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Andrej PREDIN

Zelena energetika?

V kolikor želimo naš planet ohraniti naslednjim generacijam takšen, da jim bo omogočal izkusiti življenje v naravnem okolju na podoben način, kot smo ga doživljali mi, je odgovor na naslovno vprašanje zagotovo pritrdilen. Žal je področje energetike, kot gospodarska panoga, ena najbolj okoljsko obremenjujočih panog, ki neposredno in posredno izredno vpliva na okolje. Neposredno pri sami proizvodnji električne energije, posredno pa pri potratnem izkoriščanju praktično vseh energetskih in surovinskih virov in neučinkoviti uporabi energije. Učinkovita raba energetskih virov šele v zadnjem času zares pridobiva na pomenu, kot eden od neposrednih ukrepov zmanjšanja onesnaževanja okolja, predvsem pri nižanju izpustov toplogrednih in drugih plinov ter prašnih delcev v okolje. Izpusti ogljikovega dioksida in druge emisije izjemno vplivajo na podnebne spremembe tako globalno kot lokalno.

V tej številki JET-a so zbrani strokovni prispevki s področja ekologije, fotovoltaike in možnosti koriščenja obnovljivih energetskih virov ter znanstveni prispevek s področja analize trdnih delcev v vodi in njihov vpliv na vzgonsko silo profilirane lopatice v kavitacijskem tunelu.

Obnovljivi energetski viri so ključnega pomena pri zagotavljanju nižjih izpustov. Za trajno stabilnost oskrbe Republike Slovenije z električno energijo je nujno potreben trajen in stabilen energetski vir, kot je na primer jedrska elektrarna, ki ob normalnem obratovanju nima nobenih toplogrednih plinskih izpustov in praktično nobenega vpliva na okolje.

Green energy technology?

If we want to preserve our planet for future generations, allowing them to experience life in the natural environment as we did, the response to the title question is certainly positive. Unfortunately, the energy production is one of the most environmentally burdensome industries, with extraordinary impact on the environment, directly and indirectly – directly with the electricity production and indirectly with wasteful exploitation of resources, accompanied by the inefficient use of the energy. The efficient use of energy resources has just recently become an issue and is gaining importance as a means of directly reducing environmental pollution, particularly in reducing greenhouse emissions, other gases and dust particles in the environment. Emissions of carbon dioxide and other emissions are recognised as having an exceptional impact on climate change, both globally and locally.

In this issue of JET, the published professional contributions come from the fields of ecology, solar and renewable energy sources and the scientific contribution from the field of the analysis of solid particles in water and their impact on the profiled blade lift force in a cavitation tunnel.

Renewable energy sources are crucial in our efforts to enable lower emissions. For a permanent and stabile energy supply in the Republic of Slovenia, the electricity source needed is sustained and stable, such as a nuclear power plant, i.e. one with no greenhouse gas emissions and no impact on the environment during its normal operation regime.

Krško, May 2010

Andrej PREDIN

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PROJECTIONS AND DEVELOPMENT PROJECTION OF PHOTOVOLTAICS IN SOLAR-POWERED ELECTRICITY GENERATION

PROJEKCIJE IN RAZVOJNI POTENCIAL FOTOVOLTAIKE PRI PRIDOBIVANJU ELEKTRIČNE ENERGIJE IZ SONCA

Vladimir Malenković[ℜ], Uroš Merc[ℜ], Evgen Dervarič[ℜ]

Keywords: photovoltaics, photovoltaic module, solar photovoltaic power plants, environmental care, energy source.

Abstract

One of the most serious issues of modern society is the question of the strategic energy potential of individual electricity sources, which should combine accessibility, reliability, technological acceptability and, above all, acceptability with regards to sustainable environment development. In the light of increasingly pressing climate changes, a modern electricity source should comply with the most current economic, social and natural norms. Photovoltaics are considered to be one of the fastest developing global economic industries. The sun, being by far the largest renewable (inexhaustible, actually) energy source, has potential unlike any other energy source. From the historical point of view, we are approaching the end of an era that has been marked with an exceptionally short but extremely intense use of fossil fuels. The period ahead of us is bringing us back to nature, with technological development facilitating that return. Photovoltaics are considered to be the most acceptable renewable energy sources, distinct in their modularity, dispersion, robust design, silent operation, environmental

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[ℜ] dr. Vladimir Malenković, HSE-Holding Slovenske elektrarne, d.o.o., Koprska ulica 92, 1000 Ljubljana, tel: +38614704110, vladimir.malenkovic@hse.si

[ℜ] dr. Uroš Merc, Bisol, d.o.o., Latkova vas 59a, 3312 Prebold; tel. +38641918806, uros.merc@bisol.si

[ℜ] doc. dr. Evgen Dervarič, University of Ljubljana-Faculty of Natural Sciences and Engineering, Aškerčeva 12, 1000 Ljubljana, tel. +38641650575, evgen.dervaric@ntf.uni-lj.si

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soundness and price competitiveness. Europe's objective is to ensure a 12 % share of electricity generated from solar energy by the year 2020.

Povzetek

Eno izmed najpogosteje zastavljenih vprašanj sodobne družbe se nanaša na strateški energetski potencial posameznih elektroenergetskih virov, ki morajo združevati tako njihovo dostopnost, zanesljivost, tehnološko sprejemljivost in predvsem sprejemljivost z vidika trajnostnega razvoja okolja. V luči vse bolj perečih podnebnih sprememb mora sodoben elektroenergetski vir zadostovati najsodobnejšim normam ekonomskega, družbenega ter socialnega okolja človeka in narave. Fotovoltaika velja za eno izmed najhitreje razvijajočih se svetovnogospodarskih panog. Sonce, kot daleč največji, obnovljiv ter za človeka neomejen energetski vir, predstavlja potencial, kakršnega nima noben drug energetski vir. Obdobje, katerega koncu se nezadržno približujemo, je zgodovinsko gledano zaznamovano z izjemno kratko, a hkrati izjemno intenzivno rabo fosilnih goriv. Obdobje, ki je pred nami, nas vrača nazaj k naravi, vrnitev pa omogoča tehnološki razvoj. Fotovoltaika velja za najbolj sprejemljiv obnovljivi vir, ki ga odlikuje njegova modularnost, razpršenost, robustnost, neslišnost delovanja, ekološkost ter cenovna konkurenčnost. Kot visokotehnološki vir je sonce znatno po svojem deležu in potencialu. Cilj Evrope je do leta 2020 zagotoviti 12 % električne energije iz sonca v celotnem naboru električne energije.

1 INTRODUCTION

In the first half of the 21st century, civilization is rapidly approaching a decline of the period of fossil fuels and oil domination. The oil price in the global market is increasing rapidly (with the exception of the recessionary period) and a decrease of its quantities can be expected in the next few years. At the same time, the burning of fossil fuels drastically increases carbon dioxide emissions and the atmospheric temperatures, severely endangering the change of the planet's chemical composition and global climate, and bringing fatal consequences to the future of human civilisation and the planet's ecosystem. The world needs a new, strong economic stimulation that will give a fresh impetus to discussions on climate change and oil reserve shortages, and turn economic limitations into new economic opportunities. These goals are now being realised as various industries around the world are laying the groundwork for a post-carbon third industrial revolution.

In the light of the report by the leading American climatologist James Hansen, the director of NASA’s Goddard Institute for Space Studies, a large demand for new and modified economic visions is very much present. Hansen and his colleagues claim that the goal of EU (which is considered to be the most environmentally conscious and ambitious governing body) should be to reduce CO_2 emissions to 350 ppm, if humanity wishes to preserve the planet in a condition similar to the one that enabled the development of civilisation and to which the life on Earth has adapted. New discoveries based on samples collected from the ocean floor show that if the CO_2 level rises to 550 ppm, the planet's temperature will rise by 6° C, which is different from the estimated temperature growth rate for the end of the century amounting to 3° C, representing catastrophic consequences for life on Earth.

A solution for Europe and the rest of the world lies in an unbeatable new combination of social and economic vision. The third industrial revolution provides a framework for the birth of a new social world in the first half of the 21st century. Just as the widespread information technologies and internet communication have had a revolutionary impact on changes in social context and economic parameters of business operations in modern society, a revolution of widespread production of energy from renewable sources will have a major impact on Europe and the world.

The same planning methods and smart technologies that enabled the development of internet and widespread global communication connections are currently being used in the transformation of global energy grids. Individual grid users can produce electricity from renewable sources and share it (in the same way as information) with other grid users, thus commonly creating a new method of decentralised, widespread electricity generation and consumption. We need to realise the vision of connecting millions of individuals producing energy locally, in their homes, offices, factories and vehicles, storing it in form of hydrogen and sharing it with other users through a “smart electricity grid” throughout Europe and the entire world. There is a frequently asked question as to whether the renewable energy sources can, in the long run, provide sufficient energy for the operation of a national or global economy. Just as the new generation of system technologies of information grids enables the operation of several thousands of interconnected desktop computers, which generate much greater widespread computing power compared to the largest central computer, millions of local producers of energy from renewable sources with access to “smart grids” can potentially produce and share much more electricity compared to obsolete centralised forms of electricity generation from oil, coal, natural gas or nuclear technology, upon which we are currently all dependent.

2 SOLAR POWER PLANTS

2.1 Construction of solar power plants

The basic elements of solar photovoltaic power plants consist of two segments. The first segment, comprising solar photovoltaic modules, represents the central element of every solar power plant, and whose role is to convert solar electromagnetic radiation into direct current and voltage. The second segment consists of electrical elements used in the utilisation of the generated electricity for several purposes. They include inverters, load-bearing construction, connection cables, DC and AC junction points, regulators, accumulators, switch and protection devices and other installation materials. A cross-section of the construction of a solar photovoltaic module with crystalline silicon solar cells is shown in Figure 1.

A solar photovoltaic module is built of solar cells enclosed from all sides with special EVA (Ethylene-Vinyl-Acetate) foil for impermeable encapsulation of the cells between a layer of TPT (Tedlar-Polyester-Tedlar) foil at the back side of the module and glass at the front side of the module. The TPT foil provides electrical and mechanical protection, and highly permeable tempered glass offers high resistance to mechanical shock, including hail, and simultaneously provides high light permeability, thus enhancing the efficiency rate of solar cells.

One of the most important properties of photovoltaic modules is their long operating life, ensuring long-term return on investment in a solar power plant. The operating life guaranteed by high quality manufacturers of photovoltaic modules is 25 years, and the first commercially

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manufactured modules have been in service for over 40 years. Due to the reliability of operation that has been well tested in practice, and the general cost effectiveness of the crystalline silicon photovoltaic module technology, the technology will continue to occupy the leading position among photovoltaic technologies for at least 20 years.

Other technologies, such as thin-film and other new generation technologies will remain as complementary products and are not likely to replace the crystalline silicon technology for the next few decades. There is a general assumption that by the year 2030, over 40 % of the entire technological share of photovoltaics will still be represented by the technology that currently has a 95 % share. Despite the fact that the price of thin-film modules is expected to be lower than crystalline silicon solar cell modules in the year 2030 (€0,71 per Wp compared to €0,95 per Wp), the production price per kWh in case of crystalline silicon will still remain below the price per kWh of electricity generated by thin-film technologies. According to forecasts, the price in case of crystalline silicon technology will, by the year 2030, decrease to values between €0,10 and €0,16 per kWh, and in case of thin-film technologies the price will range from €0,11 to €0,16 per kWh.

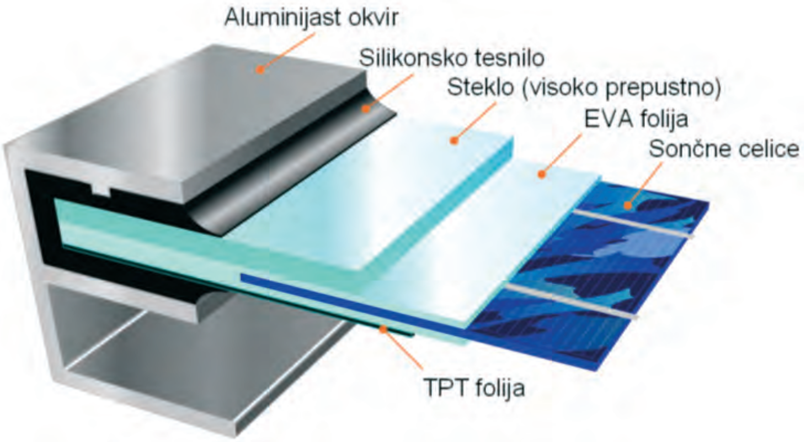


Figure 1: *Cross-section of the construction of a crystalline silicon photovoltaic module*

The main characteristics of high quality crystalline silicon photovoltaic module include:

- outstanding long-term performance,
- high voltage operation(1.000 V_{DC}),
- 5-year product warranty,
- 12-year warranty on 90 % power output,
- 25-year warranty on 80 % power output,
- Certificate IEC 61215: Ed. 2,
- Certificate IEC 61730,
- heavy load up to 5.400 Pa,
- the lowest possible NOCT (Nominal Operating Cell Temperature) value (merely 44° C) – excellent for southern countries and tracking systems,
- pre-sorting according to P_{MPP} and $I_{MPP.}$

Figures 2 and 3 show two state-of-the-art concepts of constructing the solar photovoltaic power plants which are considered to be aesthetically acceptable and require practically no maintenance for their operation.

Figure 2: *Protocol and congress centre in Brdo pri Kranju with a 43 kWp solar power plant*

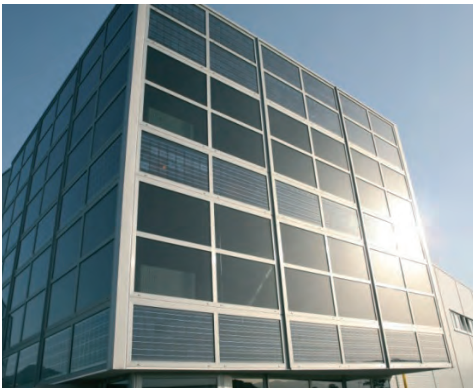


Figure 3: *The facade of the headquarters of the company BISOL, d.o.o. - the first facade in Slovenia with built-in photovoltaic modules*

2.2 Compliance of solar power stations with the requirements of the state-of-the-art energy sources

In order to comply with the requirements of the most modern energy sources, an individual energy source must meet the standards of the society which has a responsibility to encourage technological progress and encouragement of its further development. The aspects according to which we try to evaluate the suitability of an individual energy source include the following: the reproducibility of the energy source, the potential of its use, ecological acceptability, accessibility, reliability, the type of the technology used, dispersion, aesthetics, modularity, robust design, the complexity of its maintenance, the manner of operation and price competitiveness. Regarding the above criteria, let us attempt to evaluate solar power plants as the most modern electricity sources.

Solar power plants use the energy of the sun, which is the main power energy source on Earth. Due to its consistent presence and inexhaustibility, the sun is the primary renewable energy source. The solar radiation available on the Earth exceeds the total primary energy needs of civilization by 8.000 times. In other words, every hour the sun sends to the Earth the amount of energy used by humanity in one year. The sun's potential substantially exceeds the total energy needs of humanity.

From the ecological point of view, solar power plants are considered to be clean and environmentally sound, without causing any greenhouse and other gas emissions. For example, an annual production of a 1 MWp solar power plant is 1,1 GWh of electricity, which is an equivalent of consumption in 320 average Slovene households. Compared to electricity production from lignite, a 1 MWp solar power plant in Slovenia would mean saving of 1.100 tonnes of CO_2 every year of its operation. At the same time, it is an annual saving of 580 tonne of lignite, totalling over 11.000 tonne of lignite in 20 years of operation. Such a reduction in CO_2 discharge is the equivalent to 1.200 newly planted trees. The operation of solar power plants is safe and environmentally sound.

The sun is an accessible energy source all across the Earth, which is of exceptional importance in decisive strategic geopolitical issues in which energy industry is considered to be one of the most important strategic commons of the human race.

Regarding operational reliability, the sun has a double role. If a disadvantage lies in the fact that the sun shines only during daytime and that solar power plants produce less electricity in times of bad weather, it is extremely important that sooner or later, the sun will shine again. By using modern methods of meteorological forecasting and with the development of electricity storage systems providing longer periods of autonomous operation for users, solar power plants can, together with other complementary energy sources, be exceptionally successful in providing unhindered and reliable energy supply.

Solar power plants are a highly technological product with high added value, creating high quality jobs. Photovoltaic modules are a product of state-of-the-art semiconductor technologies which have, in striving for reductions in production costs, been a subject of high level research and development activities.

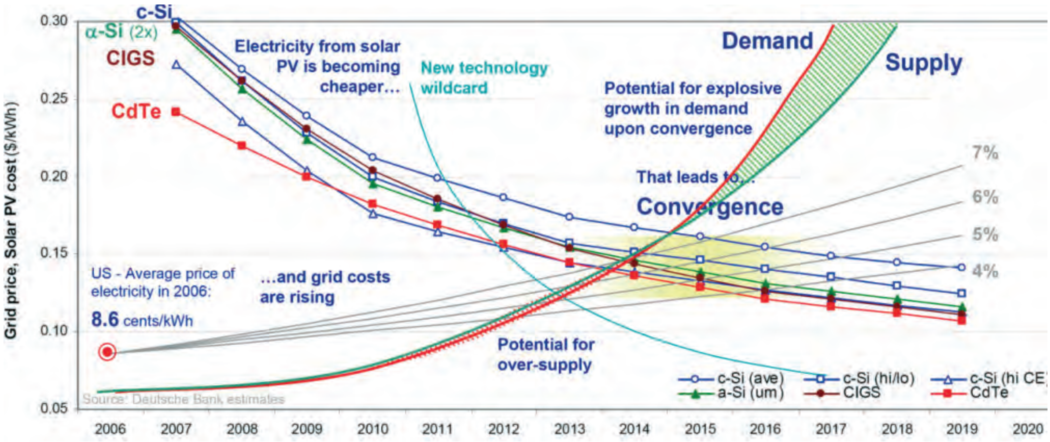
Being aesthetically acceptable, green and renewable energy sources, solar power plants can, thanks to their modular design, be used for the construction of solar power plants with the production ranging from a few milli- to several megawatts. This facilitates their spread, which crucially influences the reduction of losses in the electrical grid and provides energy autonomy and independence of solar power plant users.

In essence, solar power plants are exceptionally robust energy sources. They can be used in a wide temperature spectrum, ranging from –60° C and lower to over 90° C. In the highest quality products, the tested mechanical load of photovoltaic modules reaches up to 5.400 Pa and facilitates the use of modules in the regions with large quantities of snow. The modules have also been tested and certified for hail impact resistance. The exceptionally robust design of photovoltaic modules minimises the need for maintenance, and the operation of solar power plants is extremely reliable and entirely silent.

Consequently, it can be established that, (with an exception of price competitiveness mentioned previously) solar power plants are considered to be the most promising modern energy source. Questions regarding the often alleged high production costs remain, however. As the calculations in this paper will show more accurately, photovoltaics are already at the threshold of competitiveness.

2.3 Photovoltaics at the threshold of price competitiveness

In evaluating the price competitiveness of solar power plants, one should keep in mind that photovoltaics is a sector that has only recently moved from the laboratory to mass industry and, as it is the case with all other commercially competitive sectors, a certain amount of time is necessary for the technology to improve, develop and reach the necessary economy of scale. However, attention should be brought to the fact that numerous currently commercial technologies still receive numerous supports, e.g. non-reimbursable stimulation to develop the activities of utilisation of coal or nuclear energy, ranging from direct state guarantees, soft loans to other various direct and indirect non-reimbursable funds. It should be noted that the cost of adverse impact on the environment is not taken into account at all when calculating the production costs for electricity production from conventional, environmentally unfriendly technologies, and its adverse impact on the environment is not settled in any way. Initial stimulations in the development of photovoltaics are important because it is a revolutionary technology with the highest technological and commercial potential and will become competitive to conventional energy sources in a matter of few years. With every doubling of global production, the price of photovoltaic modules is reduced by 20 %. In the current growth of the sector, this means that the production price of electricity production from the sun decreases by 7 % to 9 % every year, which is the very factor that propels the competitiveness of photovoltaics.



Source: Deutsche Bank estimates

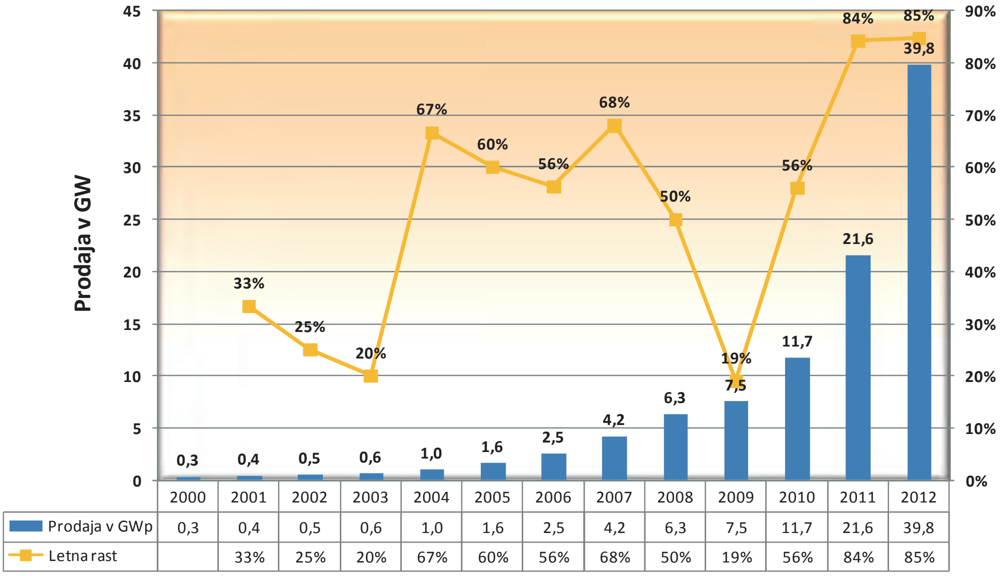
***Figure 4:** The relation of grid price of electricity and production costs of photovoltaics*

Today, photovoltaics are already at the threshold of price competitiveness. The analysis of Deutsche Bank recently showed, in the case of Germany (Figure 4) that with standard decreases in the prices of electricity generated from the sun and with constant increases in the costs of grid electricity generated from conventional energy sources, photovoltaics will reach the break-even point and convergence by the year 2014 at the latest. However, based on future expectations regarding the relation of supply and demand, numerous industrial analysts expect the break-even point to be reached even before the year 2012.

To provide reliable and rapid development of price competitiveness of such an electricity source and thus an integrated implementation of photovoltaics into human daily life, non-reimbursable stimulations are still necessary, but limited to an extremely short time period. It will take only a few more years to facilitate the development of the most potential electricity source in terms of price, with a long-term potential of merely € 0,04 per kWh.

2.4 Factors of production cost reduction

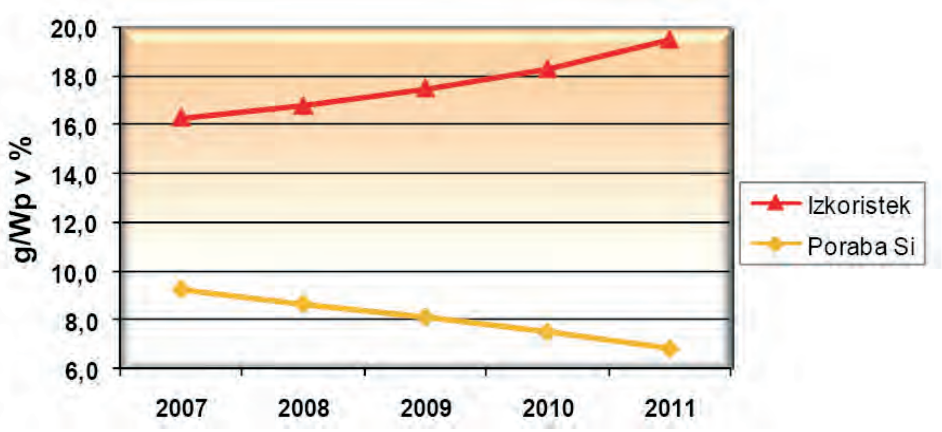
The photovoltaic industry is in full bloom. By the end of the year 2007, global cumulative installed capacity of photovoltaic systems amounted to more than 9.200 MW; at the end of the year 2000, only 1.200 MW had been installed. The growth of the solar electricity industry has been so strong that its current value already exceeds €13 billion every year. Clear commercial and political commitments to support the expansion of photovoltaics indicate that all current activities of the photovoltaic sector clearly forecast a mass transformation and expansion of the sector in the future. The goal that the photovoltaic industry strives to achieve is the realisation of common efforts for a significant increase in share of solar electricity in the global electricity mix and a simultaneous reduction of greenhouse gas emissions. Figure 5 illustrates the growth of the photovoltaics sector between the years 2000 and 2008, and predicts an upward trend of the sector to the year 2012. Between the years 2000 and 2008, the average annual growth rate of photovoltaics amounted to 46 %, and the expected annual growth rate from 2008 to 2012 amounts to no less than 59 %, meaning that considering the predictions, the average annual growth rate of the sector between the years 2000 and 2012 would amount to 50 %.



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Prodaja v GWp	0,3	0,4	0,5	0,6	1,0	1,6	2,5	4,2	6,3	7,5	11,7	21,6	39,8
Letna rast		33%	25%	20%	67%	60%	56%	68%	50%	19%	56%	84%	85%

Figure 5: *Growth in global sales of photovoltaic modules by year*

Beside the economy of scale as the most important production cost reduction factor, technological improvements lead photovoltaics on the way to price competitiveness in relation to conventional energy sources. In the technological point of view, the most essential cost factors are the amount of material used for the production of 1 watt of power (by solar cells becoming thinner, the amount of used material is being reduced) and the increasing factor of solar cell conversion efficiency. Both parameters, by year of development, are shown in Figure 6. With a successful combination of all cost potentials, the possible rate of production cost reduction by the year 2012 amounts to over 60 % of current costs. In this amount, 25 % of cost reduction is to be facilitated by cost reduction at the level of planning and construction of the photovoltaic system, 10 % by reducing production costs at the level of production of solar cells and photovoltaic modules, 10 % at the level of silicon production, and the remaining 15 % resulting from an increased efficiency rate of solar cells by a few percentage points.



Leto	2007	2008	2009	2010	2011
Debelina celic	180 μm	170 μm	160 μm	150 μm	120 μm

Figure 6: *Reduction of material required to produce one watt of solar cell power and the factor of solar cell conversion efficiency*

2.5 Photovoltaics' market potential by the year 2020

When studying the price competitiveness of solar power plants in comparison with conventional electricity sources, an analysis should be done in the light of the diagram shown in Figure 4. With the constant growth of prices of conventional electricity resulting from the decline of non-renewable resource reserves and from the constant growth of electricity consumption, and with the constant decrease of production costs of electricity production from the sun, it is possible to recognise breaks points of solar power plant competitiveness in individual markets and thus determine the size of the end market for photovoltaics regarding commercial segment and region. Knowing the general market limitations regarding commercial acceptability, general grid limitations and known demands for substitute capacities of the existing production capacities, one can define new industry goals for photovoltaics, determining the share of electricity generated from the sun and the share of solar power plants in the total amount of newly constructed production capacities for electricity production.

Considering the predicted long-term upward trends of conventional electricity prices and an annual 8 % decrease of production costs in solar power cells, which is also considered by the German legislation to promote the development of photovoltaics, it possible that by the year 2020, photovoltaics will, in the European electricity market amounting to 3.446 TWh, represent a direct competitiveness in the amount of 3.133 TWh, equalling more than 90 % of the entire European market, including northern countries such as Great Britain as well as Scandinavia.
In absolute terms, no less than 66 % of electricity is used during the light part of the day, which determines the upper level of power plants' usefulness in providing electricity supply. Due to increased electricity consumption, 40 % of electricity production capacities will have to be replaced or additionally constructed in Europe by the year 2020. The goal of photovoltaics is to cover 12 % of electricity demand in Europe by the year 2020 despite the electrical grid limitations, which is already commercially feasible with currently available technology. With additional implementation of advanced electricity storage systems and the development of advanced smart energy grids, the potential of photovoltaics may be even greater. Nevertheless, a 12 % share of photovoltaics in the entire electricity production would represent a 25 % share of all investments in the production capacities by the year 2020, which would make photovoltaics the main new source of electricity in Europe, annually producing 420 TWh of electricity from the sun; the total capacity of installed power plants would amount to 350 GWp. Altogether, it would mean a 40 % average annual growth of the sector by the year 2020, by taking into account that in the year 2007, a total amount of 4,5 GWp of solar power plants were installed in Europe and that 1 GWp of installer power generates 1,2 TWh of electricity.

The assumptions stated in the set ambitious goals are very realistic and are based on meeting certain preconditions. By accomplishing the goals, photovoltaics may become the main source of electricity in Europe; however, it will require substantial industrial support and political will collaborating closely and striving for the common goal. The explicit task of the industry is to continue its efforts to reduce production costs, to encourage innovation and technological development, to invest in production capacities, research and development, and to educate new highly qualified human resources. The tasks of politicians are to provide, with appropriate legislation, support for development in the period prior to competitiveness, to promote public consciousness, to arrange regulatory conditions such as grid access and price competitiveness, and to cooperate with the industry in investments in education, research and development. The positive effects of close cooperation provide the following:

- a leading position of European photovoltaic industry in the world,
- 2 million new workplaces in production, assembly and maintenance
- greater energy independence and security of energy supply in Europe,
- environmentally sound electricity for over a billion of people all over the world,
- 900 million tons of saved CO_2 emissions all over the world (1,6 million tons of CO_2 savings planned by the year 2030, equalling the CO_2 emissions of 450 coal fired thermal power plants,
- slowdown of environmental changes,
- slower increase in prices of conventional energy sources.

An investment in a solar photovoltaic power plant from mid-2009 in Slovenia, without considering state supports and with the presumed discount rate, will return the net of the current value of 6,5 % only after 39 years. The calculation also takes into account that in such period, spent inverters must be replaced with new ones twice, a 0,5 % annual degradation of a solar power plant and, due to security factors, a replacement of 50 % of the entire solar power plant after 25 years of its operation, although current solar power plants have been operating for 40 and more years. In the calculation, the relation of foreign sources and own capital has been taken into account, in a 70:30 ratio at a 6 % interest rate for a 15-year period. The maintenance and insurance costs have been estimated at an annual amount of 0,7 % of the investment's initial value with a 2 % annual cost growth rate. The market price of green electricity on the free market has been presumed at €0,110 per kWh and is increasing at a 7 % annual growth rate. The main disadvantage of such investments is that the investment is not liquid for the first 14 years, so the payment of obligations required borrowing. Therefore, an investment without state support is currently not yet rational and efficient.

Figure 7 shows an example calculation of the profitability of investment in solar power plants in Slovenia in the year 2012, considering the presumed decrease in costs and prices of solar power plants. The calculation (excluding state supports) shows that the net present value (NPV) of the investment with a 6,5 % discount rate will be positive after 15 years of operation. The internal rate of return (IRR) per period exceeding 30 years amounts to more than 15 %. All other calculation parameters used are equal to those presumed in the previous paragraph, only the original market price of electricity amounts to € 0,135 per kWh, which is equivalent to 7 % annual price growth rate from the year 2009. The investment is liquid and provides covering financing obligations and other costs directly from the profit of the solar power plant's operation. The profitability calculation shows very clearly that in Slovenia the price of electricity generated from the sun might become competitive to market prices of conventional energy sources by the year 2012, without ensured redemption prices or other state supports. The latter actually reflects the true price competitiveness to conventional electricity sources.

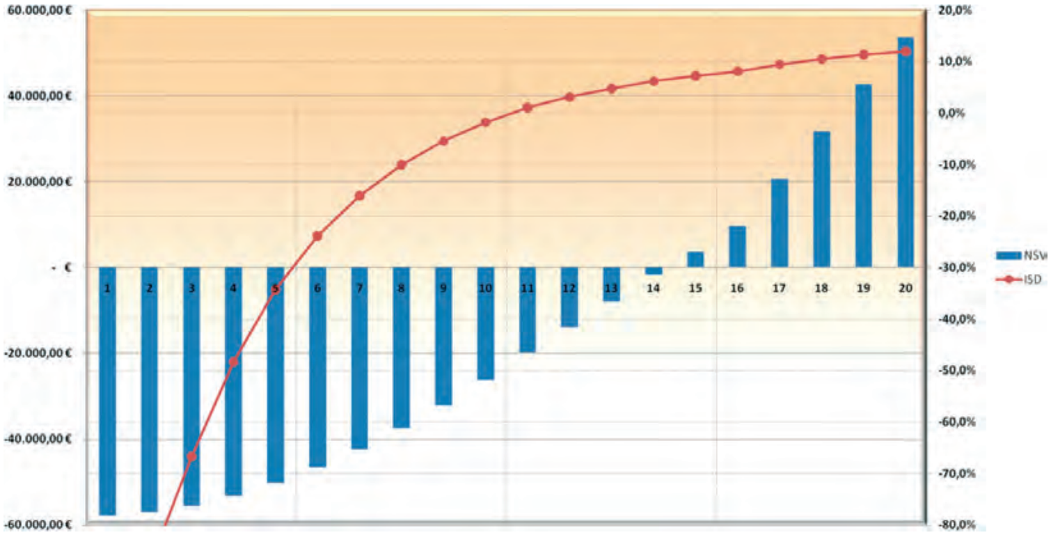


Figure 7: *An example calculation of 20-year profitability of an investment into a 100-kWp solar power energy in Slovenia in 2012, to set an example without state supports*

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3 CONCLUSION

Climate change and declining reserves of fossil fuels enhance the concern for global warming and strengthen the efforts to achieve energy independence. Together with increasing prices of fossil fuels, they are a strong motivation for the efficient and immediate use of renewable energy sources. The sun represents the most promising and an unlimited means of using renewable sources. For their numerous features, such as the reproducibility of the energy source, the potential of use, ecological acceptability, accessibility, reliability, the type of the technology used, distribution, aesthetics, modularity, robust design, the complexity of its maintenance and the manner of operation, solar photovoltaic power plants prove to be the most modern electricity source. However, they should fulfil the conditions of price competitiveness, which can be achieved by further enhancing the economy of scale and reducing the production costs. An investment in a solar photovoltaic power plant is a low-risk factor investment and is considered to be a very predictable and acceptable highly profitable investment. The primary goal of photovoltaics is to provide humanity with one of the most basic primary goods: green electricity. The underlying advantages of investing in solar power plants are the following:

- known electricity price in the long term, for the period of 20 years and longer,
- environmentally sound investment,
- positive liquidity of the investment,
- acquisition of new technological and business knowledge,
- new high quality and high technological workplaces,
- investments can be intended for long-term annuity savings scheme providing more secure and financially less dependent future,
- due to reliable long-term profitability of solar power plants guaranteed by state contracts, it is the pension funds that often decide to invest in solar power plants,
- an interesting modern architectural solution from both aesthetic and technological point of view.
- possibility of direct sales of electricity in the market,
- use of a solar power plant long after the expiry of the period of expected profitability.

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ŠALEK VALLEY AND REDUCING THE GHG FOOTPRINT

ŠALEŠKA DOLINA IN ZMANJŠEVANJE OKOLJSKEGA ODTISA

Natalija Špeh[ℜ], Vilma Fece

Keywords: sustainable development evaluation ,ecological footprint, economic indicators, investments, current expenditure, Slovenia, Šalek Valley

Abstract

GHG (greenhouse gas) ecological footprint as a sustainable development indicator is formed by the data connected to management of landscape, materials and energy in the selected landscape unit.

Ecological footprint accounting is a method of sustainable development evaluation, which could be carried out by different models. The ecological footprint evaluation model presents a holistic assessment. It depends on the availability of the indicators and the data which represent the characteristics of the state and the trends of the sustainable evaluation. The relation to the economic development is stressed and performed by the economic indicators in the ecological footprint evaluation of the discussed area.

Šalek Valley is one of the leading Slovene regions regarding the indicators of investments' value and value of current expenditure connected to the environment protection.

The presented ecological footprint model of Šalek Valley is a transparent method also applicable to the smaller landscape units, e.g. communities, settlements, which makes it even more useful. It would be interesting to compare the researched area with the ecological footprint models of the similar landscape-vulnerable areas, which used to be or still are degraded and polluted as the result of the post-Second World War intensive industrialization and urbanization processes; these include the Zasavje region, Meža Valley, Celje basin, and Jesenice area.

[ℜ] Corresponding author: Assist. Prof. Natalija Špeh, Tel.: +386 3 898 6410, Fax: +386 3 898 6413, Mailing address: Environmental Protection College, Trg Mladosti 2, 3320 Velenje, Slovenia, E-mail address: natalija.speh@guest.arnes.si

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Povzetek

Okoljski odtis kot kazalec trajnostnega razvoja predstavimo s podatki, ki se nanašajo na upravljanje s prostorom, snovmi in energijo v izbrani pokrajinski enoti.

Ekološko sledenje je ena od metod vrednotenja trajnostnega razvoja, ki jo lahko izvajamo z različnimi modeli. Zasnova modela ocenjevanja okoljskega odtisa, ki predstavlja celostno (holistično) presojo, je odvisna od razpoložljivosti kazalcev oz. podatkov, s katerimi predstavljamo lastnosti stanja ter smernice trajnostnega (uravnoteženega) in sonaravnega razvoja. Pri vrednotenju okoljskega odtisa izbrane pokrajinske enote s poudarkom na odnosu do gospodarskega razvoja lahko le-tega izražamo z ekonomskimi kazalci.

Šaleška dolina je med tistimi slovenskimi regijami, ki v pozitivnem pomenu izstopajo po kazalcih vrednosti investicij in tekočih izdatkov, namenjenih za varstvo okolja.

Pričujoči primer je ena od možnih interpretacij okoljskega odtisa za območje Šaleške doline, ki je preverljiva oziroma jo je možno aplicirati tudi na manjše pokrajinske enote, npr. lokalne skupnosti, naselja, kar povečuje njeno uporabno vrednost. Zanimiva bi bila primerjava preučevanega območja z okoljskimi odtisi podobnih pokrajinsko ranljivih območij, tj. s posledicami intenzivne industrializacije in urbanizacije v povojnem času preteklega tisočletja obremenjenih pokrajin, kot so Zasavje, Mežiška dolina, Celjska kotlina, širše območje Jesenic.

1 INTRODUCTION

Sustainability indicators provide a roadmap for public policy. An effective set of indicators highlights critical social, economic, and environmental problems and provides a way to measure the effectiveness of programs designed to alleviate these problems. The choice of indicators reflects how a given population defines progress. Traditional indicators – such as gross domestic product (GDP) or corporate profits – reflect a faith in growth and efficiency as the primary mechanisms for improving public welfare, [8].

Since Šalek Valley was thoroughly transformed because of the exploitation of underground lignite, especially in its lower parts, significant efforts have been made to improve and renew the landscape and its sources. We have presented the environmental costs in this paper using the analysis of the quantitative estimations within the method of sustainable indicators. Estimating the Šalek Valley ecological footprint, we perform the investments (indicator A) and the current expenditure (indicator B), regarding the environmental protection. As the starting point, we consider that Šalek Valley has an important share of the the regional environmental costs.

2 LANDSCAPE CAPITAL

Contemporary definitions distinguish between non-renewable and renewable natural sources, the landscape (Haggett 2001) and the ecosystems' services (the nutrient cycles, the balance of gases, climate and water). Thus, the concept of natural sources includes all the environmental sources (Plut, 2004). We can also talk about environmental capital which forms, together with the manmade and human capital, the complexity of landscape structure.

$$LS = EC + \mathrm{MC} + HC \qquad (2.1)$$

Where:

LS=landscape structure; all landscape sources/capitals

EC=environmental capital (biodiversity, water, ground, material goods)

MC=manmade capital (buildings, machines, infrastructure)

HC=human capital (knowledge, skills)

Figure 1: *The complexity of landscape structure (Pearce et al, 1994)*

The non-renewable sources are environmental components that take shape slowly over geological history. When we consider them anthropocentrically (from the aspect of their usefulness to man) we can talk of stock, i.e. quantitatively limited (finite) sources.

The area researched had the mineral raw material lignite naturally present in it. It became a natural source at the end of the 19th century when it was discovered and started to be used in energy production. However, the awareness of the non-renewable characteristics of the underground natural source appeared only recently, when, on a global scale, nature and its sources have been exploited so intensively that the self-purifying capabilities of the ecosystem’s structure have been exceeded. According to Plut (2004), humanity had become a ‘geological power’ and we can already see the catastrophic consequences of natural degradation, because the ecosystem’s benefits (goods and services) have not been considered and evaluated properly. They used to be regarded as self-evidently available and free of charge.

3 ECOLOGICAL FOOTPRINT

Ecological Footprint Accounts enable moving from the sustainability concept to a measurable goal. They compute sustainability in specific and understandable terms by using the best available scientific data. They allow individuals, policy analysts and governments to measure and communicate the economic, environmental and social (distributional and security impacts) of natural resource (capital) use.

A population’s Ecological Footprint presents humanity’s demands on nature and can be compared to the biological capacity (ecological supply or the productive area needed to produce the resources used and absorb the waste generated by the chosen population). When human demands exceed ecological production, the natural capital (assets on which current and future generations depend) declines. The situation is called ‘’overshoot’’ or the “global ecological deficit” (Redefining Progress, 2000).

According to Redefining Progress’ latest footprint analysis, humanity is exceeding its ecological limits by 39%. Or, put another way, we would need to have over one third more than the present biocapacity of Earth to maintain the same level of prosperity for future generations,[5].

Ecological Footprint Accounts also determine the area required to produce the biological resources a country uses and to absorb its wastes, and compare this with the area available. This area is reported in global hectares (global acres), hectares (acres) with world-average productivity, for each year from 1961 through 2005. We intended to place Slovenia on the

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world scale regarding the Ecological Footprint and the Biocapacity indicators with the figures below.

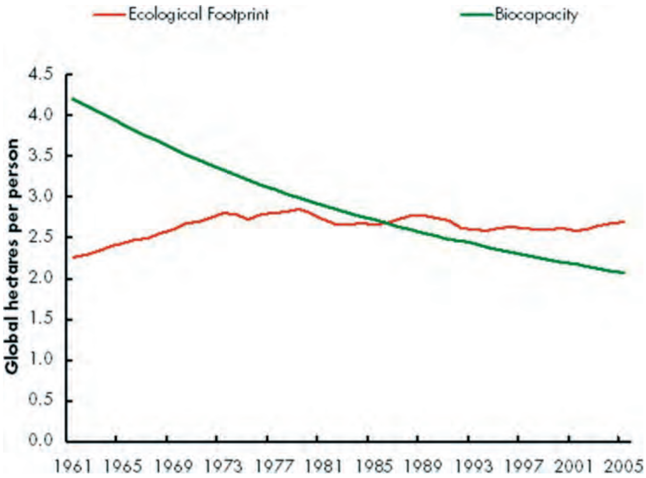

Figure 2: *Tracks, in absolute terms, the average per person resource demand (Ecological Footprint) and per person resource supply (Biocapacity) in the World since 1961[1*]. Biocapacity varies each year with ecosystem management, agricultural practices (such as fertilizer use and irrigation), ecosystem degradation, and weather, [6].*

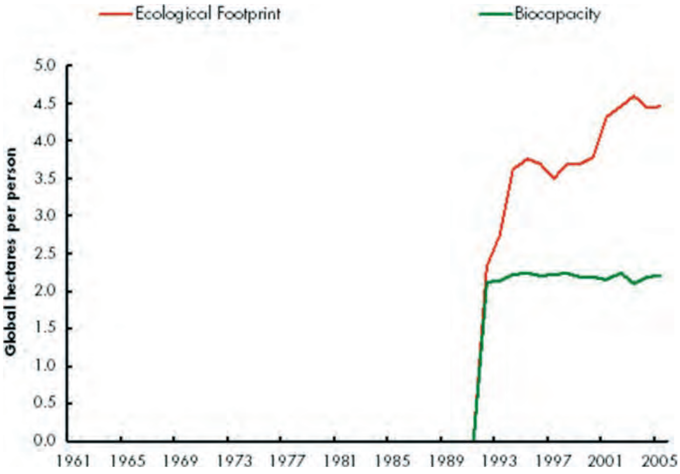

Figure 3: *Tracks, in absolute terms, the average per person resource demand (Ecological Footprint) and per person resource supply (Biocapacity) in Slovenia since 1961*. Biocapacity varies each year with ecosystem management, agricultural practices (such as fertilizer use and irrigation), ecosystem degradation, and weather, [6].*

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[*] Unfortunately, the data for Slovenia enable the comparison of the Figures 2 and 3 only after the 1991 when Slovenia became an independent state. According the red line, which shows Ecological Footprint data, Slovenia with over 4.0 global hectares per person and greatly exceeds the World average of approximately 2.5 global hectares per person. Regarding the indicator of Biocapacity, the wood area must be in favour in Slovenia: the data keep the value of 2.0 global hectares per person in the researched period, whereas the world average has been decreasing from 2.5 in 1991 to 2.0 in 2005; the value was almost 4.5 global hectares per person at the study begin in the year 1961. Figure 4 data offer a further explanation on the Slovene Ecological Footprint changes.

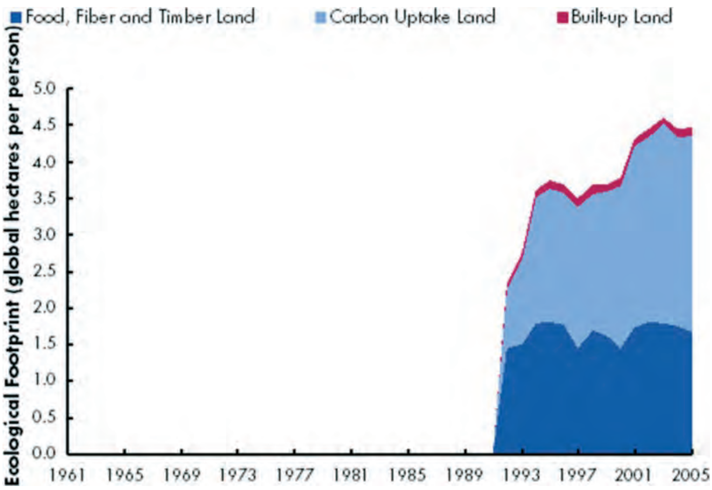

Figure 4: *The components of the average per person Ecological Footprint in Slovenia since 1961*[*].

Table 1: *Basic data about Ecological Footprint and Biocapacity (calculated by Global Footprint Network) and the Human Development Index (calculated by the United Nations Development Programme) in 2005.*

State/data	**Area (mio of ha)**	**Population (mio)**	**Ecological footprint**	**Biocapacity (mio of global ha)**	**Human Development Index**
SLOVENIA	2.0	2.0	8.8	4.3	0.92
AUSTRIA	7.8	8.2	40.8	23.4	0.95
CROATIA	10.0	4.6	14.6	10.0	0.85
USA	995.9	298.2	2.809.7	1.496.4	0.95
SWITZERLAND	3.1	7.3	36.3	9.2	0.96

Source:[6]

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[*] ECOLOGICAL FOOTPRINT uses yields of primary products (from cropland, forest, grazing land and fisheries) to calculate the area necessary to support a given activity.

BIOCAPACITY is measured by calculating the amount of biologically productive land and sea area available to provide the resources a population consumes and to absorb its wastes, given current technology and management practices. Countries differ in the productivity of their ecosystems, and this is reflected in the accounts.

HUMAN DEVELOPMENT INDEX (HDI) combines normalized measures of life expectancy, literacy, educational attainment, and GDP per capita for countries worldwide. It is claimed as a standard means of measuring human development—a concept that, according to the United Nations Development Program (UNDP), refers to the process of widening the options of persons, giving them greater opportunities for education, health care, income, employment, etc. The basic use of HDI is to measure a country's development, [9]. After the data, published annually by the UN, Slovenia belonged to the second best category of HDI and was the 26th ''most liveable'' country in the world in 2006, [5].

The above-performed data of Slovenia and another three European states show almost similar state according the HDI indicator. Croatia is exceptionally low. Checking the Biocapacity and Ecological Footprint indicators, the data shows Slovenia as a much less consuming state compared the others since both values are half of the Croatia values. Austria and Switzerland have almost four times higher Ecological Footprints. The Biocapacity value of Austria is five times higher than Slovene, while Switzerland's Biocapacity indicator was only twice as high as in Slovenia. The United States belong to a quite special category.

4 SLOVENE STATISTICAL REGIONAL INVESTMENTS (INDICATOR A) AND THE CURRENT EXPENDITURE (INDICATOR B) CONCERNING ENVIRONMENTAL PROTECTION

Table 2: *Investments (indicator A) and current expenditures (indicator B) for environmental protection in the Savinja Statistical Region in comparison to other Statistical Regions in Slovenia (Source: [11])*

REGION/ indicator	**A**		**Share**		**B**		**Share**		**Index A**	**Index B**
YEAR	**2001**	**2006**	**2001 (%)**	**2006 (%)**	**2001**	**2006**	**2001 (%)**	**2006 (%)**	**2006/2001**	**2006/2001**
Pomurje	939	23.656	0.5	8.1	3.993	9.439	2.7	2.9	25.2	2.4
Podravje	27.779	40.778	16.1	13.9	11.730	97.672	7.8	29.79	1.5	8.3
Koroška	5.229	19.517	3.0	6.7	7.524	11.576	5.0	3.59	3.7	1.5
Zasavje	3.472	18.415	2.0	6.3	3.138	2.041	2.1	0.69	5.3	0.6
Spodnje Posavska	7.106	5.258	4.1	1.9	24.412	7.073	16.3	2.19	0.7	0.3
Jugovzhodna Slovenija	4.553	8.079	2.6	2.7	11.893	15.573	7.9	4.79	1.8	1.3
Osrednje Slovenska	26.494	58.116	15.3	19.9	31.022	92.785	20.7	28.29	2.2	2.9
Gorenjska	6.664	23.164	3.9	7.9	10.724	16.913	7.2	5.19	3.5	1.6
Notranjsko Kraška	9.205	2.641	5.3	0.9	2.207	3.768	1.51	1.1	0.3	1.7
Goriška	5.746	11.776	3.32	4.0	5.725	11.830	3.8	3.6	2.0	2.0
Obalna	9.902	13.007	5.7	4.4	7.799	11.133	5.2	3.4	1.3	1.4
Savinjska	65.669	67.814	38.0	23.2	29.407	48.752	19.7	14.8	1.0	1.6
Slovenija	**172.767**	**292.222**	**100**	**100**	**149.574**	**328.555**	**100**	**100**	**1.7**	**2.2**

The index of indicator A (Investments for environmental protection) shows the Pomurje region as the prominent region with the value 25.2 in the period 2001/2006. The region of Zasavje follows with an index of 5.3, then the Koroška (3.7) and the Gorenjska (3.5) regions. The lowest index was in the Notranjsko-Kraška (0.7) and the Spodnje Posavska regions (0.3). The average Slovene index value for the same period was 1.7. (Figure 5)

Regarding the index of indicator B for the same period, the highest increase of current expenditures for environmental protection occurred in the Podravska region (index 8.3). The Osrednje Slovenska (2.9) and the Pomurska (2.4) region follow. The lowest index was performed

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in the Zasavska (0.7) and again the Spodnje Posavska region (0.3). The average Slovene index value for the same period was 2.2 (Figure 6).

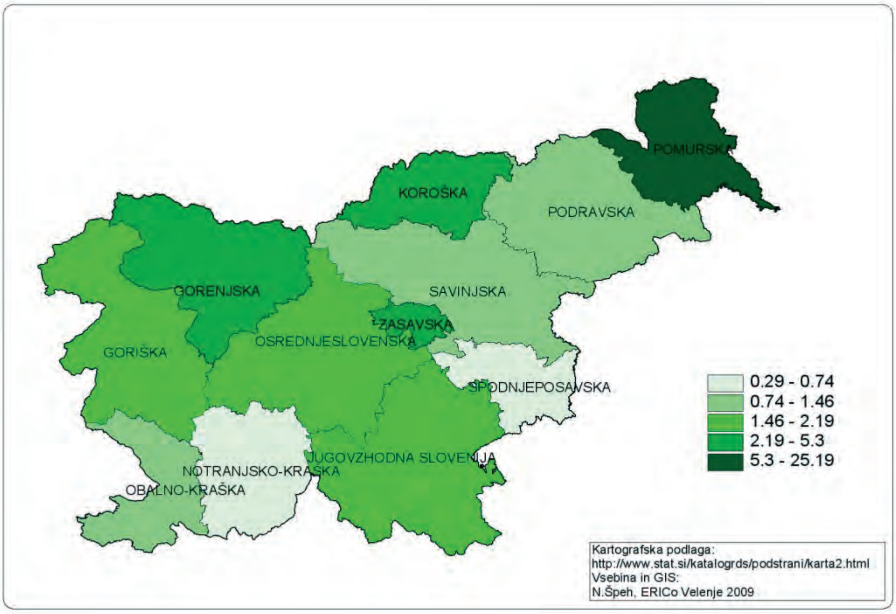

Figure 5: *Slovene statistical regions according to the index of indicator A (investments in environmental protection)*

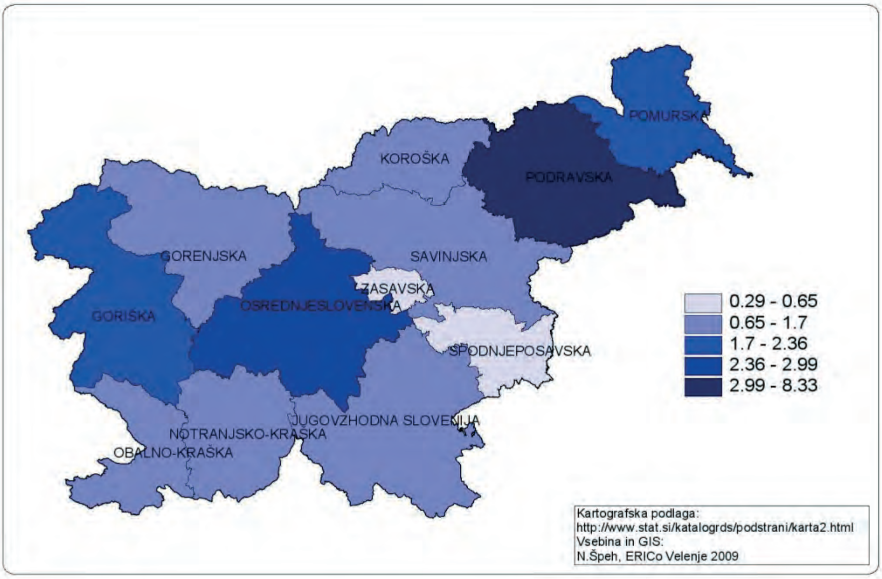

Figure 6: *Slovene statistical regions according to the index of indicator B (current expenditure for environmental protection)*

5 THE ŠALEK VALLEY SHARE IN THE SAVINJA STATISTICAL REGION

Discussing the investments for the environmental protection (indicator A), the share of Šalek Valley in the Savinja Statistical Region was the lowest in 2004 (8,4%). However, the value has significantly increased in the last year of the study period with 31.4% of the total investments in the region. Otherwise, the average share in the period studied was 20%.

Table 3: *The share (in %) of investments (indicator A) and the current expenditure (indicator B) for the environmental protection of the Šalek Valley in comparison to the total expenditure of Savinja Statistical Region*

Indicator/year	2001	2002	2003	2004	2005	2006
A	26.0	14.1	22.1	8.4	19.0	31.4
B	34.7	30.1	43.9	38.2	36.5	33.8

(Source: Statistical Office of the Republic of Slovenije, 2009)

Concerning the indicator of current expenditure (indicator B) in the studied period, the average share of the Šalek Valley was around 33% of the total current expenditure for the environmental protection in the Savinja Statistical Region. The share was extremely high in 2003 (43.9%), but the lowest one never decreased below 30%.

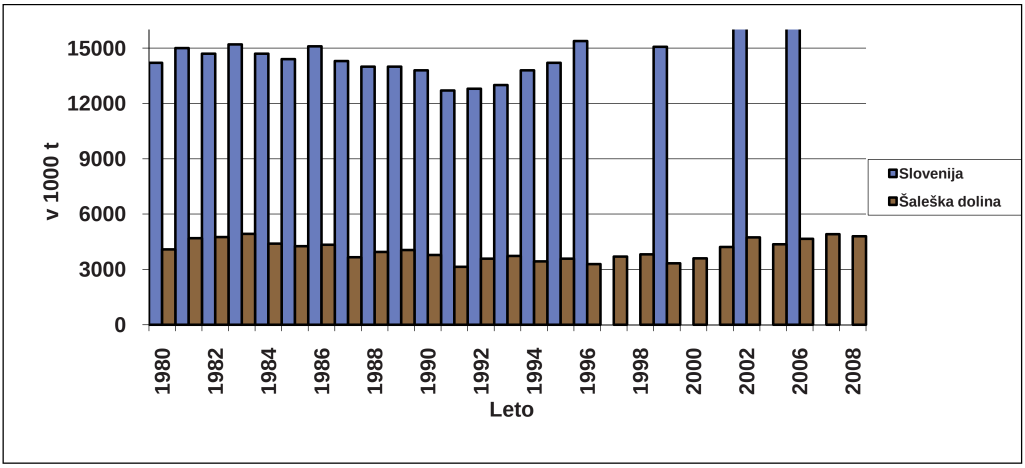

Figure 7: *CO_2 emissions in Slovenia and the Šalek Valley in the period 1980-2006*
(Source: Bilteš, [9]*)*

The emitted value of carbon dioxide in the Šalek Valley in 1990 was 3,782,023 tonnes or 94,551 kg per capita. In the same year, the Slovene average value was 6,800 kg, and European one was 9216 kg per capita (Rode, Šušteršič, 1997). In 2008, Šalek Valley had still very high value of around 120,000 kg per capita.

Table 4: *Some actions in Šalek Valley towards regional ecological (carbon) footprint reducing*

ACTOR	ACTIVITY
Velenje Coal Mine	PROGRAMME FOR HANDLING WITH GHG: Mine gases in the process of coal exploitation, Origin, transport and accumulation of carbon gases in the Velenje basin, Researching of the Velenje lignite saturated with CO_2 and regarding various stress states, CO_2 in CH_4 drainage and utilization.
Šoštanj Thermal Power Plant	Building gas turbines, Design of system for CO_2 capturing at origin
ERICo Environmental Research and Industrial Cooperation	Measurements of the air emissions at the TPP and other companies (ash, air flux, temperature and moisture) Researching the concentrations and possibilities of the Velenje Coal Mine gas use
Holding of Slovene Power Stations	Emissions' trading Adaptation of Slovene energy production activities to the EU Climate-Enegy Packet demands
Velenje Community	Ecological internet system (EIS), Public Urban Traffic Project (In partnership with Institute for Remote Heating, ESOTECH, d.d., Public Utilities Company Velenje) Central Energy Station Velenje, Remote Cooling in Velenje Community. (In partnership with Energy Agency of Savinja, Šalek and Koroška Region) Streetlight in Velenje Community
GORENJE d.d.	Implementation of BAT (IPPC commitment) Energy Review made CECED Energy reduced household appliances (A, A+ and A++ class)

(Source: Mine Green-House Gases CO_2 in CH_4, Mine Safety, Prevention, Managing and Utilization, International Workshop, Velenje, 2008; Bilteš 2007, Annual Report TEŠ, [11])

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6 CONCLUSIONS

GHG emissions increased by 0.6% in 2006, over 2005. According to the Environmental Agency of the Republic of Slovenia data, there were 20.591 mio of tonnes emitted (in CO_2 Gg equivalents) in Slovenia in the 2006. That means 1.2% emissions more than in the base year. The most are in the energy production sector, which includes fossil fuels consumption. Together with manufacturing, construction, transport and other sectors, this area contributed 81% of all emissions and was followed by agriculture at 10%, industrial processes at 6% and waste at 3%.

***Table 5**: Total greenhouse gas emissions, Slovenia, 2006*

CO_2 (Gg) equivalent	1986[1)]	2002	2003	2004	2005	2006
Total deductions	18.751	14.541	14.455	14.449	15.037	15.858
Total no deductions	20.340	20.037	19.773	20.092	20.468	20.591
CO_2 reductions	14.704	10.764	10.742	10.784	11.329	12.145
CO_2 reductions without	16.294	16.259	16.061	16.427	16.759	16.878
Methane CH_4	2.384	2.257	2.212	2.186	2.191	2.158
Nitrous oxide N_2O	1.376	1.336	1.299	1.261	1.280	1.309
Partly hydrofluorocarbons HFCs	-	50	64	80	96	112
Complete hydrofluorocarbons PFCs	276	116	119	120	124	116
Sulphur hexafluoride SF_6	10	17	18	18	19	19

-no occurence
1)the base year
Source: Environmental Agency of the Republic of Slovenia

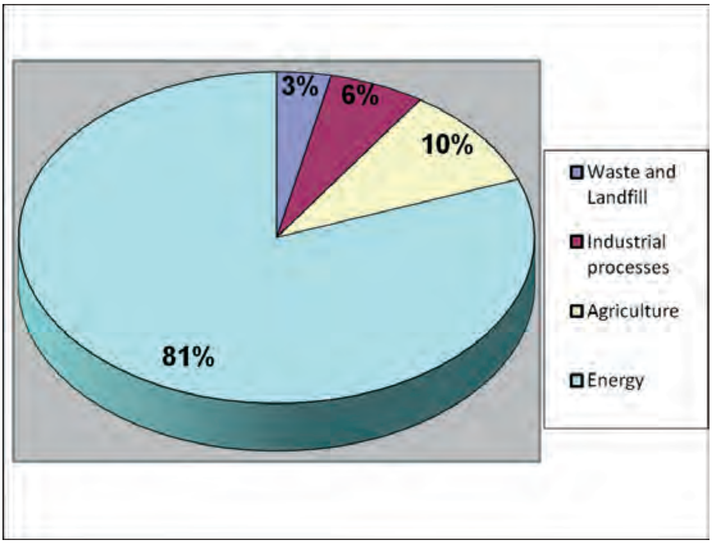

***Figure 8:** Greenhouse gas emissions by source, Slovenia, 2006 (Total 20,284 Gg CO2 equivalent)*
* The concept of energy include: the use of fuels in energy production, in manufacturing and construction, transport and other sectors. Source: [12].

Greenhouse gas emissions in 2006 have the largest contribution to carbon dioxide [CO2] (82.0%), produced mainly from the combustion of fuels, followed by methane [CH^4] (10.5%) and N^2O (6.4%), which are primarily made in the agriculture and landfill, and emissions of hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF6), which are very small (1.1%), but important because of their high greenhouse effect.

Since the indicator of the Direct Material Input (DMI) data of Statistical Office of Slovenia, [13] proves the continuous increase of the energy sources use, both renewables and nonrenewables, and increasing material import, our footprint (individual, national, global) has a very low potential to meet the environmental limits of our planet. The DMI indicator in 2005 in Slovenia was 26 tonnes per capita and was the highest in the period 2000-2005.

The above-presented footprint analysis of Šalek Valley is only an example in which the regional economic factors are evidently recognized as socially very responsible. Šalek Valley can be seen as very environmentally conscious, when we look at the researched indicators of the share (in%) of investments (indicator A) and the current expenditure (indicator B) for the environmental protection of the Šalek Valley in comparison to the total expenditure of Savinja Statistical Region

It would be an interesting to prepare a Comparative Footprint Analysis for the Slovene regions that used to be (or are still) quite environmentally burdened, eg. Zasavje, Meža Valley, the Jesenice area and the Celje basin. Of course, more precise (taking into account more indicators, also social and environmental) municipal and regional footprint analysis research, for all the Slovene regions would perform more relevant conclusions on the GHG footprint. The analysis would enable the measurement of the amount of renewable and non-renewable ecologically productive land required to support the resource demands and absorb the wastes of a city or region. Although there also exist explanations on the non-anthropogenic origins regarding the global warming process, a thorough change of our lifestyle is absolutely necessary.

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THE IMPACT OF INVESTMENT IN RENEWABLE ENERGY SOURCES ON THE NATIONAL ECONOMY

NARODNOGOSPODARSKI UČINKI INVESTICIJ V OBNOVLJIVE VIRE ENERGIJE

Sebastijan Repina[1] and Mejra Festić[2]

Keywords: renewable sources, investment, macro-economic effects.

Abstract

Renewable energy sources technologies contribute to GDP growth, value added and increase in employment. Large hydro-power plants contribute significantly to research and development and they are – from the point of view of economic criteria – the most acceptable electricity plants. The analysis is based on the input-output model and the effects are related to the period of building and construction of energy plants.

The target value for the production of electricity from renewable resources increases to 3,146 GWh by 2020. For the realization of this target, additional investment activity in the amount of 3,045 million euros is needed. If we suppose that equal amount of investment is put into different renewable sources technologies, large hydro power stations will contribute the most to the improvement of macro-economic indicators (except at amortization and import, where the impact is expected to be average). In contrast, wind power stations are expected to contribute to the improvement of macro-economic indicators the least. Photovoltaics is expected to contribute the most to additional research and development expenditures.

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[1] Sebastijan Repina, BS (econ.), researcher, EIPF – Economic Institute, Ljubljana, 00386 1 252 1688, fax: 00386 1 212 1688. seba.repina@gmail.com; sebastijan.repina@eipf.si

[2] Mejra Festić, PhD. (corresponding author), EPF UM – Faculty of Business and Economics University of Maribor and EIPF – Economic Institute, Ljubljana. 00386 2 235 5381, fax: 00386 2 235 5266. mejra.festic@uni-mb.si; mejra.festic@eipf.si

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Povzetek

Tehnologije OVE prispevajo k rasti bruto domačega proizvoda, dodani vrednosti in rasti zaposlenosti v narodnem gospodarstvu. K raziskavam in razvoju najbolj prispevajo velike hidro elektrarne, ki so tudi z vidika ekonomičnosti najbolj sprejemljive elektrarne OVE. Vsi učinki input-output analize so analizirani za čas gradnje novih energetskih objektov OVE.

Ciljna vrednost do l. 2020 za pridobivanje električne energije iz OVE se poveča za 3.146 GWh - za kar je potrebnih 3.045 mio EUR investicij. Če bi v vsako tehnologijo OVE vložili enak znesek investicij, bi k izboljšanju makro-kazalnikov največ prispevale velike HE (razen pri amortizaciji in uvozu, kjer je vpliv povprečen). Po drugi strani pa bi k izboljšanju makro-kazalnikov najmanj prispevale vetrne elektrarne.

1 INTRODUCTION

Renewable sources technologies (RST) contribute towards the increase of gross domestic product, value added and employment growth in the national economy. A substantial contribution of RST can be observed in research and development growth. The contribution may differ in accordance with different technologies. Large hydro power stations, which are the most economical RST power stations, contribute the most towards research and development.

The target value for production of electricity from the renewable resources increases is 3,146 GWh by 2020. For such an increase, 3,045 million Euros in investments is needed. Large hydro power stations will contribute the most (1,299 GWh) – for which 618.3 million Euros in investments will be needed; wind power stations will contribute 567 GWh, which can be reached through investments in the amount of 345.6 million Euros; photovoltaics will contribute an additional 469 GWh, for which 1,641.5 million Euros of investment is needed; biomass will contribute 267 GWh and require 11.3 million Euros of investment; small hydro power stations will contribute 194 GWh and require 148.8 million euros of investment; natural gas will contribute 191 GWh and require 95.5 million Euros of investment. The smallest contribution towards achieving the RST goal in 2020 is by means of geothermal power stations, which will contribute 150 GWh and require 93.8 million Euros of investment.

If an equal amount of investment is put in each RST technology, large hydro-power plants would contribute the most to the improvement of macro-economic indicators (except at amortization and import, where the impact is expected to be average) and the least towards research and development in the national economy. In contrast, wind power stations would contribute the least towards the improvement of macro-economic indicators (except at amortization). Photovoltaics would contribute the most towards additional research and development, which would lead towards increased involvement of universities and research institutes in developmental processes of these technologies. It can be concluded that the domestic economy profits the least from wind power stations (except additional electricity).

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1. 1 Econometric analysis of investments in RST

1. 1. 1 Methodology

Input-output analysis served as the basic quantitative analytical tool for the analysis of the macro-economic effects of building planned RST investments, through which we quantified its influence on production, value added, financial resources for employees (employee salaries), taxes, use of fixed capital, business profit, cost of R&D and import. Direct and indirect (through suppliers of reproduction material and appropriate services and through further reproduction enquiries of these suppliers) influence of RST investments was assessed by input-output analysis on input-output matrix data for Slovenian economy in 2007.[3] The aggregate value of individual economic variables in 2007 was taken into account.

Direct and indirect influence of investments during construction was assessed by:

$$M = (I\text{-}Ad)\text{-}1 * Y \tag{1. 1}$$

$$H = (\text{diag } BDP/X) * (I\text{-}Ad)\text{-}1 * Y \tag{1. 2}$$

$$G = Au * (I\text{-}Ad)\text{-}1 * Y \tag{1. 3}$$

$$Z = (\text{diag } F/X) * (I\text{-}Ad)\text{-}1 * Y \tag{1. 4}$$

Y represents the value of planned RST investment. This value is distributed to sectors or providers of investment goods, according to their average share (on the national economy level) in the offer from 2007. The import part of the offer is added to the total influence of investment on import.

M represents global influence on economic activities, while its sum represents the influence on the entire economy; Ad represents the matrix of technical quotients – the column of domestic input in a given sector divided by its production; I is a single matrix, (I-Ad)-1 is a matrix multiplier, which shows global (direct and indirect through suppliers of intermediate goods and appropriate services) influence of planned RST investments.

H represents global influence of planned RST investments (Y) on gross added value, where diag BDP/X represents diagonalised matrix of direct quotients of gross domestic product or its individual components (financial resources for employees, use of fixed capital, etc.), GDP is gross domestic product, and X represents the production of an industry. G shows global influence of planned RST investments (Y) on import. Au is the import component of technological matrix acquired by dividing the import of industries with their production.

Z represents global influence of planned RST investments (Y) on the employment of production factors (work and developmental activities measured by costs for R&D); diag F/X is a diagonalised matrix of direct quotients of production factor F in industrial production (X).

The assessment of the influence of planned RST investments on activities, value added, financial resources for employees, net business profit, net taxes, import, employment and cost of R&D is based on Leonti's production function and assumes constant yield of production factors,

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[3] The following was taken into consideration in our simulations:

- IO table of Slovenian economy in 2007 (SURS 2008).
- Number of employees (SURS 2008).
- Research and development costs (SURS 2008).

elasticity of substitution that equals 0 and homogeneity of production within sectors. The results of the input-output analysis can be considered as initial tendencies with an indicated direction.

The first part of the analysis shows the effects of investments for individual technologies in national economy, by taking into account target values for year 2020; the second part of the analysis represents the effects of these investments in accordance with the RST potential.

1. 1. 2 The influence of investments in individual technologies on national economy

Table 1: *Macroeconomic effects during the construction of biogas*
Effects on the national economy

	m. €	**% from aggregate level**
Production	146.906	0.206
Value added (GDP)	53.570	0.155
Gross employee cost (salaries)	31.396	0.183
Use permanent capital (amortization)	9.075	0.202
Business profit	12.341	0.259
Number of employees (jobs)[4]	1,783	0.185
Cost of R&D	0.596	0.123
Direct and indirect import	47.230	0.170
Total public finance income (without employer contributions)	17.980	0.137

Of which Direct Import: 5.300

Effects shown in Table 1:

Influence on economic activity (line 2): the construction of the planned investment will lead to an increase of Slovenian production in the amount of 146 million Euros. This represents 0.21% of total Slovenian production.

Influence on gross domestic product (line 3): the construction of the planned investment will have influence on almost 54 million Euros of gross domestic product in Slovenia, which represents 0.16% of Slovenia’s gross domestic product.

Influence on financial resources for employees (line 4): the planned investment will have influence on almost 32 million Euros larger gross employee payments. This represents 0.19% of gross payments of employees in Slovenia.

Influence on use of fixed capital (line 5): the construction of the planned investment will have influence on almost 9 million Euros of written amortization and thus on the increase of funds for reconstruction investments. This represents almost 0.20% of total Slovenian amortization.

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[4] Employment in the case that all investment activity will be done in one year.

Influence on business profit (line 6): the scope and structure of investment will lead to almost 13 million Euros of business profit in Slovenian companies. This represents 0.26% of total business profit in Slovenia.

Influence on employment (line 7): the increase in economic activity of Slovenia's economy due to the planned investment will enable indirect and direct involvement of 1,783 employees. This will not necessarily represent the creation of new jobs, but will productively influence people who may already have a job. Total work force involvement for the planned investment represents 0.19% of the working population in Slovenia.

Influence on developmental activity (line 8): the construction of planned power lines will lead to 0.6 million Euros of additional cost for development and research activity. This represents almost 0.12% of total costs for R&D in the Slovenian economy.

Influence on import (line 9): the planned investment will lead to 47 million Euros of indirect and direct import required for equipment and construction work, which represents almost 0.17% of Slovenian import of goods and services in 2007.

Influence on public finance income (line 10): due to the construction of planned RST investment, increased activities in the Slovenian economy will have an influence on increased public finance income. The total effect will amount to 18 million Euros. This will represent a considerable increase of Slovenian budget, as well as health and pension funds. Total public finance income will increase by almost 0.14% (the influence of tax reform in 2007 has not been taken into account).

***Table 2:** Macroeconomic effects during the construction of hydro small technology*
Effects on the national economy

	m. €	**% from aggregate level**
Production	206.887	0.290
Value added (GDP)	75.927	0.220
Gross employee cost (salaries)	44.448	0.259
Use permanent capital (amortization)	13.276	0.295
Business profit	17.132	0.359
Number of employees (jobs)	2,477	0.257
Cost of R&D	0.820	0.169
Direct and indirect import	82.245	0.262
Total public finance income (without employer contributions)	25.081	0.191

Of which Direct Import: 17.707

***Table 3:** Macroeconomic effects during the construction of hydro big technology*

Effects on the national economy

	m. €	**% from aggregate level**
Production	1,023.350	1.435
Value added (GDP)	370.370	1.074
Gross employee cost (salaries)	211.321	1.231
Use permanent capital (amortization)	58.642	1.302
Business profit	94.976	1.991
Number of employees (jobs)	12,443	1.293
Cost of R&D	2.531	0.523
Direct and indirect import	295.565	1.006
Total public finance income (without employer contributions)	128.777	0.982

Of which Direct Import: 47.611

Effects shown in Table 2 and Table 3:

Influence on economic activity (line 2): the construction of the planned investment will lead to an increase of Slovenian production in the amount of 207/1.023 million Euros. This represents 0.29/1.43% of total Slovenian production.

Influence on gross domestic product (line 3): the construction of the planned investment will have influence on almost 76/370 million Euros of gross domestic product in Slovenia, which represents 0.22/1.07% of Slovenia's gross domestic product.

Influence on financial resources for employees (line 4): the planned investment will have influence on almost 44/211 million Euros larger gross employee payments. This represents a 0.26/1.23% of gross payments of employees in Slovenia.

Influence on use of fixed capital (line 5): the construction of the planned investment will have influence on almost 13/58 million Euros of written amortization and thus on the increase of funds for reconstruction investments. This represents almost 0.29/1.3% of total Slovenian amortization.

Influence on business profit (line 6): the scope and structure of investment will lead to almost 17/95 million Euros of business profit in Slovenian companies. This represents 0.36/2.00% of total business profit in Slovenia.

Influence on employment (line 7): the increase in economic activity of Slovenia's economy due to the planned investment will enable indirect and direct involvement of 2,477/12,443 employees. This will not necessarily represent the creation of new jobs, but will productively influence people who may already have a job. Total work force involvement for the planned investment represents a 0.26/1.29% of the working population in Slovenia.

Influence on developmental activity (line 8): the construction of planned power lines will lead to 0.82/2.53 million Euros of additional cost for development and research activity. This represents almost 0.17/0.52% of total costs for R&D in the Slovenian economy.

Influence on import (line 9): the planned investment will lead to 82/295 million Euros of indirect and direct import required for equipment and construction work, which represents almost 0.26/1.00% of Slovenian import of goods and services in 2007.

Influence on public finance income (line 10): due to the construction of planned RST investment, increased activities in the Slovenian economy will have an influence on increased public finance income. The total effect will amount to 25/129 million Euros. This will represent a considerable increase of Slovenian budget, as well as health and pension funds. Total public finance income will increase by almost 0.2/1.0% (the influence of tax reform in 2007 has not been taken into account).

Table 4: *Macroeconomic effects during the construction of bio-mass technology*
Effects on the national economy

	m. €	**% from aggregate level**
Production	173.661	0.243
Value added (GDP)	63.316	0.184
Gross employee cost (salaries)	37.644	0.219
Use permanent capital (amortization)	11.038	0.245
Business profit	13.750	0.288
Number of employees (jobs)	2,104	0.219
Cost of R&D	0.823	0.170
Direct and indirect import	48.023	0.195
Total public finance income (without employer contributions)	20.910	0.159

Of which Direct Import: 0.00

Effects shown in Table 4:

Influence on economic activity (line 2): the construction of the planned investment will lead to an increase of Slovenian production in the amount of 173 million Euros. This represents 0.24% of total Slovenian production.

Influence on gross domestic product (line 3): the construction of the planned investment will have influence on almost 63 million Euros of gross domestic product in Slovenia, which represents 0.18% of Slovenia's gross domestic product.

Influence on financial resources for employees (line 4): the planned investment will have influence on almost 38 million Euros larger gross employee payments. This represents 0.22% of gross payments of employees in Slovenia.

Influence on use of fixed capital (line 5): the construction of the planned investment will have influence on almost 11 million Euros of written amortization and thus on the increase of funds for reconstruction investments. This represents almost 0.24% of total Slovenian amortization.

Influence on business profit (line 6): the scope and structure of investment will lead to almost 14 million Euros of business profit in Slovenian companies. This represents 0.29% of total business profit in Slovenia.

Influence on employment (line 7): the increase in economic activity of Slovenia's economy due to the planned investment will enable indirect and direct involvement of 2,104 employees. This will not necessarily represent the creation of new jobs, but will productively influence people who may already have a job. Total work force involvement for the planned investment represents 0.22% of the working population in Slovenia.

Influence on developmental activity (line 8): the construction of planned power lines will lead to 0.82 million Euros of additional cost for development and research activity. This represents almost 0.17% of total costs for R&D in the Slovenian economy.

Influence on import (line 9): the planned investment will lead to 48 million Euros of indirect and direct import required for equipment and construction work, which represents almost 0.19% of Slovenian import of goods and services in 2007.

Influence on public finance income (line 10): due to the construction of planned RST investment, increased activities in the Slovenian economy will have an influence on increased public finance income. The total effect will amount to 21 million Euros. This will represent a considerable increase of Slovenian budget, as well as health and pension funds. Total public finance income will increase by almost 0.16% (the influence of tax reform in 2007 has not been taken into account).

Table 5: *Macroeconomic effects during the construction of Photovoltaics*
Effects on the national economy

	m. €	**% from aggregate level**
Production	2,241.988	3.143
Value added (GDP)	818.088	2.373
Gross employee cost (salaries)	527.746	3.075
Use permanent capital (amortization)	141.640	3.145
Business profit	137.427	2.880
Number of employees (jobs)	32,281	3.354
Cost of R&D	30.889	6.378
Direct and indirect import	893.586	3.342
Total public finance income (without employer contributions)	269.696	2.056

Of which Direct Import: 70.174

Effects shown in Table 5:

Influence on economic activity (line 2): the construction of the planned investment will lead to an increase of Slovenian production in the amount of 2,242 million Euros. This represents 3.1% of total Slovenian production.

Influence on gross domestic product (line 3): the construction of the planned investment will have influence on almost 818 million Euros of gross domestic product in Slovenia, which represents 2.4% of Slovenia's gross domestic product.

Influence on financial resources for employees (line 4): the planned investment will have influence on almost 527.7 million Euros larger gross employee payments. This represents 3.07% of gross payments of employees in Slovenia.

Influence on use of fixed capital (line 5): the construction of the planned investment will have influence on almost 142 million Euros of written amortization and thus on the increase of funds for reconstruction investments. This represents almost 3.2% of total Slovenian amortization.

Influence on business profit (line 6): the scope and structure of investment will lead to almost 137 million Euros of business profit in Slovenian companies. This represents 2.9% of total business profit in Slovenia.

Influence on employment (line 7): the increase in economic activity of Slovenia's economy due to the planned investment will enable indirect and direct involvement of 32,281 employees. This will not necessarily represent the creation of new jobs, but will productively influence people who may already have a job. Total work force involvement for the planned investment represents 3.35% of the working population in Slovenia.

Influence on developmental activity (line 8): the construction of planned power lines will lead to 30.9 million Euros of additional cost for development and research activity. This represents almost 6.4% of total costs for R&D in the Slovenian economy.

Influence on import (line 9): the planned investment will lead to 893 million Euros of indirect and direct import required for equipment and construction work, which represents almost 3.4% of Slovenian import of goods and services in 2007.

Influence on public finance income (line 10): due to the construction of planned RST investment, increased activities in the Slovenian economy will have an influence on increased public finance income. The total effect will amount to 269 million Euros. This will represent a considerable increase of Slovenian budget, as well as health and pension funds. Total public finance income will increase by almost 2.1% (the influence of tax reform in 2007 has not been taken into account).

Table 6: *Macroeconomic effects during the construction of wind technology*
Effects on the national economy

	m. €	**% from aggregate level**
Production	309.717	0.434
Value added (GDP)	119.487	0.347
Gross employee cost (salaries)	67.579	0.394
Use permanent capital (amortization)	20.774	0.461
Business profit	29.471	0.618
Number of employees (jobs)	3,863	0.401
Cost of R&D	1.623	0.335
Direct and indirect import	383.361	0.918
Total public finance income (without employer contributions)	39.681	0.303

Of which Direct Import: 157.248

Effects shown in Table 6:

Influence on economic activity (line 2): the construction of the planned investment will lead to an increase of Slovenian production in the amount of 307 million Euros. This represents 0.43% of total Slovenian production.

Influence on gross domestic product (line 3): the construction of the planned investment will have influence on almost 119 million Euros of gross domestic product in Slovenia, which represents 0.34% of Slovenia's gross domestic product.

Influence on financial resources for employees (line 4): the planned investment will have influence on almost 67.5 million Euros larger gross employee payments. This represents 0.4% of gross payments of employees in Slovenia.

Influence on use of fixed capital (line 5): the construction of the planned investment will have influence on almost 21 million Euros of written amortization and thus on the increase of funds for reconstruction investments. This represents almost 0.46% of total Slovenian amortization.

Influence on business profit (line 6): the scope and structure of investment will lead to almost 29.5 million Euros of business profit in Slovenian companies. This represents 0.62% of total business profit in Slovenia.

Influence on employment (line 7): the increase in economic activity of the nation's economy due to the planned investment will enable indirect and direct involvement of 3.869 employees. This will not necessarily represent the creation of new jobs, but will productively influence people who may already have a job. Total work force involvement for the planned investment represents 3.35% of the working population in Slovenia.

Influence on developmental activity (line 8): the construction of the planned power lines will lead to 1.6 million euros of additional cost for development and research activity. This represents almost 0.33% of total costs for R&D in the Slovenian economy.

Influence on import (line 9): the planned investment will lead to 383 million Euros of indirect and direct import required for equipment and construction work, which represents almost 0.92% of Slovenian import of goods and services in 2007.

Influence on public finance income (line 10): due to the construction of planned RST investment, increased activities in the Slovenian economy will have an influence on increased public finance income. The total effect will amount to 40 million Euros. This will represent a considerable increase in the Slovenian budget, as well as health and pension funds. Total public finance income will increase by almost 0.3% (the influence of tax reform in 2007 has not been taken into account).

Table 7: *Macroeconomic effects during the construction of geothermal technology*
Effects on the national economy

	m. €	**% from aggregate level**
Production	136.511	0.191
Value added (GDP)	49.957	0.145
Gross employee cost (salaries)	28.730	0.167
Use permanent capital (amortization)	8.189	0.182
Business profit	12.320	0.258
Number of employees (jobs)	1,664	0.173
Cost of R&D	0.458	0.094
Direct and indirect import	58.090	0.178
Total public finance income (without employer contributions)	17.071	0.130

Of which Direct Import: 14.297

Effects shown in Table 7:

Influence on economic activity (line 2): the construction of the planned investment will lead to an increase of Slovenian production in the amount of 136 million Euros. This represents 0.2% of total Slovenian production.

Influence on gross domestic product (line 3): the construction of the planned investment will have influence on almost 50 million Euros of gross domestic product in Slovenia, which represents 0.14% of the nation's gross domestic product.

Influence on financial resources for employees (line 4): the planned investment will have influence on almost 29 million Euros larger gross employee payments. This represents 0.17% of gross payments of employees in Slovenia.

Influence on use of fixed capital (line 5): the construction of the planned investment will have influence on 8.2 million Euros of written amortization and thus on the increase of funds for reconstruction investments. This represents almost 0.18% of total Slovenian amortization.

Influence on business profit (line 6): the scope and structure of investment will lead to almost 12.3 million Euros of business profit in Slovenian companies. This represents 0.26% of total business profit in Slovenia.

Influence on employment (line 7): the increase in economic activity of Slovenia's economy due to the planned investment will enable indirect and direct involvement of 1,664 employees. This will not necessarily represent the creation of new jobs, but will productively influence people who may already have a job. Total work force involvement for the planned investment represents a 0.17% of the working population in Slovenia.

Influence on developmental activity (line 8): the construction of planned power lines will lead to 0.46 million Euros of additional cost for development and research activity. This represents almost 0.1% of total costs for R&D in the Slovenian economy.

Influence on import (line 9): the planned investment will lead to 58 million Euros of indirect and direct import required for equipment and construction work, which represents almost 0.18% of Slovenian import of goods and services in 2007.

Influence on public finance income (line 10): due to the construction of planned RST investment, increased activities in the Slovenian economy will have an influence on increased public finance income. The total effect will amount to 17 million Euros. This will represent a considerable increase of Slovenian budget, as well as health and pension funds. Total public finance income will increase by almost 0.13% (the influence of tax reform in 2007 has not been taken into account).

Table 8: *Macro-economic effects for the construction of all RST technologies*
Effects of potential RST investments on the national economy

	m. €	**% from aggregate level**
Production	4,239.020	5.942
Value added (GDP)	1,550.715	4.498
Gross employee cost (salaries)	948.864	5.528
Use permanent capital (amortization)	262.634	5.832
Business profit	317.417	6.653
Number of employees (jobs)	56,615	5.882
Cost of R&D	37.740	7.792
Direct and indirect import	1,808.100	6.071
Total public finance income (without employer contributions)	519.196	3.958

Of which Direct Import: 312.337

Effects shown in Table 8:

Influence on economic activity (line 2): the construction of the planned investment will lead to an increase of Slovenian production in the amount of 4.239 million Euros. This represents 6% of total Slovenian production.

Influence on gross domestic product (line 3): the construction of the planned investment will have influence on almost 1.551 million Euros of gross domestic product in Slovenia, which represents 4.5% of the nation's gross domestic product.

Influence on financial resources for employees (line 4): the planned investment will have influence on almost 949 million Euros larger gross employee payments. This represents a 5.53% of gross payments of employees in Slovenia.

Influence on use of fixed capital (line 5): the construction of the planned investment will have influence on almost 263 million Euros of written amortization and thus on the increase of funds for reconstruction investments. This represents almost 5.83% of total Slovenian amortization.

Influence on business profit (line 6): the scope and structure of investment will lead to almost 317 million Euros of business profit in Slovenian companies. This represents 6.65% of total business profit in Slovenia.

Influence on employment (line 7): the increase in economic activity of Slovenia's economy due to the planned investment will enable indirect and direct involvement of 56,615 employees. This will not necessarily represent the creation of new jobs, but will productively influence people who may already have a job. Total work force involvement for the planned investment represents 5.9% of the working population in Slovenia.

Influence on developmental activity (line 8): the construction of planned power lines will lead to 38 million Euros of additional cost for development and research activity. This represents almost 7.8% of total costs for R&D in the Slovenian economy.

Influence on import (line 9): the planned investment will lead to 1,808 million Euros of indirect and direct import required for equipment and construction work, which represents almost 6% of Slovenian import of goods and services in 2007.

Influence on public finance income (line 10): due to the construction of planned RST investment, increased activities in the Slovenian economy will have an influence on increased public finance income. The total effect will amount to 519 million euros. This will represent a considerable increase of the Slovenian budget, as well as health and pension funds. Total public finance income will increase by almost 4% (the influence of tax reform in 2007 has not been taken into account).

2 CONCLUSION

The indicator of the ratio between invested funds and produced RST electricity is quite interesting. On average, the ratio between the value of investment and the amount of produced electricity is 0.97 million Euros/GWh, which means that (on average) 0.97 million Euros of investment in RST technologies is needed for the production of 1 GWh. The most economical are the ratios for biomass (0.42 million Euros/GWh), large hydro-power plants (0.48 million Euros/GWh), biogas (0.50 million Euros/GWh), wind-power plants (0.60 million Euros/GWh), geothermal energy (0.63 million Euros/GWh) and small hydro-power plants (0.77 million

Euros/GWh). The most expensive is photovoltaics, which requires 3.50 million Euros of investment for 1 GWh of electricity.

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Appendix to calculations in Tables 1-8:

Table A: *A comparison of technologies and their macro-economic indicators during the construction of individual RST energy plants, by taking into account target values in 2020 (with regard to the required investment)*

	HE Large	HE Small	Photovolt	Wind	Biomass	Geothermal	Biogas	Sum
Technical potential (GWh)	1,299.0	194.0	469.0	576.0	267.0	150.0	191.0	3,146.0
Investment (mio €)	618.3	148.8	1,641.5	345.6	111.3	93.8	95.5	3,054.8
Investment (mio €/GWh)	0.476	0.767	3.500	0.600	0.417	0.625	0.500	0.971
	Share related to investment (v %)							
Production	165.51	139.04	136.58	89.62	156.03	145.53	153.83	138.77
Value added (GDP)	59.90	51.03	49.84	34.57	56.89	53.26	56.09	50.76
Gross employee cost (salaries)	34.18	29.87	32.15	19.55	33.82	30.63	32.88	31.06
Use of permanent capital	9.48	8.92	8.63	6.01	9.92	8.73	9.50	8.60
Business profit	15.36	11.51	8.37	8.53	12.35	13.13	12.92	10.39
Number of employees	20.1	16.6	19.7	11.2	18.9	17.7	18.7	18.5
Expenditures for R&D	0.41	0.55	1.88	0.47	0.74	0.49	0.62	1.24
Direct and indirect import	47.80	55.27	54.44	110.93	43.15	61.93	49.46	59.19
Total public finance income (without employer contributions)	20.83	16.86	16.43	11.48	18.79	18.20	18.83	17.00

Table B: *Target values in 2020 and the scope of investment according to RST technologies*

	Technical potential Target values 2020 (GWh)	Investment (v mio €)	Investment (mio €/GWh)
Large HE	1,299.0	618.3	0.476
Small HE	194.0	148.8	0.767
PHOTOVOLTAICS	469.0	1,641.5	3.500
WIND	576.0	345.6	0.600
BIOMASS	267.0	111.3	0.417
GEOTHERMAL	150.0	93.8	0.625
BIOGAS	191.0	95.5	0.500
Sum:	3,146.0	3,054.8	

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POSSIBLE USES OF RENEWABLE ENERGY SOURCES IN THE ŠALEK VALLEY

MOŽNOSTI RABE OBNOVLJIVIH ENERGETSKIH VIROV V ŠALEŠKI DOLINI

Luka Zajec$^{\Re}$, Natalija Špeh[1]

Keywords: renewable energy sources, mobile meteorological station, use of renewable sources, The Šalek Valley

Abstract

The energy supply in the Šalek Valley has, since the end of the 19th century, traditionally relied upon exploitation of non-renewable fossil fuel, mainly originating from coal. This article will reveal a possible pathway towards prospective renewable energy sources suitable for the local environment. With the introduction of renewable energy sources to the local electricity market, individual households and smaller local communities would benefit the most.

Renewable energy sources are the most promising natural sources, especially in regard to the ambitious Kyoto Protocol goals, which need to be met, yet seem difficult to achieve. The technologies for Carbon Capture and Storage (CCS) are too expensive and have yet to be proved successful. By the year 2030, they will not play an important role in reducing the greenhouse gases emissions. This is why it is wiser to invest in renewable energy sources (Hozjan, 2009). The CCS technology opens many issues, among them reliability, sustainability and consequently security. One of the possible pathways for syn-gas production for microturbine electricity production or transport fuel is through gasification or pyrolysis.

The Šalek Valley has a great potential for the exploitation of renewable energy sources, but unfortunately they are not exploited to a suitable extent. The purpose of this research paper is

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$^{\Re}$Luka Zajec, M.Sc. Slovenian Forest Service, Vorančev trg 1, SI-2380 Slovenj Gradec, Tel.: +386(0)41 363 533, luka.zajec@gmail.com

[1] Natalija Špeh, PhD, Environmental Protection College, Trg mladosti 2, SI-3320 Velenje, +386 (0)3 898 64 10; f: +386(0)3 898 64 13, natalija.speh@erico.si

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to evaluate the possibility of harnessing renewable energy sources on several selected places in the Šalek Valley. A further data analysis should indicate the optimal renewable energy sources for the selected sites with the economical and technical risk analyses.

The data were collected through a classic mobile weather station. The station was upgraded with solar and thermal collectors, photovoltaic cells and wind-speed meters. The gathered solar radiation data from the selected sites were also tested with the Homer RETScreen software.

Our goal was to design a portable data acquisition station that would be simultaneously capable of gathering several different parameters from the field and sending them to a data centre using the commercial mobile network.

We assume that the gap between the potential and the current exploitation of the renewable energy sources is substantial. It is encouraging that the oldest financial institution in the EU, the European Investment Bank (EIB) obliged itself to extend the loans and warrants for the electricity produced from the renewable sources from the current 15% to 50% by 2010. Within the boundaries of environmental protection, the EIB has granted a loan of 30 million euros to Ekosklad for financing the investments in reducing the water and air pollution, including reduction of greenhouse gases. Currently, Slovenia is behind schedule in producing facilities using renewable energy sources (Hozjan, 2009).

Povzetek

Energetska oskrba v Šaleški dolini je tradicionalno vezana na izkoriščanje neobnovljivih fosilnih virov energije (premog) že od konca 19. stoletja. Pričujoči prispevek razkriva možnosti uporabe nekaterih obnovljivih virov energije, primernih za ožjo, lokalno potrošnjo, s čimer bi se popestril obstoječ način oskrbe z električno energijo posameznih gospodinjstev oz. manjših lokalnih skupnosti.

Obnovljivi viri energije predstavljajo vedno bolj pomemben naravni kapital in soustvarjajo temelj za doseganje ambicioznih kyotskih ciljev, ki se nam tako uspešno izmikajo. Tehnologije za zajem in shranjevanje ogljika (Carbon Capture and Storage-CCS) so predrage in nepreverjene in do leta 2030 gotovo ne bodo pomembno vplivale na zmanjševanje učinkov izpuščanja toplogrednih plinov. Tako je verjetno smotrneje vlagati v obnovljive vire energije (Hozjan, 2009). Še posebej pa ostaja odprto vprašanje njihove zanesljivosti, trajnosti in posledično varnosti. Ena izmed možnosti za proizvodnjo sintetičnega plina za pogon mikro-turbin pri proizvodnji elektrike ali transportnih goriv je skozi uporabo uplinjevalcev ali pirolizatorjev.

Šaleška dolina ima velik potencial za izkoriščanje obnovljivih virov energije, ki pa se v dolini premalo izkoriščajo. Namen raziskave je bil izmeriti razpoložljivost obnovljivih virov energije na izbranih merilnih mestih Šaleške doline in ugotoviti teoretične možnosti za njihovo izkoriščanje. S kasnejšo analizo podatkov smo želeli izvedeti, kje bi lahko optimalno uporabljali izbran obnovljivi vir energije in kakšna bi bila tehnološka in ekonomična upravičenost izvedbe takšnega projekta.

Zaradi pomanjkljivih in lokalno variabilnih klimatskih podatkov, ki so nujno potrebni pri analizi upravičenosti posameznih obnovljivih virov energije, smo želeli dopolniti mrežo lokalnih klimatskih postaj z ažurnimi vremenskimi podatki z različnih merilnih mest, razširjenih po celotni Šaleški dolini, z namenom poiskati najprimernejšo mikrolokacijo za izkoriščanje posameznega obnovljivega vira energije. V ta namen smo zgradili merilni sistem, ki je bil zasnovan kot

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avtonomna mobilna klasična meteorološka postaja. Merili smo temperaturo, vlago, zračni pritisk, hitrost in smer vetra ter osončenost. Kot nadgradnjo meteorološke postaje smo postavili zbiralce obnovljivih virov energije: toplotni kolektor, modul sončne celice ter merilnik vetra. Merilniki so bili dinamični in so spreminjali lego glede na položaj največje osvetljenosti. Z merilnim sistemom, ki je mobilen, smo zajemali podatke na izbranih merilnih mestih ter med primerjanjem ugotavljali možnosti za optimalno rabo obnovljivih virov.

Izmerjeni parametri s terena so bili poslani po telekomunikacijskih omrežjih v zbirni center v obliki SMS sporočil, kjer so bili shranjeni za nadaljnjo analizo. Izmerjene podatke o osončenju na izbranih merilnih lokacijah smo preizkusili na Nasinem programskem modulu Homer RETScreen.

Sodimo, da je vrzel med potenciali in dejansko izkoriščenostjo obnovljivih virov energije precejšnja. Vzpodbuden pa je podatek, da se je najstarejša finančna ustanova EU, Evropska investicijska banka (EIB), zavezala, da bo v okviru proizvodnje električne energije iz obnovljivih virov do leta 2010 povečala delež posojil in garancij s sedanjih 15 na 50 odstotkov. V okviru varovanja okolja je EIB tudi Ekoskladu odobrila posojilo v vrednosti 30 milijonov evrov za financiranje majhnih in srednjih investicij, povezanih z zmanjšanjem onesnaženja vode in zraka, vključno z izpusti toplogrednih plinov. Slovenija zaenkrat zaostaja pri izgradnji proizvodnih naprav na obnovljive vire energije (Hozjan, 2009).

1 INTRODUCTION

The world population (6.75 billion people in 2008) has doubled in the past four decades; in the past three decades, the world’s energy consumption has more than doubled. In the future, we can expect an inflated consumption of energy on a global scale if the world's population reaches nearly 9 billion by the year 2040; which it will, according to some projections (U.S. Census Bureau, 2008).

The world economy requires enormous amounts of energy, most of which comes from fossil fuels (oil, natural gas, methane and coal).

In particular, it is envisaged that in the coming three decades, this type of fuel will cover 85% of the energy needs. However, in relation to this view, two important concerns emerge:

- Accessibility of resources and energy security with its price;
- Greenhouse gases emitted from the use of fossil fuels, changing the global climate system.

The energy sector is mostly responsible for the production of so-called “greenhouse gases” (GHG). Therefore, alternative energy sources need to be utilized to reduce the emission of these harmful gases. A series of parallel actions needs to be taken for improving energy efficiency in the relevant sectors of the economy:

- An increase in conversion efficiency;
- Protection and development of mechanisms for collection and removal of greenhouse gases;
- Promotion of sustainable forest management, afforestation and reforestation;

- Adoption of measures to limit and reduce greenhouse gas emissions in the transport sector;
- Limiting methane emissions through recovery and use of gas in the area of waste management;
- Research, promotion, development and increased use of renewable energy.

Renewable sources of energy in the context of the threat of the global climate change are one of the best means of resolving the issue of future energy demand and protection of the environment.

Renewable energy is generated from natural resources such as sunlight, wind, rain, tides and geothermal heat. These sources are naturally replenished. Currently, various forms of financial incentives issued by the European Union, individual states or local authorities exist.

Among the technologies for the conversion of renewable resources are hydro power, geothermal energy, wind and wave energy, photovoltaics and biomass.

Biomass, such as forest residues and agricultural crops can, under certain conditions, provide a viable renewable source for electricity generation and heat. It can supply local communities close to production areas or offer products (biodiesel, biogas) that can replace some of the current fuels used for heating and transportation.

Particularly interesting in this context are energy crops, which are intended to provide biomass to produce electricity or heat. The modern techniques of cultivation (Short Rotation Forestry) have maximized the yield per hectare by using fertilizers, pesticides and genetically modified tree species. The species used in energy production should have important agronomic values of high growth rates and increased biological and climate resistance.

Currently, electricity production from biomass is achieved through the technology of thermal incinerators and energy recovery from the flue gas of steam cycles. Higher efficiencies can be achieved through technologies such as gasification and pyrolysis. These technologies have not yet reached the industrial level of technological development needed for the production of synthetic gas of medium to low heat calorific value, which can be used in internal combustion engines and gas turbines. An interesting perspective is that the use of syn-gas from biomass, given the optimal performance with minimal environmental impact, is based on the use of micro-gas power in the range of 30-500 kW (Zajec, 2009).

2 RENEWABLE ENERGY

The International Energy Agency includes in the term “renewable energy” the following energy sources: combustible renewables and wastes (CRW), hydropower, wind, solar, geothermal and ocean energy (IEA, 2007).

Combustible renewables and wastes are in turn defined as: solid biomass, biogas, liquid biofuels and municipal wastes.

Combustible renewables and wastes:

CRW constitute the main part of today's renewable energy with a share of 11% of the world's energy supply. They are made up mainly of wood and charcoal used by poor populations for cooking and heating.

In recent years, liquid biofuels have risen in popularity to supplement the use of fossil fuels in transportation. Brazil (from sugar cane) and United States (from maize) extensively use bio-ethanol to replace gasoline. In Europe, biodiesel (transesterification from vegetable oils) is used as a blend to common diesel. The European Union has an objective of substituting 20% of the traditional fuels in road transport with biofuels before 2020.

Hydropower:

Hydropower is the second largest renewable energy source, with a share of 2% of the world's total energy supply. It accounts for 16% of global electricity production. Hydropower has the unique feature of being the only large scale means of storing electricity through the collection of water into large reservoirs for later re-conversion into electricity. Hydropower growth is limited as the most viable sites are generally already in use.

Wind, solar, geothermal and ocean energy sources:

These alternative energy sources are still negligible in terms of energy production compared to classical energy sources, but they will gain the importance in the future due to the health and climate care. Today they represent less than 0.5% of the world's total energy supply. However, there is a real market for them, especially in developed countries.

Wind-power production has notably quadrupled worldwide since 1995 and in some countries has become a significant part of electricity generation, as in Denmark, where it accounts for 23% of national energy production. Wind power can also be designed as an independent off-grid system.

2.1 Renewal of interest in wood in developed countries

Wood as an energy source is the focus of a renewed interest in developed countries. In the European Union, wood energy shares grew from 3% to 3.2% of the total energy consumption in 2003.

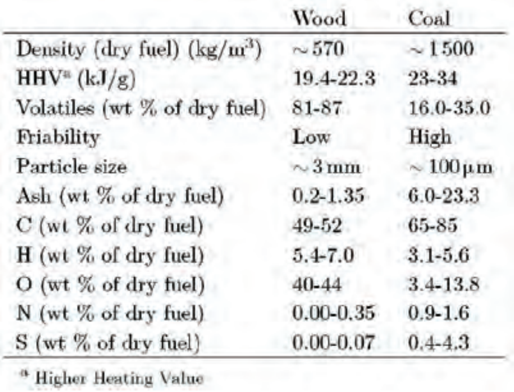
Wood cannot totally replace fossil fuels. However, it may be a partial answer to the problems of CO_2 emissions and oil dependency. Wood is a CO_2-neutral fuel, provided trees are grown as much as they are burned, and wood is available in almost all countries.

Furthermore, harvesting, transforming and converting wood into thermal energy requires manpower. The development of the wood energy industry benefits local employment and contributes to sustaining social and economic activity in rural and forested areas.

2.2 Wood compared to coal

Table 1 presents a comparison between the physical properties of wood and its fossil counterpart, coal.

Table 1: *Typical properties of wood and coal (Bellais, 2007)*



	Wood	Coal
Density (dry fuel) (kg/m^3)	~570	~1500
HHV^a (kJ/g)	19.4-22.3	23-34
Volatiles (wt % of dry fuel)	81-87	16.0-35.0
Friability	Low	High
Particle size	~3 mm	~100 µm
Ash (wt % of dry fuel)	0.2-1.35	6.0-23.3
C (wt % of dry fuel)	49-52	65-85
H (wt % of dry fuel)	5.4-7.0	3.1-5.6
O (wt % of dry fuel)	40-44	3.4-13.8
N (wt % of dry fuel)	0.00-0.35	0.9-1.6
S (wt % of dry fuel)	0.00-0.07	0.4-4.3

^{a} Higher Heating Value

Wood is a cleaner fuel compared to coal. It has low sulphur content; there is usually no need for De-SO_x treatment of the flue gas in wood combustion (IEA, 2002). The fuel-bound nitrogen is typically 1% in coal and the combustion temperature is also lower due to a lower HHV, which reduces the fuel and thermal NO_x formation. However, a De-NO_x installation might still be necessary.

The product of HHV and density gives the energy density. Calculations from data in *Table 1* give energy density for coal that is three to five times greater than for wood.

Hence, for wood to be cost competitive, it is important to limit fuel transportation and storage needs. As a result, wood power plants are usually considered in forested areas. The volatile content in wood is much higher than in coal, typically four times. Coal power plants produce up to 1,000 MW, while wood plants are usually of small-to-medium size, from small domestic burners-stoves to ca. 45 MW facilities. Because of the low combustion intensity of wood and the costly transport of bulky material, wood is limited to local harvesting range. Typical facilities that use wood systems are schools, colleges, hospitals, public buildings, hotels and motels, commercial buildings, greenhouses, large-scale agricultural operations and manufacturing plants (Maker, 2004).

3 POSSIBLE USES OF RENEWABLE ENERGY SOURCES IN THE ŠALEK VALLEY

3.1. Current Climate Data

The Šalek Valley is surrounded with mountains and small hills in the NW-SE exposition. Through the valley two major rivers with an average capacity of 2.9m^3/s (2.5 m^3/s – Paka) flow (ARSO, 2009). There are three lakes in the valley that were created by immersion of the ground in the mining area.

The specific orographic landscape of the Šalek Valley requires detailed on-site measurements of various climate data in order to optimize specific renewable energy sources, exact micro-location and extraction technology.

The climate data from the meteorological station (Velenje – Gorenje) presented in Table 2 shows the average number of sunny and cloudy days per month.

Table 2: *Velenje - Climate date (1961-1990)**

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AVG	SEP	OCT	NOV	DEC	YEAR
Average temperature	-1.0	1.1	4.6	9.1	13.9	17.0	18.8	18.0	14.7	9.8	4.5	0.3	9.2
no. of days with temp <= 0.0 °C	26.5	20.5	14.0	3.0	0.3	0.0	0.0	0.0	0.0	2.7	11.8	23.1	101.9
no. of days with temp. >= 25 °C	0.0	0.0	0.0	0.3	3.5	9.8	16.4	13.2	5.4	0.3	0.0	0.0	49.0
no. of clear days (cloudy <2/10)	4.9	5.2	5.6	4.6	5.2	4.9	7.6	8.4	7.6	7.9	5.6	5.1	72.7
no. of cloudy days (cloudy >8/10)	12.5	11.4	11.6	10.6	8.5	8.6	5.6	6.0	6.9	9.6	11.6	12.7	115.6
no. of foggy days	3.8	2.9	1.9	1.0	0.5	0.2	0.3	1.4	4.3	6.3	4.2	3.1	29.9

* Ministry of the Environment and Spatial Planning | AGENCIJA REPUBLIKE SLOVENIJE ZA OKOLJE, www.arso.gov.si/vreme/napovedi in podatki/velenje.htm

These data do not take in consideration the specific orographic landscape of the valley, where weather conditions frequently change. For sufficient climate data, specific measurements are required in order to plan and optimize the most suitable micro location for a specific technology for harnessing a renewable energy source.

3.2 Mobile Meteorological Station

A classic mobile weather station was built (Korošec, Tržan, 2006) to evaluate the possibility of harnessing renewable energy sources on several selected sites in the Šalek Valley. The data analysis should indicate the optimal renewable energy sources for the selected sites.

Figure 1*: Establishing the mobile meteorological station on a high school roof (Korošec, Tržan, 2006.)*

The measured parameters were temperature, humidity, atmospheric pressure, speed and direction of wind and solar radiation. The weather station was upgraded with solar and thermal collectors, photovoltaic cells and wind-speed meters.

The gathered solar radiation data from the selected sites were also tested with the Homer RETScreen software.

Our goal was to design a portable data acquisition station that would be simultaneously capable of gathering several different parameters from the field and sending them to the data centre using the commercial mobile network.

The gathered data from the exact location of the meteorological station were transmitted to the computer by a mobile phone. This system enabled live streaming of the weather data using the short messages service (SMS) on the cell phone.

Figure 2: *Electronic part of the meteorological station (Korošec L., Tržan S.)*

4 RESULTS

4.1 Wind Energy

The wind data, taken in the centre of Velenje, show that wind energy rarely exceeds 1.5 m/s^2 in a short period of time. Practice from abroad and a literature study show the optimal wind speed for harnessing the wind energy should be in the range of 5–25 m/s^2.

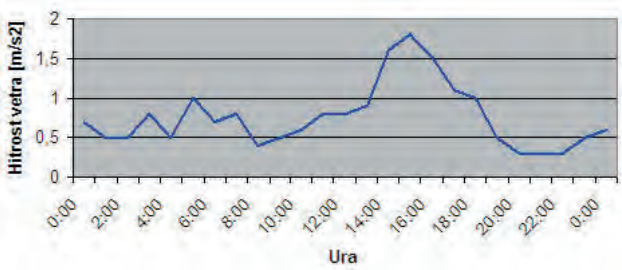


Figure 3: *Average wind speed in the centre of Velenje in the winter of 2006*

Additional measurements are required throughout the year on different locations around Velenje for a technical analysis. The mobile meteorological station can be of help. Small turbines can be tested in the mountain region. Wind energy is one of the most promising renewable energy sources in Europe but it is of limited use in Slovenia, especially in the Šalek Valley.

4.2 Geothermal Energy

The commercial use of geothermal energy is divided into:

- High temperature sources with temperatures higher than 150°C, mostly for electricity production in Iceland, Hawaii (USA), Japan
- Low temperature sources, water temperature lower then 150°C, mostly for heating spaces and electricity production through the Kalina cycle.

In Slovenia, only low temperature geothermal sources were found. The field analysis has shown that the prospective geothermal regions of Slovenia are:

- the Panonian basin (>100 l/s low temp. water sources 40–70°C).
- the Rogaška-Celje-Šoštanj region (area 450 km^2, total over 250 l/s water with temp. 18.5 –48°C).
- the Planina-Laško-Zagorje region (>150 l/s, temp. of water 21–43°C),
- the Krško-Brežice region (> 240 l/s, temp. of water 15–64°C),
- the Ljubljana depression (150 l/s, temp. of water 18–30°C)

A test drill near Topolščica found water with the temperature of 42.5°C and was deemed unsuitable for space heating and pool heating in Terme Topolščica.

4.3 Geothermal Energy / Heat Pumps

A part of geothermal energy use in domestic applications is using heat pumps. Widely spread vertical and horizontal geothermal collectors can significantly increase energy independence and decrease the import of foreign fossil fuel products. Heat pumps are designed for small-scale applications for space heating.

Regarding soil structure, different heat extractions are expected from 20 W/m (sandy soil) to 100 W/m (ground water and use of water/water heat pumps).

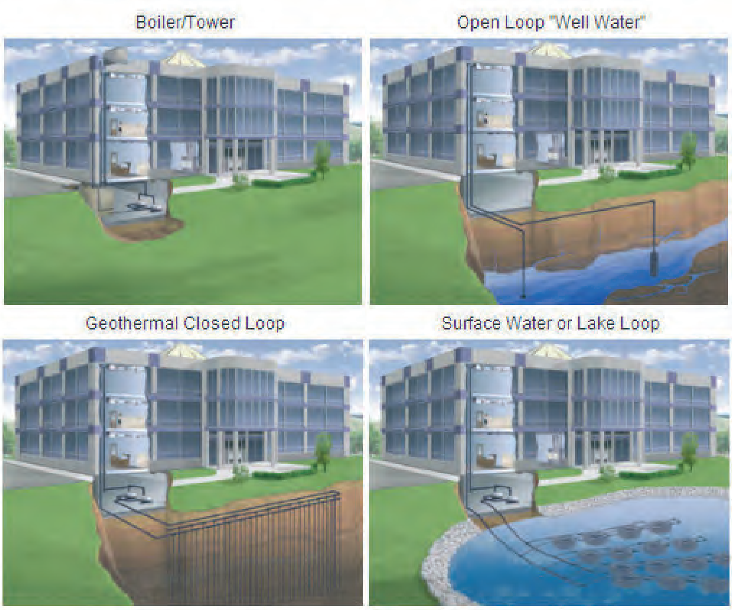


Figure 4: *Different applications of water source heat pumps (McQuay, 2009)*

Water Source Heat Pump (WSHP) systems are one of the most efficient and environmentally friendly ways of heating and cooling buildings, with better control of energy use and lower seasonal operating costs. The systems are commonly applied to a wide range of facilities from domestic homes to larger facilities (office buildings, hotels, health care facilities, banks, schools, condominiums and apartments).

The specific location of the Šalek Valley with three lakes near the city centre has great potential for water source heat pumps.

4.4 Solar Energy

Solar energy is the ultimate renewable energy source. For commercial purposes, an indirect use of solar energy is used in forms of solar collectors or PV.

Solar collectors are commonly used for water heating, space heating or pool heating.

Figure 5: *Solar collectors with a thermosyphon system and solar cells (PV-Photovoltaics)*

Photovoltaics (or PV) is the field of technology and research related to the application of solar cells by converting solar energy (sunlight, including ultraviolet radiation) directly into electricity (solar electricity), suitable for grid and off-grid applications. The average energy efficiency is between 12 and 18%. The photovoltaic solar electricity potential in the EU is the highest in the SW Mediterranean region with global irradiation of 2,100 kWh/m^2/year. In Slovenia, the sum of global irradiation incidence is between 1,000-1,400 kWh/m^2/year and in the Šalek region 1,250 kWh/m^2/year (JRC European Commission, 2006). Each EU member state offers different subsidies for the installation of PV or solar collectors.

Table 3: *Monthly average insolation incidence on a horizontal surface in the Šalek Valley (kWh/m^2/day)**

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AVG	SEP	OCT	NOV	DEC
Velenje- Gorenje	1.51	2.44	3.51	4.24	5.16	5.32	5.39	4.81	3.56	2.24	1.47	1.17

*NASA Surface meteorology and Solar Energy: HOMER Data (2009)

In the Šalek region, the use of solar collectors is economically feasible and can present an important source of energy for space and water heating throughout the year. The use of them in the Šalek region is questionable without state subsidies, but can be important for smaller off-grid applications.

4.5 Hydro-energy

Two major rivers flow through the valley and there are three lakes. No major development is expected in hydro-power production since all promising sites have already been occupied. The hydro potential can be important only for micro hydro-plants on smaller streams.

4.6 Biogas

In the last decade, a major step forward was made in waste-water treatment. The central waste water treatment plant (WWTP) was upgraded with a sewage sludge purification and simultaneous production of biogas for cogeneration (production of electrical and heat energy).

Landfill gases should be treated as well by limiting methane emissions through the recovery and use of gas in the area of waste management for cogeneration or transport biogas.

4.7 Biomass

Slovenia is one of the most forested countries in Europe, just after Finland and Sweden; 1.17 million ha of forests cover more than half of its territory (forestation amounts to 57.7%). Slovenia has a long tradition of sustainable, environmentally friendly and multi-purpose forest management. In total, over 300 million m^3 of wood is stored in Slovenian forests with annual growth over 7.6 million m^3 and possible cutting of 4.4 million m^3 of wood/year. The total annual

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cut is 3.3 million m^3 which leaves over 1.1 million m^3 of wood for accumulation per year (Slovenian Forest Service, 2005). Consequences are severe: loss of forest stability, changing landscape, forest fires, augmentation of predators and bark beetles, etc.

Figure 6: *Over 50% of the Šalek Valley is covered with forest (Google Earth Map, 2009)*

Wood was an important domestic energy source in the past and will certainly remain so in the future. Over 50% of the Šalek region is covered with forest (50% GGN Velenje and 71% GGN Bele Vode). According to the data of the forest management plans created by the Slovenian Forest Service, the growing stock of the Šalek Valley forests amounts to two million cubic metres or 370 m^3 per hectare, which is higher than the Slovenian average of 257 m^3/ha. With annual growth of 10.1 m^3 of wood per hectare, forests in the Šalek Valley present one of the fastest growing forests in the country. On average, one forest owner owns 1.7 ha of forest which makes it difficult to use forest products economically. The result is a number of deserted forests with many withered trees that pose a serious risk to the economical and ecological stability of the forests.

Solutions can be found in collaboration of forest owners, the Slovenian Forest Service and different forest management organisations. Traditionally, forest wood was used for many different purposes including construction timber, house heating and cooking. Wood and coal stoves that are commonly in use are technically and energetically inefficient. Modern wood logs, wood chips or pellet stoves are user-friendly and often reach efficiency over 91%.

Forest wood should have multiple functions (furniture, construction timber etc.) before it ends as firewood. Only a part of forest residuals and branches should end up as firewood in primary production. Slovenia has high quality forest wood resources that are capable of success on the wood market. Co-firing wood residuals or waste construction timber in a separate boiler in TEŠ (Thermoelectric power plant Šoštanj) is optional and temporary.

5 CONCLUSIONS

The Šalek Valley has been paying a high (too high) ecological burden for its rapid industrialization and urbanization in the second half of the 20th century. Intensive underground exploitation of coal as a non-renewable natural source for electrical and distance-heating

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production in TEŠ (Thermoelectric power plant Šoštanj) and other intensive businesses, and a fast-growing population have been a tremendous environmental burden (Špeh, 2006). The Šalek Valley was one of the most anthropogenically damaged regions in the country. People's awareness for a healthier and cleaner environment in 1989 forced the local government to act towards a sustainable and environmentally friendly path. An environmental institute (ERICo) was established for ecological researches, emission filters (SO_2, No_x) were installed at TEŠ, a waste water treatment plant was built, and natural rehabilitation of deserted and intoxicated soil from the waste and coal ash was put in motion. Development continues towards a sustainable and more renewable future.

The Šalek Valley has great potential for exploitation of renewable energy sources. The specific location of the valley, with three lakes near the city centre holds a great potential for water source heat pumps. Solar energy extraction (solar collectors, PV) is mostly limited to summer months. Using sources of biomass or wastes (landfill, WWTP) can be vital for space heating or for production of transport fuels.

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Nomenclature

t	time
OPEC	Organisation of the Petroleum Exporting Countries
HHV	Higher Heating Value
Mtoe	Million tonnes of oil equivalent
De-SOx	Denitrification

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PARTICLE INFLUENCE ON CAVITITATION DEVELOPMENT AT BLADE PROFILE (NACA 4418)

VPLIV DELCEV NA RAZVOJ KAVITACIJE NA LOPATIČNEM PROFILU (NACA 4418)

Boštjan Gregorc[ℜ], Andrej Predin[1]

Keywords: particles, cavitation, noise, torque, measurements;

Abstract

This paper deals with torsion torque and noise changes as a consequence of cavitation development with a blade with a NACA 4418 profile. Measurements were performed in a cavitation tunnel, where the cavitation development and torque change were observed. The noise measurements set the state of occurrence of cavitation. Based on the measurements results data, the ratio of torque differences was set as a function of three different concentrations of particles in liquids and in two different slope angles covered. By reducing the cavitation number (relative pressure system decrease) in order to enhance the vapour phase on the blade suction side, torque starts and the noise increase.

Povzetek

Prispevek obravnava spremembo torzijskega momenta in hrupa v odvisnosti od razvitosti kavitacije na krilu NACA 4418. Meritve so potekale na kavitacijskem tunelu, kjer smo opazovali razvoj kavitacije in vpliv na spremembo torzijskega momenta. Z meritvami hrupa smo določevali časovno točko nastanka kavitacije. Na podlagi meritev smo določili razlike razmerja torzijskega momenta v odvisnosti od treh različnih koncentracij delcev v kapljevini ter pri dveh različnih naklonskih kotih krila. Z zmanjševanjem kavitacijskega števila (zmanjšanje relativnega tlaka v sistemu) se zaradi povečanja parne faze na sesalni strani krila pričneta torzijski moment in hrup povečevati.

[ℜ] Boštjan Gregorc, PhD student, Dravske elektrarne Maribor, E-maill: bostjan.gregorc@dem.si

[1] Prof. Andrej Predin, PhD, Faculty of Energy Technology, University of Maribor, E-mail: andrej.predin@uni-mb.si

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1 INTRODUCTION

Model testing and research laboratories provide results only for certain controlled boundary conditions. In actual operating conditions, the boundary conditions can only be partially matched in some cases. In the case of hydropower operation, the physical and biological characteristics of water (temperature, viscosity, surface tension, the content of dissolved and undissolved air content of impurities) are changing. When the flow of rivers and streams changes, the amount of impurities (particles) in water is also changing. A stronger local rainfall causes an increase of impurities in water up to 30 times, depending on the underlying conditions. Changing the content of particles in the water can also lead to an increase in the likelihood of occurrence of abrasion and cavitation in hydraulic machinery. Cavitation represents a loss of energy according to the optimal operating conditions. In the case of the operation of water turbines, the cavitation effect on reducing utilization damages the turbine driver and other exposed areas.

Determination of changes in yield on prototypes of impurities in the water is difficult to achieve from the perspective of performance measurement. Constantly changing various parameters (oscillation generating power pulsation pressure, difference in altitude, temperature, air content and small concentrations of particles) affect the credibility of the results. The change in turbine efficiency is detected only at the stage of major cavitation erosion and abrasion of particles in water. For these variations of parameters in the case of the prototypes, we influence material in the water on the development of cavitation in an isolated blade studied in the laboratory. Due to the controlled conditions of entry in the execution of the measurements, particles with known diameters, densities and concentrations were used in the tunnel.

2 INFUENCE OF MULTI-PHASE FLOW (LIQUID-VAPOUR-SOLIDS) ON HYDRAULIC MACHINES OPERATING

Changing the concentration of solid phase (particles) in water affects the efficiency of hydraulic machines. Research related to the movement of liquids and particles in the transition through the pump and turbine have been investigated many authors [9,13,14]. For research, different materials, particle concentrations, and various basic material surfaces are used. For the evaluation of developments and implications in the process of cavitation and abrasion, authors used different CCD cameras-visualization [4,5,6], PIV Technology, methods of weighing, and vibration methods. In the case of service stations, by increasing the concentration of particles in the water, flow is reduced and so is efficiency. It also reduces the amount of pump pressure and NPSH (Q) [9]. In tests, it was found that the largest differences arise in the case of NPSH as a function of increasing pressure level (H_{sk}). By increasing the concentration, the resistance of liquid particles at the stationary surface is increased. Multi-phase flow (liquid-vapour-solids) also causes a change coefficient of buoyancy.

When the cavitation number decreases and when the vapour phase occurs (multiphase flow), particles act in combination with cavitation, erosion and abrasion [9, 16]. Particles in liquids are also caused by the rapid formation of initial cavitation. Initial cavitation in the multiphase flow of liquid-vapour occurs 10–15% earlier as in the case with operating with pure water [9]. Particles in liquids act as the initiator of the formation of the emergence of the vapour phase, also known as cavitation cores [11].

The impact of faster creation of cavitation due to particles in water also affects the rapid decrease of the efficiency of the pump or turbine. Within this area, this could represent a threat condition with cavitation erosion. In reality, this results in a highly erosive materials, and costly repairs. It indirectly increases the overall density of liquids and particles, which has a positive impact on the increase in driver torque. Erosion damage influenced on the roughness of the surface and creating the conditions for the formation of additional turbulence at the surface flow.

2.1 Cavitation cores

The presence of impurities (particles) forms the basis for the formation of so-called cavitation cores. Cores reduce the tensile strength of water as a result of changes in surface tension liquid [3,11]. The dependence of the tensile strength σ_n of surface tension γ and the distance between molecules d is shown in the following dependence:

$$\sigma_n = 2\gamma / d \tag{2.1}$$

The formation of a gaseous phase in a liquid is directly tied to overcome intermolecular forces. In the case of liquids without particles, the theoretical tensile spinout water is 750 MPa. When particles and gas impurities are present in the water, the water tensile strength decreases. The resulting decrease in the tensile strength of water affects the formation of vapour phase at higher cavitation numbers. Particles in water can be considered as sort of bud, which takes place where the vapour is collapsed into liquid. These are places where the vapour phase arises and changes its aggregate phase.

2.2 Cavitation development

The formation of cavitation is based on several important criteria: body size, surface roughness, turbulence flow, temperature, influence of liquid volume content of gas and particles (impurities). In the event that the local static pressure falls below the value of the vaporising pressure, liquids and particles create a multiphase flow (liquid-vapour-particles), which is increased in the static (reference) pressure condenses and becomes a liquid two-phase flow with particles. This means that by reducing the pressure in the system, or by increasing fluid flow speed, we change point of emergence of the vapour phase. With no-dimensional number σ, the dependency of hydraulic parameters of cavitation appearance could be determined.

$$\sigma = \frac{p_k - p_{mu}(T_k)}{\dfrac{\rho_m \cdot v_m^2}{2}} \tag{2.2}$$

where p_k represents the reference system pressure, p_{mu} is the fluid vapour pressure, ρ_m is fluid (mixture) density and v_m is the flow velocity. With cavitation number decrease, the possibility of cavitation development increases. Hydrodynamic cavitation causes a change of resistance, change hydromechanics flow, thermal, lighting effects and erosion in areas of surface flows. During the operation of hydraulic machinery, the most significant cavitation is in the form of a cloud. It causes a decrease of efficiency of machinery and mechanical damage due to high local pressures in the vapour implosions (a few tens of MPa).

In water turbines and pumps, the unequal operating noise is present. The released pressure wave at the collapse of vapour phase is spreading through the fluid and is drawn from a wide range of noise frequencies. The noise is accompanied with increased vibration in the occurrence of cavitation. Vibration or noise is perceived as consequences of the shock-wave are spreading in space and striking the surrounding area. The noise generated at the collapse of the bubble is located in the high frequency band. Capturing cavitation noise is highly dependent on the position of the sensor as well as in the measurements of the current around the observed body. The sound speed also affects attenuation in the field of multi-phase flow and the ratio between the vapour-phase particles and liquid phase.

2.3 Forces on profiled blade in cavitation tunnel

There are changing forces with the creation of multi-phase flow in flowing liquid (water) around the observed wings or hydraulic shovels. Flow field around hydraulic shape is generally a function of body size, flow attack angle, flow velocities, and matter properties of liquid [3]. The dimensionless numbers used to describe the external flow situation are: Froude $F_r = v_k / \sqrt{gl}$, Reynolds $R_e = v_k l / \upsilon$ and Mach $M_a = v_k / c$ number.

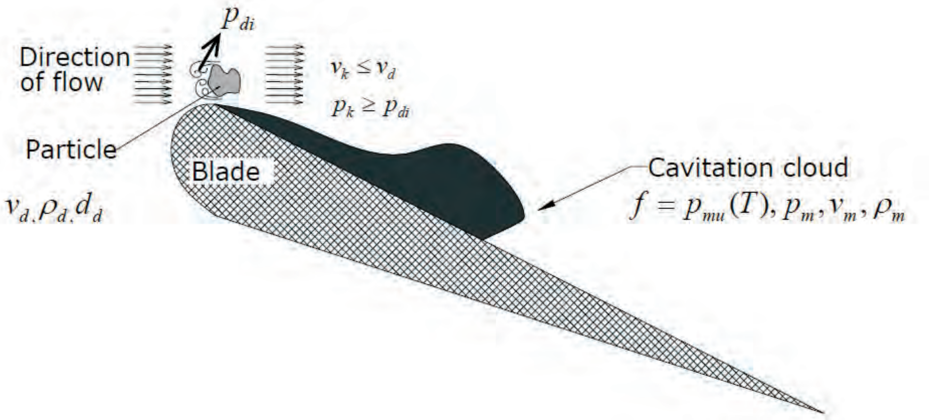

Figure 1: *Influential parameters on vapour phase development.*

In a mixture of water, at the observed blade profile, the movement of particles at blade surface are observed, and the lift and resistance force are determined. At appropriate conditions $p_k \le p_{mu}$, on the suction side of blade, at appropriate flow velocities, the vapour phase develops. The impact of the vapour phase is reflected in lift force, which increases depending on the development of the vapour phase. Particles in the mixture are moving slowly in the continuous phase leading to altered pressure particle tracks.

This paper presents the determination of the change in torque applied to a NACA 4418 hydraulic wing shape. Based on the geometry and taking into account the clamping blade, we set the coefficient of torque as:

$$c_t = \frac{12M_t}{\rho_m \bar{v}_m^2 A(l_1^3 - l_2^3)} \tag{2.3}$$

Where M_t is torque, ρ_m is mixture density, $\bar{v}_m$ is average velocity of mixture in the tunnel, A is characteristic area, l_1 is length between fixing point and trailing edge of blade, l_2 is the length between the fixing point and leading edge of blade profile. The equation (2.3) considers the resistance moment of area and its gravity center length.

3 EXPERIMENT

The impact of the change in particle torque and the development of cavitation were observed on the blade (NACA 4418). Testing was carried out on a small cavitation tunnel that is designed to research the development of cavitation in various forms of hydraulic blades. The measuring line is made in accordance with the recommendations for the implementation of cavitation tests following the ISO 2548 standard. The test rig is closed and allows flow velocities in the tunnel up to 5 m/s. The cavitation number change was performed by the controlled application of pressure in the system.

The flow rate was changed with frequency regulation (rotating speed) of the driving pump motor. Measurement of flow rates and flow velocities are preformed using venture nozzle, and the ultrasonic flow meter.

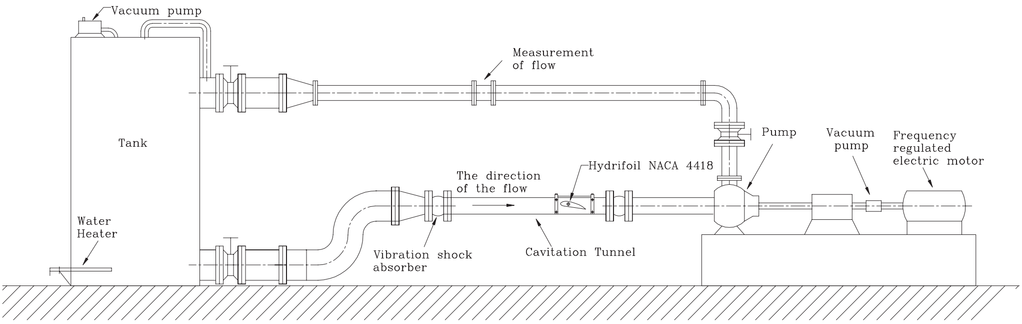

Figure 2: *Cavitation tunnel with the blade at intake pump side.*

The length of the blade is 104 mm and width is 64 mm, with overall length cavitation plane is part of the tunnel at length $l = 17 \cdot L$. The blade material is Cu Zn 40. The blade is a flexible spanning with two ball bearings. The blade is observed through the Plexiglas on the two perpendicular sides. Measurement of the torque is via the shaft cover and the chassis dynamometer accuracy is 0.1% (Alborn K - 25). The connection to dynamometer shaft and is implemented with cantilever handle length 94.5 mm. Capturing cavitation noise, we follow the

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sensor (Cirrus Research plc - CR: 800B) mounted above the plexiglass and isolated from its surroundings with Styrofoam. The sensor is set away from the occurrence of cavitation on the blade from 11 to 13 mm. Pressure in the channel was measured before and after the opening. The cavitation channel is separate from the rest measuring lines with rubber dampers.

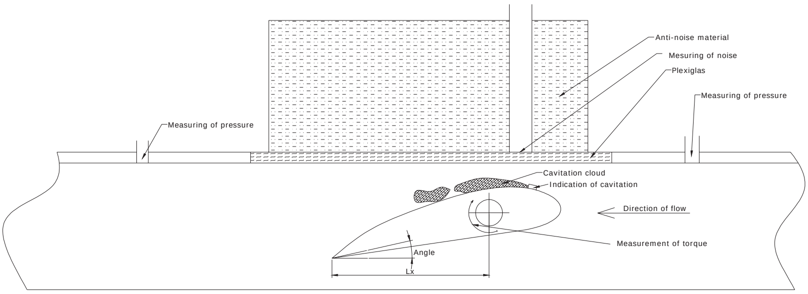


Figure 3: *Schematic of a foiled blade (NACA 4418).*

Measurements were performed at different flow velocities in the tunnel (2.6 m/s, 2.9 m/s, 3.3 m/s and 3.6 m/s). The flow velocity at the minimum intersection between blade and body of the tunnel was between 6.6 m/s and 9.1 m/s, which means that the Reynolds number ($R_e = v_m \cdot l / \upsilon$) is between $2 \cdot 10^5$ and $3.5 \cdot 10^5$. Measurements are performed at two different blade angles settings (16˚ and 20˚). Slope angle α is positive if intake angle is larger than outtake angle at the output. Torque has a positive sign when the hydraulic power pushes up the leading edge of the blade. The reference static pressure with a mixture of particles is designated p_k in the case of clean water and is used to determine the cavitation number. Torque measurement took place without taking into account the relative friction in the bearings. Cavitation noise was included in the various frequency bands (from 25 Hz to 16 kH), and at various cavitation numbers. Visual monitoring of initial cavitation was monitored at a metal initiator that is located in the middle part of the input blade part (initiator is square 4 mm x 2 mm x 6 mm). The initiator is set away from the leading edge of the blade at a distance 12 mm. Measurements were started with pure water (tap water), then a certain concentration of particles in the system was added three times.

3.1 Preparation of water mixture

For measuring the impact on the development of cavitation, we used particles (sand) material FR 240/F. The density of particle is $\rho = 1700\, kg / m^3$, which are insoluble in water, inert and do not oxidize.

Determination of particle size for testing was chosen on the basis of measurements of the actual size of the particles in the Drava River. Measurements of particle size, surface area and concentration in different annual periods and at different flow rates were determined with a microscope, by filtering, and by weighing. The size of particles in river water was determined by means of a Nikon SMZ - 2T stereoscopic microscope, Sony high-resolution CCD video camera and Lucia M software package. The average density of particles in the Drava River is approx. $\rho = 2200\, kg / m^3$ [7].

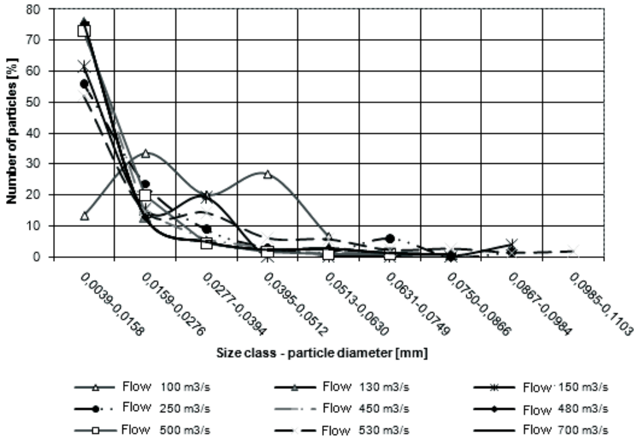


***Figure 4:** Size of particles determination, depending of Drava flow rates*

On the basis of certain real size of river particulates (Figure 4) through screens, we obtain the corresponding procedure for the testing of comparable particles in the cavitation tunnel. Particle size is classified and determined on the basis of analysis diameters. For measurements in the cavitation tunnel, we used three different concentrations of particles. All measurements were performed at the same conditions (flow rates, the reference pressure in the system, temperature).

	Particles density [kg/m^3]
Clean water	0
Concentration 1 (**Con1**)	1,1
Concentration 2 (**Con2**)	1,6
Concentration 3 (**Con3**)	3,22

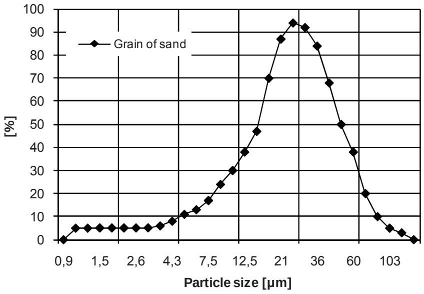


***Figure 5:** Determination of particle size classes FR 240/F of the sieving analysis and the concentration used for testing in the cavitation tunnel.*

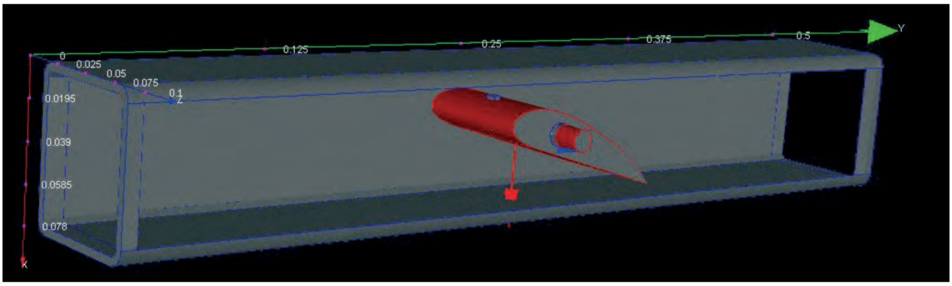


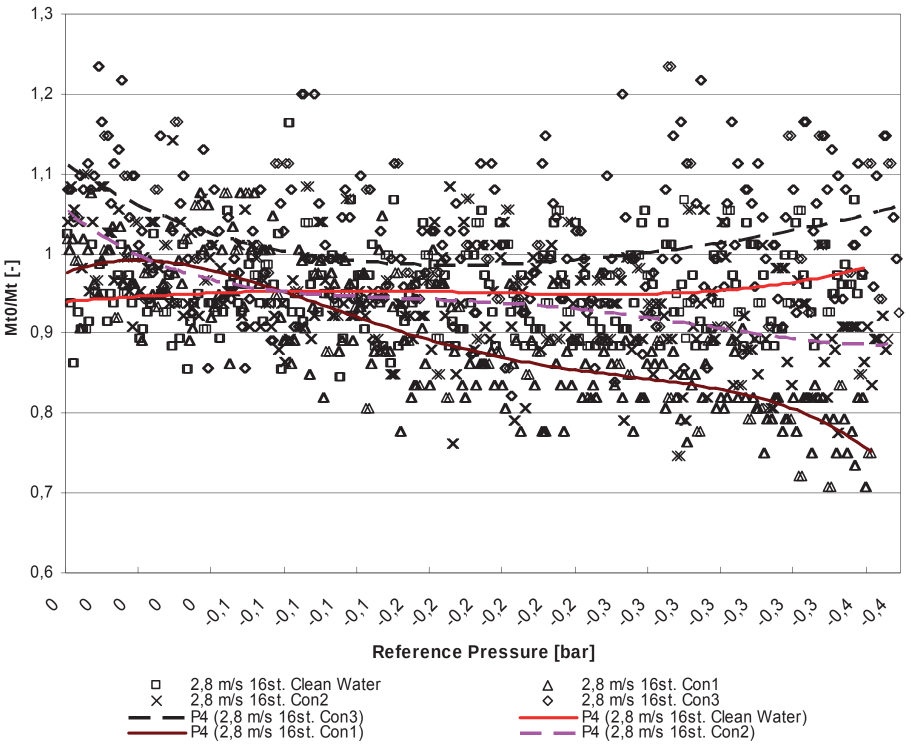
***Figure 6:** Cavitation tunnel sketch with embedded blade*

3.2 Results and data analyses

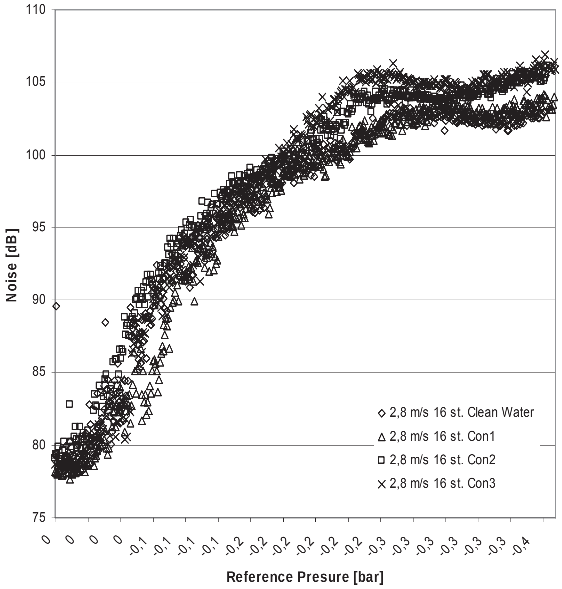
Torque change is given by the dimensionless ratio of the torque applied to the condition of the reference pressure M_{t0}/M_t (2.9 m/s, α = 16°) or M_t/M_{t0} (2.6, 3.6 m/s, α = 20° and 3.3 m/s, α = 16°). Torque varies with the change of the reference pressure in the system. The resulting noise, as a result of the cavitation development, is given in dB. Torque and the noise are shown relative to a reference pressure in the system, the concentration of particulate matter, the average speed of the mixture in the channel, and blade angle (α). Standard deviation is shown as a function of the reference pressure in the system and depending on the torque.

By increasing the reference pressure in the system (Figure 7) the torque decreases to a minimum. By lowering the reference pressure in the system, noise increases by 30% (developed vapor phase). On the basis of measurement noise and torque, we note that a change of noise is detected much earlier than the torque change.

Noise amplitude fluctuations as well as increased torque monitor increased vibrations. Increasing the concentration of particles causes a faster change in momentum as well as noise in comparison with pure water.



a)



b)

Figure 7: *(a) Torque and (b) noise in dependency of particles in water – concentration, and reference clean water (2.6 m/s, α = 16^o)*

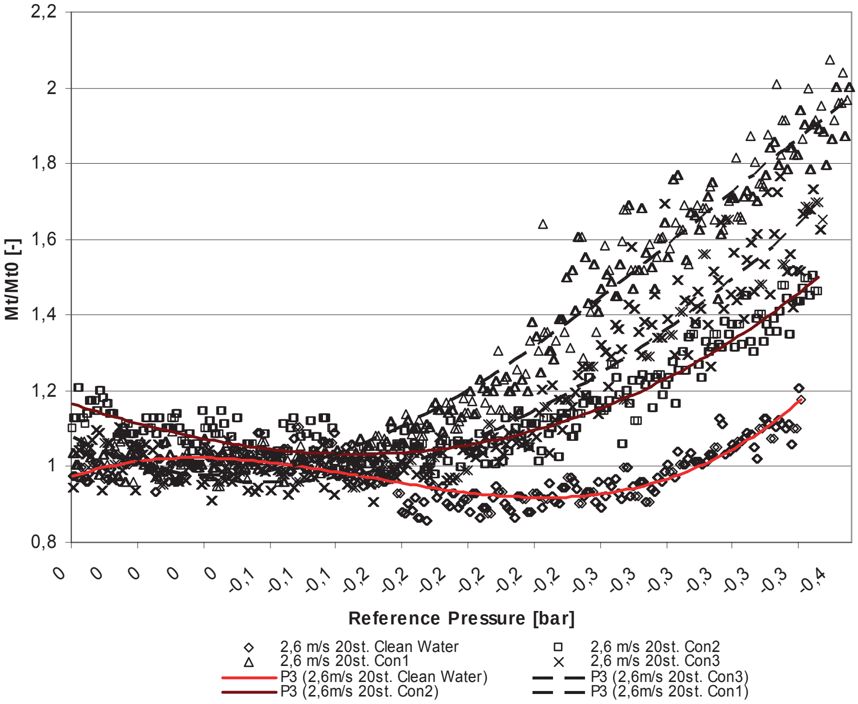


Figure 8: *Characteristic torque in dependency of concentration change, regarding clean water at 2.6 m/s, α =20^o.*

By increasing the gradient blade angle (Fig. 8), the distribution of vapour phases following the suction side blade surface changes. From the measurements, it is clear that regardless of the underlying value of torque, in all cases the torque falls slightly as a result of the formation of the vapour phase on the surface of the blade. By reducing the reference pressure in the system, the torque does not change linearly with regard to a change in pressure but exponentially. The largest change in momentum can also be seen in the maximum concentration of particles in water, while in comparison with pure water it changes by 60% (reference pressure -0.4 bar).

By increasing the flow rate and reducing the pressure of the reference mixture in the cavitation tunnel, torque increased in all cases of different concentrations (up to 2 to 3 times regarding basic value -M_{t0}). The difference between pure water and the maximum concentration of particles is 70%. By increasing the angle of the blade, cavitation occurs in a smaller absolute change in pressure in the system. The greatest change in momentum was caused by Con3 at the reference pressure - 0.4 bar.

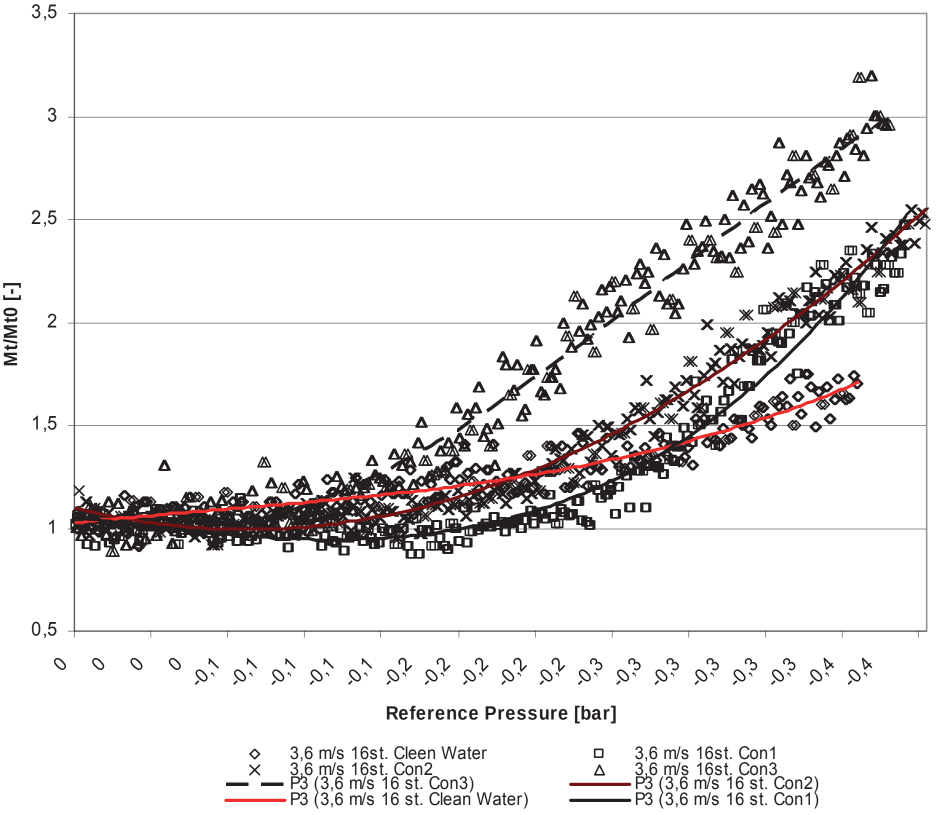


Figure 9: *Characteristic torque in dependency of concentration change, regarding clean water at 3.6 m/s , α =20°.*

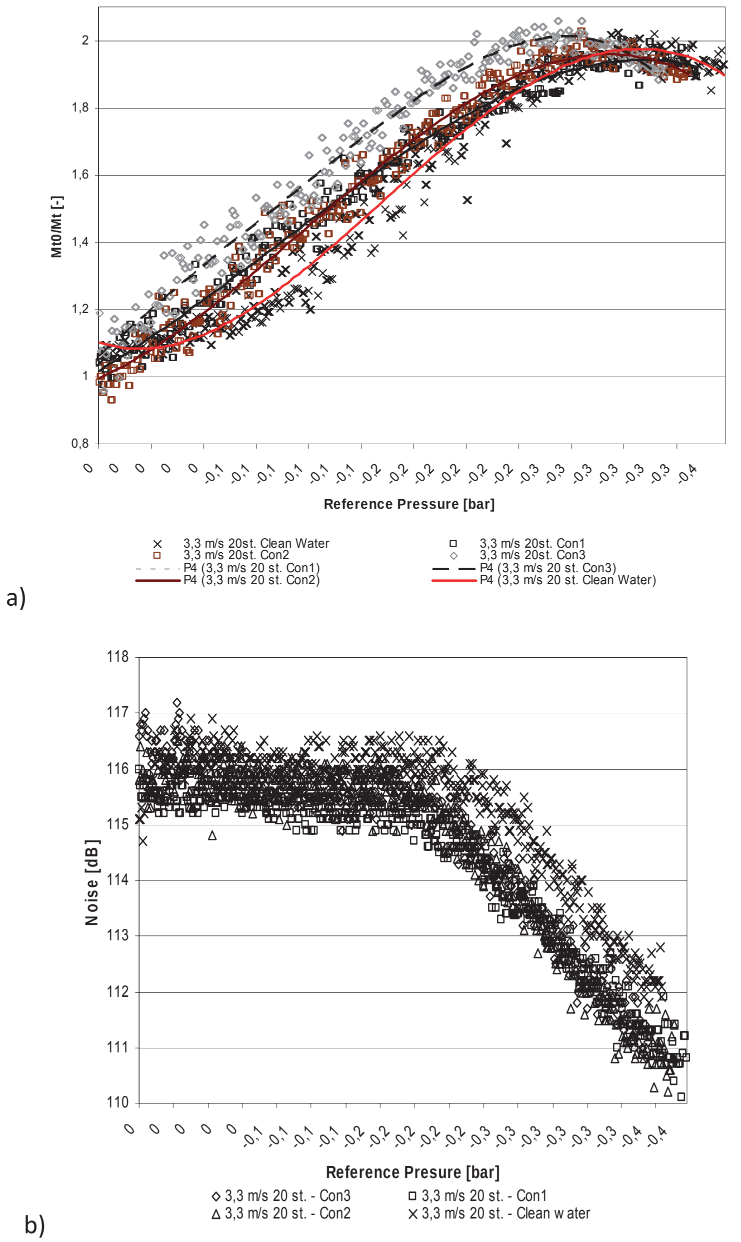


Figure 10: *(a) Torque and (b) noise in dependency of particles in water – concentration, and reference clean water (2.6 m/s, α =16^{o})*

Strongly developed vapour phase on the suction side of blade has an impact on reducing noise. The vapour phase leads to increased sound damping in the field of sound propagation. The damping of sound is also partly influenced by particles in a multiphase flow. We anticipate that the developed cavitation is no longer in the place of vapour imploding at the suction blade side surface, but in the course of liquids and particles. A pronounced decrease in noise occurs in the range of the occurrence of the developed supercavitation.

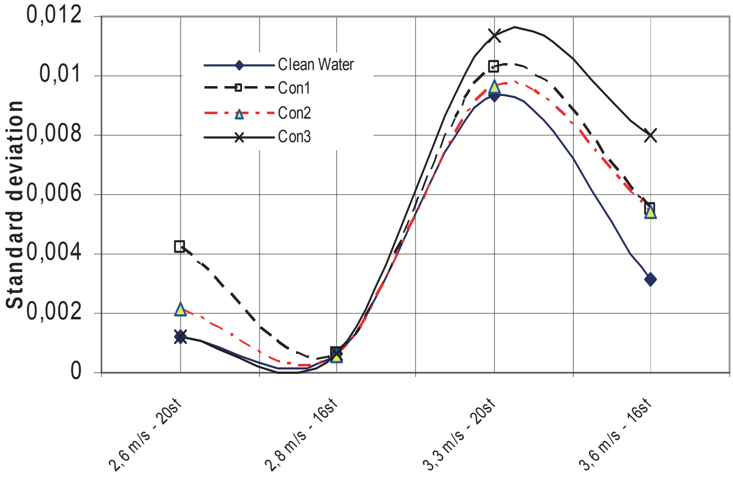


Figure 11: *Standard deviation of torque in dependency of particle concentration change in water at 3.3 m/s , α =20^o.*

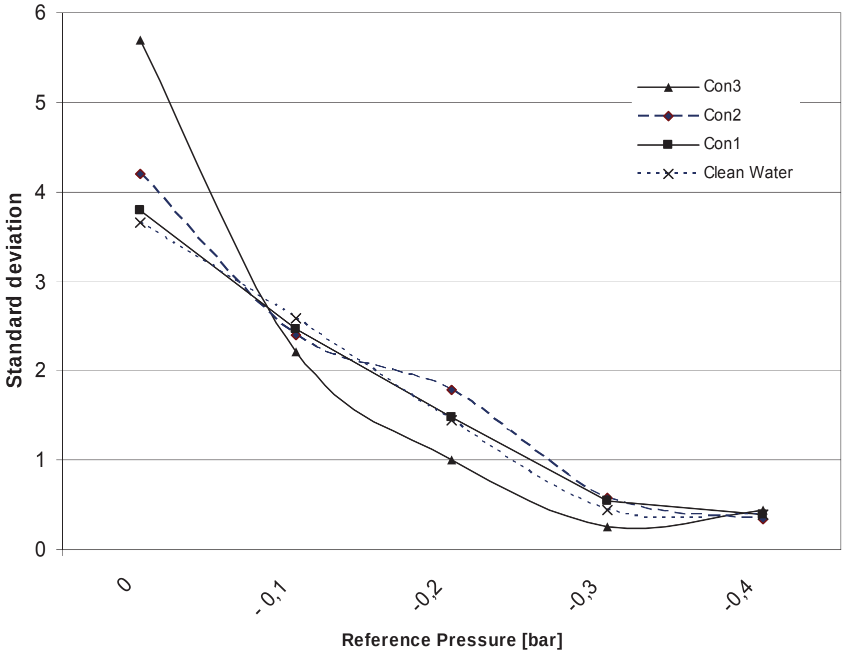


Figure 12: *Standard deviation of noise in dependency of particle concentration change in water at 3.3 m/s α =20^o.*

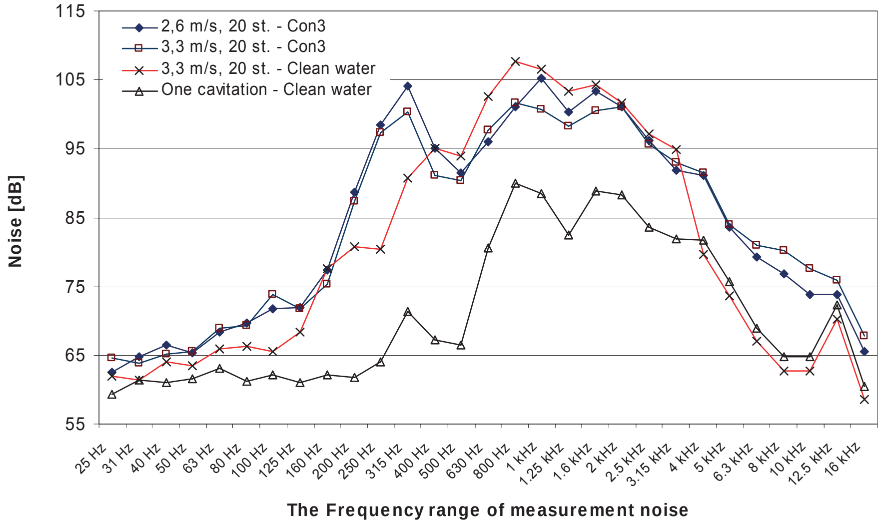


Figure 13: *Noise power in dependency of frequency band, at different particles concentration in water.*

The maximum deviation varies in proportion to the increase in gradient angle blades, and partly by increasing the speed of the mixture in the cavitation channel. Derogation standard deviation is included in the overall reduction in the reference pressure. Pronounced deviation is observed at all concentrations, as well as clean water in the area of 3.3 m/s and $\alpha = 20^o$.

Standard deviation of noise data for a given reference pressure is shown in Figure 12. The maximum deviation of the noise is observed in the zone of the occurrence of the vapour phase. Reducing the reference pressure in the system decreases the standard deviation.

The measurement noise as a function of frequency spectrum and the state of liquid (pure water, concentration 3), the maximum noise occurs at a frequency of 1 kHz. It is also at a frequency of 315 Hz where increased noise was detected, which may be due to a cavitation cloud tearing [3]. The impact of particles on the strength of the noise is pronounced over the frequency 4kH where the noise is increased. The increase in noise is also observed at a frequency of 12.5 kHz.

4 CONCLUSIONS

In the cavitation tunnel, we explored the effect of particles in the water to change the relative ratio of lift forces and the relative intensity noise on a blade foiled with the NACA 4418 profile, in three different concentrations of particles in water. In examining the impact of particles on lift force and noise, we compared the measured relative securities of clean water free of particles. From the measured values, we have come to the following conclusions:

A) On a small corner of the inclined blade ($\alpha = 16^o$), the developed vapour phase change produces a greater lift force, as in the case of a large gradient angle ($\alpha = 20^o$). Change in the lift force depends on the surface of the developed vapour phase, or the distance from the centre of shrinkage blade profile. When cavitation increases, vapour cloud cover over the centre axis of the trapped the torsion torque increases.

B) By reducing the reference system pressure, increases develop in the multiphase flow of liquid, particle and vapour phase across the "intake" to the airfoil surface, which in turn increases the ratio of lift forces. The experimental measurement shows that the lift force increases with an increasing concentration of particles in water.

C) Increasing the speed of the mixture over the cavitation tunnel formation causes increased intensity of the vapour phase; this in turn, increases the ratio of lift forces.

D) The developed cavitation cloud is unstable and does not have a compact form. Breakage of the cloud causes the pressure and lift force pulsations. Most pulsating lift forces occur in an area where the cloud does not "fall off" from the inlet suction surface cover.

E) Standard deviation ratio of lift forces is most pronounced for all levels, including for clean water, at 3.3 ms^{-1} at angle of 20˚.

F) The formation of cavitation on the blade is rapidly detected by increased noise in the range of the occurrence of vapour phase. Noise increases in developed cavitation by 35%, in comparison to the state without cavitation. For noise measurements, we depend on visual creation of the vapour phase. Determination of the emergence of the vapour phase by measurement of the relative noise gives satisfactory results. The noise is detected independently of the visual forms of the vapour phase in the presence of increasing concentrations of dispersed particles.

H) Standard deviation of noise is pronounced at the stage of the emergence of the vapour phase that recorded the largest deviations. Noise measurement quickly detects the emergence of the vapour phase in the system, as in the case of measurements of buoyancy forces.

I) The values of maximum amplitude of noise in some frequency areas are reached in the range of 1 kHz. The effect of concentration of particles on the strength of noise appears markedly higher than 4 kH. In this area, the noise is greater than in the case of clean water, i.e. free of particles.

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