation can be reduced to:

$$I_{sat2} \cong \frac{B_{sat} \cdot l_g}{N \cdot \mu_0}. \tag{2.10}$$

By choosing the appropriate length of the air-gap l_g, the value of saturation current can be set higher than the peak value of inductor current $I_{L,\max}$ in order to prevent the inductor from going into saturation during the converter's operation. When the core with the air-gap is employed, the inductance is changed to the next final value:

$$L = \frac{\mu_0 A_c N^2}{l_g} . \tag{2.11}$$

Finally, the necessary correction for the value of the number of turns N has to be done based on (2.11) in order to fulfill the requirement for the boost converter inductance L value:

$$N = \sqrt{\frac{L l_g}{\mu_0 A_c}} . \tag{2.12}$$

With the new value of the number of turns N the value of saturation current I_{sat2} is also changed according to (2.9) or (2.10), so the verification if this current is higher than the peak value of inductor current $I_{L,max}$ has to be done once more.

When the above condition is fulfilled, the selection of the diameter of copper wire for the inductor must be made. The selection is based on fact that the current density maximum value should not be larger than J_{max}. The current density J_{max} depends on the converter input current I_d and the cross section of the copper wire S_{Cu}; therefore, the copper wire diameter d_{Cu} can be determined as:

$$d_{Cu} \geq \sqrt{\frac{4 I_d}{\pi J_{\max}}} . \tag{2.13}$$

The copper wire diameter from which the inductor will be wound off should be the first largest one with respect to the calculated value in (2.13). From the required number of turns N and the copper wire diameter, the dc winding resistance of the inductor R_L can be calculated:

$$R_L = \frac{\rho l_{wire}}{S_{Cu}} = \frac{4 \rho N d_{core}}{d_{Cu}{}^2} \tag{2.14}$$

were l_{wire} is a length of the copper wire, d_{core} is a diameter of the toroidal coil-former (bobbin) as can be seen in Figure 3(b) and ρ is a copper specific electrical resistivity. It is desired to obtain the given inductance L with as small winding resistance R_L as possible, because the winding resistance R_L influences the copper losses and consequently the boost converter efficiency. From (2.14), it is obvious that the value of winding resistance depends on the number of turns N. When the core with the air-gap is employed, the same inductance L is obtained with more turns compared to the core without air-gap. As already stated, more turns means more losses, so the decision about using core with air-gap has to be carefully made. The resistance R_L also reduces the output voltage transfer ratio of the real boost converter:

$$\frac{U_o}{U_d} = \frac{R(1-D)}{R_L + R(1-D)^2} . \tag{2.15}$$

By calculating the derivative of (2.15) with respect to the duty ratio D, the maximum duty ratio during operation could be limited at:

$$D_{\max} = 1 - \sqrt{\frac{R_L}{R}}\ . \tag{2.16}$$

From (2.16) and (2.15), the maximum value of the boost converter output voltage can be obtained as:

$$U_{o,\max} = \frac{U_d}{2\sqrt{\frac{R_L}{R}}}\ . \tag{2.17}$$

After all the calculations are done and the copper wire is selected, students can build the real inductor. The required turns are carefully wound around the toroidal coil-bobbin (see Figure 3(b)) and the air-gap is made by using a piece of paper of adequate thickness. The verification, if the required inductance of the inductor L is obtained, is done by measurement using an LC-Q meter before the inductor is mounted on the boost converter test-board (see Figure 1(a)). At this stage, the resistance of the inductor R_L is also measured and compared with the (2.14).

3 ANALYSIS AND EVALUATION OF THE PROJECT TASK

When the built inductor L and the chosen capacitor C are mounted on the boost converter test-board shown in Figure 1(a), students can perform final analyses and evaluation of whether the design project task goals are fully reached. In the verification process, students connect the built boost converter to a U_d = 5 V voltage supply, they adjust the duty cycle D to a value that gives U_o = 15 V voltage at converter's output, so that the converter operates in nominal operational conditions. Now they can measure the output voltage ripple ΔU_o as well as the ripple of the inductor current ΔI_L.

The waveform of the inductor current's ripple ΔI_L is shown in Figure 4 together with the waveform of the transistor driving signal U_{PWM}. The current was measured with the current probe; from Figure 4, it can be seen that project goal for the inductor current ripple ΔI_L = 0.2 A has been reached. The maximum output voltage $U_{o,max}$ was also measured and compared with the calculated value in (2.17), and the reasons for discrepancy were discussed.

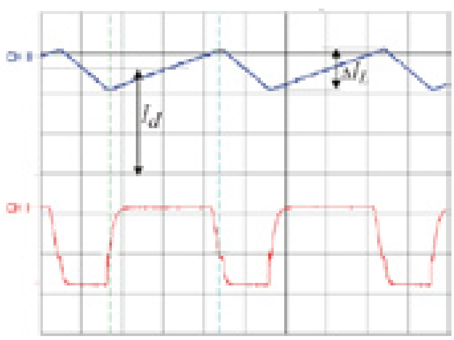


Figure 4: *Waveforms of the driving signal for transistor U_{PWM} (CH I,* 5 V/div*) and inductor current ripple ΔI_L (CH II,* 0.2 A/div*), time (*10 μs/div*)*

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4 VOLTAGE CONTROL OF THE CONVERTER

After successfully finishing the design project task, the students are also asked to design the output voltage control of the boost converter. For solving this problem, they have to gain all the basic knowledge from control theory [11]: dynamic modeling, transfer functions, Bodé plots and phase margin for the PI-controller design, etc. First, the dynamic model of the boost converter is given by small signal perturbations with state space variables of inductor's current $\tilde{i}_L$ and output voltage $\tilde{u}_o$ as:

$$\begin{aligned}\frac{d\tilde{i}_L}{dt} &= -\frac{R_L}{L}\tilde{i}_L - \frac{1}{L}\tilde{u}_o(1-D) + \frac{1}{L}U_o\tilde{\delta} + \frac{1}{L}\tilde{u}_o\tilde{\delta} + \frac{1}{L}\tilde{u}_d,\\ \frac{d\tilde{u}_o}{dt} &= \frac{1}{C}\tilde{i}_L(1-D) - \frac{1}{C}I_L\tilde{\delta} - \frac{1}{C}\tilde{i}_o\tilde{\delta} - \frac{1}{RC}\tilde{u}_o.\end{aligned} \tag{4.1}$$

Such a small-signal model in (4.1) is easy to implement within the Matlab/Simulink program, and both variables are available at the output of the integrator (see Figure 5). It is important to note that the current through the inductor (i.e. input current) could never be negative, which is why this integrator has the lower saturation limit set to zero. After setting, all required parameters of the circuit the simulation result of uncontrolled boost converter's operation are shown in Figure 6.

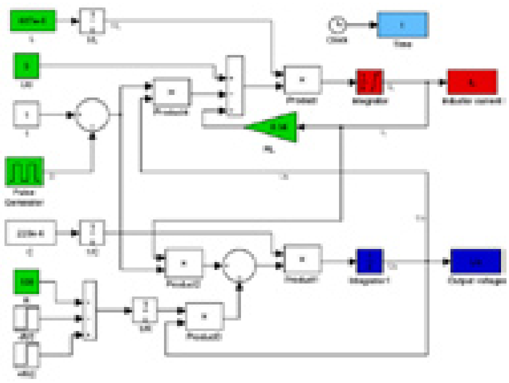
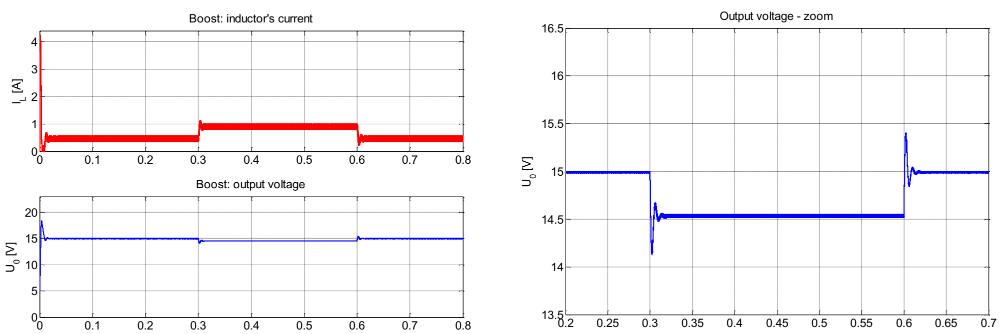


Figure 5: *Small signal model of the boost converter in Matlab/Simulink*



(a) (b)

Figure 6: *Operation of the uncontrolled boost converter when the load changes: (a) input current and the output voltage, and (b) output's voltage tolerance*

It is evident that the turn-on current spike is much higher than the steady-state value, and that when the load changes, the under-voltage and over-voltage spikes at the output terminals occur, as well as the steady state-error of 0.5 V from the nominal value of 15 V. To eliminate this voltage-error, the PI-voltage controller must be implemented. The parameters of the PI-controller (time constant and gain) are designed based on the transfer function that describes the relation between output voltage $\tilde{u}_o(s)$ and duty cycle $\tilde{\delta}(s)$ (i.e. Bodé plots), which could be obtained from the system in (4.1) as:

$$F_{\tilde{\delta}}(s) = \left.\frac{\tilde{u}_o(s)}{\tilde{\delta}(s)}\right|_{\tilde{u}_d=0} = \frac{\left(U_o(1-D)\right) - R_L I_L) - sLI_L}{LCs^2 + s\left(\frac{L}{R} + R_L C\right) + \left(\frac{R_L}{R} + (1-D)^2\right)} . \quad (4.2)$$

Based on this transfer function, the boost converter frequency characteristic (shown in Figure 7(a)) is calculated, using the Matlab program. The parameters for the PI-voltage controller are obtained from the open-loop transfer function by using the basic control-theory rule called "phase-margin". The open-loop system transfer function of the boost converter together with the PI-controller consists of:

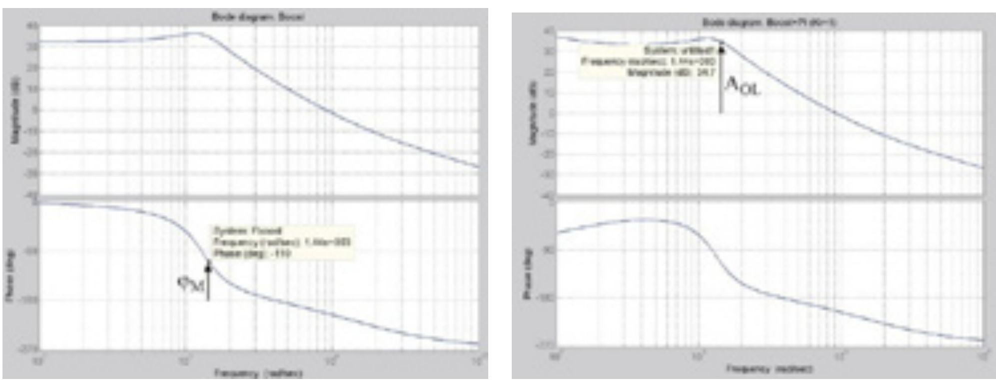
$$F_O(s) = \frac{\tilde{u}_o(s)}{\tilde{u}_{err}(s)} = F_{PI}(s) \cdot F_{\tilde{\delta}}(s) , \quad (4.3)$$

where the transfer function of the PI-voltage controller is:

$$F_{PI}(s) = K_R \frac{1 + sT_i}{sT_i} \quad (4.4)$$

The gain of the controller is set to unity ($K_R = 1$) and the phase-margin of the open-loop Bodé plot in (4.3) is prescribed to fixed value ($\varphi_M = 70°$). To eliminate the phase influence of the controller, the time constant of the integrator T_i must be set ten times higher as it follows from the depicted value at margin-frequency (see Figure 7(a)):

$$T_i = \frac{10}{\omega_{\varphi_M}} . \quad (4.5)$$



(a) (b)

Figure 7: *(a) Boost converter Bodé plots phase-margin with phase-margin for the integrator's time constant, and (b) open-loop system Bodé plots for the calculation of the controller gain*

Next, the open-loop system in (4.3) Bodé plots is calculated, together with the integral time-constant given in (4.5). The gain of the controller (depicted in Figure 7(b)) is related with the open-loop system gain A_{OL} as:

$$K_R = 10^{(-A_{OL}(dB)/20)} . \tag{4.6}$$

Which means that the gain of the controller must be negative in the same amount as open-loop gain obtained at the phase-margin to keep the output voltage constant when the load changes.

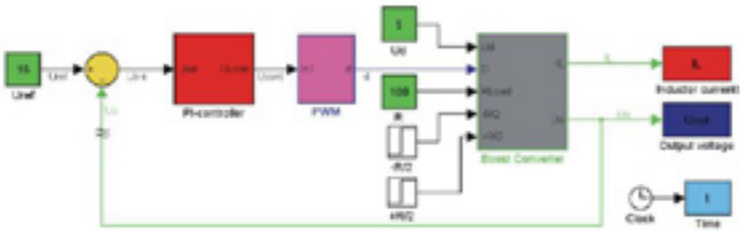
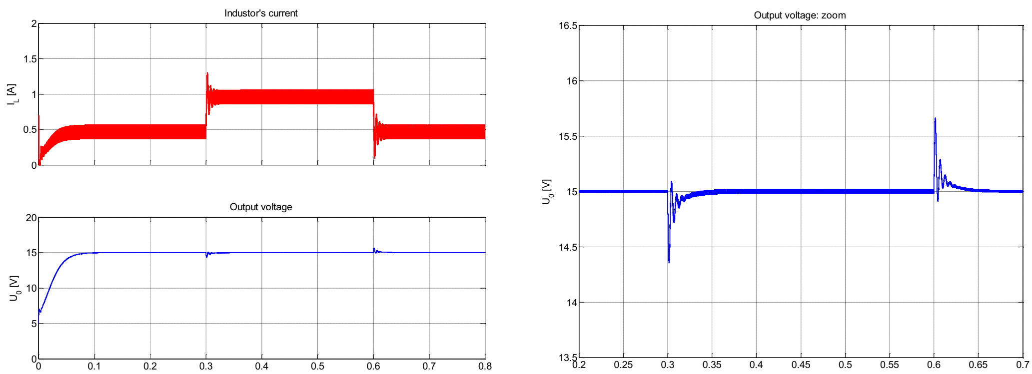


Figure 8: *Voltage control scheme of the boost converter*

Finally, the voltage controlled boost converter in Figure 8 is simulated again with the PI-controller parameters given by (4.5) and (4.6); the results are shown in Figure 9. It is clear that the controller keeps the output voltage constant even when the load changes, which was impossible in the previous case (see Figure 7(b)) and the voltage under-shoot is also reduced (Figure 9(b)).



(a) (b)

Figure 9: *Voltage control of the boost converter when the load changes: (a) input current and the output voltage, and (b) output's voltage tolerance*

5 LEARNING ACHIEVEMENTS: CONVENTIONAL TEACHING vs. PROJECT-ORIENTED TEACHING

Although the project-oriented teaching (POT) approach offers a number of advantages, as reported by several authors, we decided to grade the progress in study achievements within the same group of students. In our case, two similar topics were conducted in the class: the basic

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course on Industrial Electronics in the 4th semester, and an advanced course on Power Electronics in the 5th semester. In the first case, the students attended a conventional teaching program: from lectures in the class, homework, mid-term exams, to assistant-guided lab exercises, and the final exam. In the second case, we applied a combination of traditional lectures with the POT approach within an advanced course on Power Electronics, with an emphasis on ideas from the CDIO framework. A comprehensive survey was also conducted of the class in the 5th semester, using an anonymous questionnaire in which students could compare the conventional teaching approach against the POT combined with the CDIO initiative, express and write down their proposals, new ideas, legitimate critiques, and also possible recommendations.

The percentage comparison of the final grades between the courses in the 4th and 5th semesters is shown in Figure 10. According to the evaluation results, by using the POT method in the 5th semester, the students had obtained 10–20% higher final grades, as reflected in better scores in their final exams. This can be seen as a significant improvement with respect to other authors' observations, [3], [6]. At the same time, the lower grades had been reduced by similar percentages, as against the 4th semester as well.

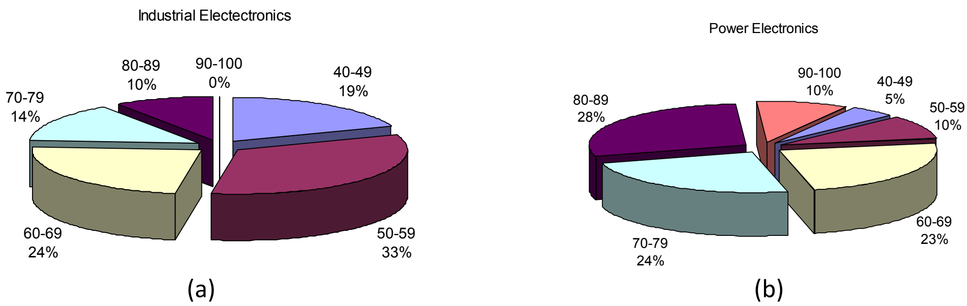

Figure 10: *Comparison of final exam scores with two different teaching approaches: (a) at the course on Industrial electronics and (b) at the advanced course on power electronics*

The opinions and suggestions from the student feedback are very positive with regard to the practical assistance of the laboratory staff. The majority of students felt that the final hands-on layout of the inductor enhanced their understanding of the theoretical background in electromagnetic theory and made the course more interesting. It is also well-known that students who learn techniques through discussions, take quizzes and find answers to problems show more interest in the course than those who learn the theory via traditional instruction approach. The average scores of the midterm and final examinations also confirm these conclusions. It was found at the end of course that majority of the students could now digest those important and difficult topics in the lecture notes, and what the teacher explained during the lectures. A comparison with other universities with conventional education shows that final yield is much higher with the POT approach.

6 CONCLUSION

This paper focuses on teaching students the fundamentals of power electronics in connection with electromagnetics and control theory with the POT approach through design of the inductor that is the part of the laboratory assignment on boost converter design. The whole project is prepared according to the CDIO principles and was well accepted by students. With respect to reported

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experiences in [10] and the fact that we worked with the students at the undergraduate professional level, the detailed specification of the tasks in the Conceive (C) phase have been provided. The students worked in groups of three and were helped as much as it took for the best of them to carry out design successfully. With this teaching approach, students were asked to apply the fundamental laws and work out details to complete design. In our opinion, students who gained a deep understanding of fundamental laws can self-educate themselves about any given subject. With working on the project design, students have also gained the important experience that calculations are approximations of the real circuit behavior.

Even though the results of comprehensive survey and the comparison of the final exams scores in two semesters confirm that POT approach improves student performance, we found it very important that the basic concepts are taught before POT is used. The POT approach found high interest among all students and can be seen as a great success. Students enjoyed building their own boost converter and their rewarding experience will hopefully encourage students from next generations to enroll in the Power Electronics course. Finally, students met the project requirements by implementing the knowledge from control theory in PI-voltage controller design.

References

[1] **Z. Jakopovic, V. Sunde and Z. Bencic,** Undergraduate Power Electronics Laboratory – Applying TSMST Method, *Journal of Power Electronics*, Vol. 10, No. 6, pp. 621–627, 2010.

[2] **S.C. Wang, Y.C. Chen and J.H. Su,** Teaching Switching Converter Design Using Problem-Based Learning with Simulation of Characterization Modeling, *Journal of Power Electronics*, Vol. 10, No. 6, pp. 595–603, 2010.

[3] **D.G. Lamar, P.F. Miaja, M. Arias, A. Rodríguez, M. Rodríguez and J. Sebastián,** A Project-based Learning Approach to Teaching Power Electronics: Difficulties in the Application of Project-based Learning in a Subject of Switching-mode Power Supplies, in proceeding of *IEEE EDUCON*, pp.717–722, 2010.

[4] **F. Martínez, L.C. Herero and S. de Pablo,** Project-Based Learning and Rubrics in the Teaching of Power Supplies and Photovoltaic Electricity, *IEEE Transaction on Education*, Vol. 54, No. 1, pp. 87–96, Feb. 2011.

[5] **R.H. Chu, D.D.C. Lu and S. Sathiakumar,** Project-Based Lab Teaching for Power Electronics and Drives, *IEEE Transactions on Education*, Vol. 51, No. 1, pp. 108–113, Feb. 2008.

[6] **A. Yadav, D. Subedi, M.A. Lundeberg and C.F. Bunting,** Problem-based Learning: Influence on Students' Learning in an Electrical Engineering Course, *Journal of Engineering Education*, Vol. 100, No. 2, pp. 253–280, Apr. 2011.

[7] **F. Blaabjerg**, A Power Electronics and Drives Curriculum with Project-Oriented and Problem-Based Learning: a Dynamic Teaching Approach for the Future, *Journal of Power Electronics*, Vol. 2, No. 4, pp. 240–249, Oct. 2002.

[8] **S.M. Miri and R.J. Fu,** A Hands-On Practical Approach to Teaching Engineering Design, *IEEE Transaction on Education*, Vol. 36, No. 1, pp. 131–136, 1993.

----

[9] **CDIO**, 2011 [Online]. Available: http:// www.cdio.org/index.html

[10] **L. Max, T. Thiringer, T. Undeland and R. Karlsson,** Power Electronics Design Laboratory Exercise for Final-Year M.Sc. Students*, IEEE Transaction on Education*, Vol. 52, No. 4, pp. 524–531, 2009.

[11] **N. Mohan, T.M. Undeland and W.P. Robbins,** *Power Electronics, Devices, Converter, Application and Design,* John Willey and Sons. New York, Singapore, Toronto, Brisbane, 1995.

[12] **T. Undeland, J. Lode, R. Nilssen, W.P. Robbins and N. Mohan,** A Single-Pass Design Method For High-Frequency Inductors*, IEEE Industry Applications Magazine*, pp. 44–51, Sept./Oct. 1996.

[13] **S. Barmada, R. Rizzo and L. Sani,** Didactic Consideration on Magnetic Circuits Excited by Permanent Magnets*, IEEE Transaction on Education*, Vol. 52, No. 4, pp. 532–537, 2009.

Nomenclature

(Symbols)	(Symbol meaning)
A_c	core cross-sectional area
A_L	inductance factor
B_{sat}	saturated flux density
C	capacitance of the output capacitor
D	duty ratio
d_{core}, d_{Cu}	diameter of the toroidal coil-bobbin, diameter of the copper wire
f_S	switching frequency
H	magnetic field strength
I_d, I_o	input- and output current
ΔI_L	max. allowed inductor’s current ripple
$I_{L,max}$	peak inductor’s current
I_{sat}	core’s saturation current
J_{max}	max. current density
L	inductance of the main inductor
l_m $(=l_c)$, l_g	average magnetic core path; length of the air-gap
l_{wire}	length of the copper winding
μ, μ_0	magnetic permeability of the core and air
N	number of turns
P_o	output power

R, R_L	load- and winding resistance
ρ	specific electrical resistivity
S_{Cu}	cross-section of the copper wire
U_d, U_o	input- and output voltage
ΔU_o	output voltage ripple

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