ELEKTROTEHNIŠKI VESTNIK 83(6): 97-103, 2019
ORIGINAL SCIENTIFIC PAPER

Comparing Environmental impacts of three typical Slovenian electricity providers with hydroelectricity

Mitja Mori[1], **Rok Stropnik**[1]

[1]Univerza v Ljubljani, Fakulteta za strojništvo, Aškerčeva 6, 1000 Ljubljana, Slovenija
E-pošta: rok.stropnik@fs.uni-lj.si

Abstract. A Sustainable development and reduction of environmental impacts in the energy generation sector can be achieved focusing renewable energy sources (RES) in electricity generation. To evaluate the environmental impact of in the entire life cycle of an individual technology or process, a life cycle assessment (LCA) methodology is used. In this paper, a LCA is made for three different typical Slovenian electricity providers for a 1kWh as functional unit. The study covers the scope from the cradle to gate (electricity at the consumer), from provisioning the necessary raw materials, electricity generation, transmission and distribution. The electricity providers use different shares of RES, fossil and nuclear fuel in their electricity generation mix that result in different environmental impacts. In setting up the LCA model, the Gabi Thinkstep software is used. To evaluate the results on global, regional and local level, the CML 2001 methodology is used. The environmental impacts of the three providers are compared with the Slovenian hydroelectricity. The results show that the lowest environmental impact has hydroelectricity followed by a provider A. When assessing the environmental impact of a particular electricity generation technology with only one environmental impact indicator, it is impossible to gather proper information about the regional and local environmental impacts, such as acidification, human toxicity, summer smog, etc., which affect the local population and their environment.

Keywords: life cycle assessment, electricity providers, hydroelectricity, Slovenia, environmental impacts

Primerjava okoljskih vplivov tipičnih ponudnikov električne energije v Sloveniji z električno energijo iz hidroelektrarn

Trajnostni razvoj in zmanjšanje vplivov na okolje v energetskem sektorju, ki se osredinja na proizvodnjo električne energije, je mogoče doseči z uporabo obnovljivih virov energije (OVE) za proizvodnjo električne energije. Za analizo vplivov proizvodnje električne energije na okolje v celotnem življenjskem ciklu je bila uporabljena metoda analize življenjskega cikla (LCA). V tem prispevku je bila izdelana LCA analiza 1kWh proizvedene električne energije za različne ponudnike električne energije na slovenskem trgu in primerjana s 100-odstotno proizvodnjo iz hidroelektrarn. Obseg študije je od zibelke do vrat, in sicer od pridobivanja surovin do uporabe električne energije. Ponudniki električne energije imajo različne deleže primarnih virov iz OVE, fosilnih goriv in jedrske energije, kar pa pomeni različen okoljski vpliv proizvedene električne energije. Metodologija LCA je bila uporabljena za postavitev numeričnih modelov v programskem okolju GaBi thinkstep. Za analizo okoljskih vplivov življenjskega cikla je bila uporabljena metodologija CML 2001 za globalne, regionalne in lokalne okoljske kazalce. Ta študija in rezultati kažejo, da imajo primarni viri energije pomembno vlogo pri vplivu proizvodnje električne energije na okolje.

1 INTRODUCTION

Energy is the life driving force of the economy, industry and people. Its supply must be safe, reliable, affordable and environmentally friendly. In Europe conversion of the primary energy sources into electricity and heat generates 80 % of all greenhouse gas emissions. To reduce harmful emissions into environment and raise the quality of life, our society has to move towards a sustainable development also in the energy sector. A sustainable development in the energy sector, in terms of electricity, should meet the electricity demand without compromising the future generations, [1].

One of the ways of ensuring a sustainable development in the energy sector is to use new technologies for electricity generation from different primary energy sources, such as renewable energy sources (RES). While the use of RES could reduce our dependence on fossil fuels, it's disadvantages are low availability, high economic viability and in some cases and according to some criteria also higher environmental impacts, [2]. The main advantage of the RES generated electricity, compared to the fossil fuel generated electricity, is that the impact on the environment is smaller and more sustainable, [3,4].

The paper compares the environmental impact of 1kWh unit generating electricity for three typical Slovenian electricity providers with the impact of 100 % electricity generating from a hydro power plant. Each technology and primary energy source used in Slovenia is investigated in the study: lignite, hydro, nuclear,

---

Received 13 November 2018
Accepted 28 March 2019

natural gas, brown coal, heavy fuel oil, biomass, biogas, wind, photovoltaic and waste to energy. For the three typical electricity providers, the ratios of the primary energy sources and the technology data are obtained from the electricity bills and public databases, [5], thus providing the data needed for setting up an LCA model for each electricity provider and the Slovenian hydroelectricity. The environmental balances are calculated and analysed using 12 environmental indicators according to the CML 2001 life cycle impact assessment methodology (LCIA), [6].

2 LCA METHODOLOGY

The LCA methodology follows the ISO 14040 and 14044 standards, [7,8]. The system is modelled using the LCA software Gabi Thinkstep, [9]. The impacts are evaluated according to the CML 2001 method, [10]. This is a problem-oriented method, often referred to as a ‘midpoint’ approach, because it considers the environmental burdens at an intermediate point between the point of intervention (extraction of resources or emissions to the environment) and the ultimate damage caused by that intervention. This method is the most commonly used by other relevant studies, [2,11–13].

2.1 *Goal, scope and functional unit definition*

The goal and scope define the questions our analysis tries to answer and set its spatial, temporal, and technological boundaries. The product function is defined and quantified by the functional unit – which in the case of this study is 1 kWh of the generated electricity. The goal of the study is to determine the environmental impacts of electricity generation of three typical electricity providers in Slovenia using different types of primary fuel in their portfolios.

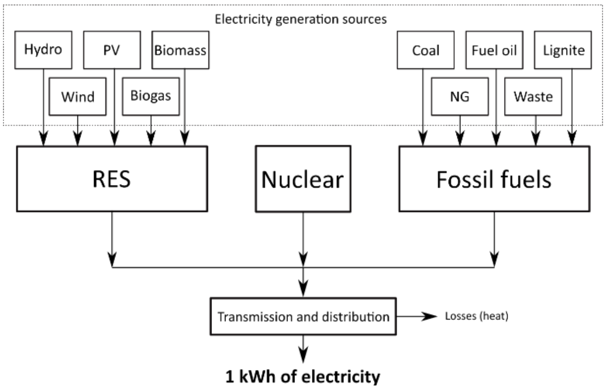

Figure 1. LCA model of electricity generation for different electricity providers.

As illustrated in Figure 1 the scope of the study is from ‘cradle to the gate’, considering the following stages: extraction and production of primary energy carriers i.e. fuels, power plant construction, electricity generation, transmission and distribution to consumers. The data used in our study are the secondary data from the 2016 generic international Gabi professional database, [14]. In the numerical model the electricity grid distribution losses (6.26 %) and the on-site electricity consumption (2.67 %) of the grid are included.

For the Slovenian grid, the 2016 fuel mix is used, defined in the Gabi professional database (see Figure 2). In the publically available portfolio for each of the three typical Slovenian providers there are three main primary fuel categories (see Figure 3): fossil, nuclear and RES. The known ratios of 11 technologies used in their portfolios are re-calculated to fit their generation source shares to be used as an input data for the LCA model.

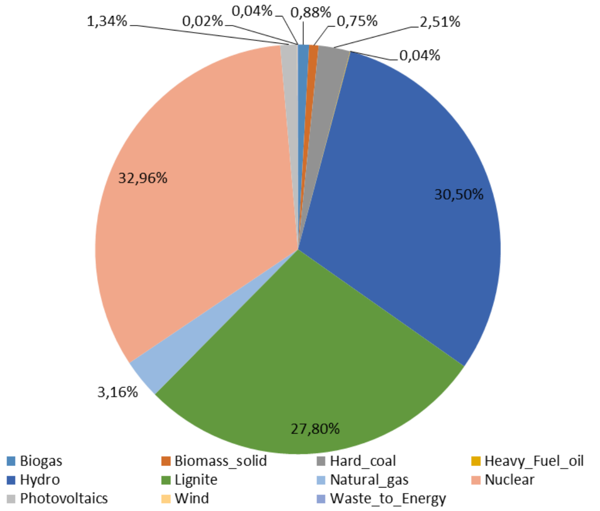

Figure 2. Slovenian grid generation source shares used in the 2016 electricity generation, [15].

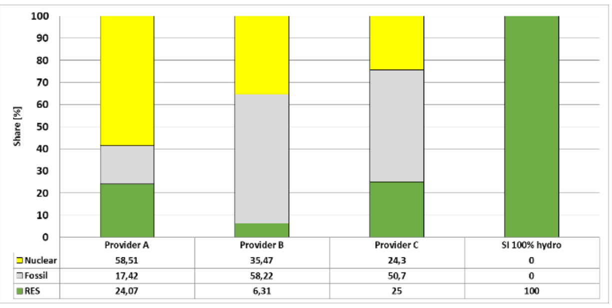

Figure 3. Share of the RES, fossil and nuclear fuel based electricity generation of the considered three typical electricity providers, [5].

2.2 *Life cycle inventory analysis*

In the life cycle inventory (LCI) analysis, the relevant flows, major resources and energy consumption throughout the life cycle are considered. The LCI data obtained from the electricity providers, generic databases [14,15], and publically available data or literature, in that order of priority, [5]. The input data used in our LCA model for each typical electricity provider are presented in Table 1. The shares of the RES based electricity generation (biogas, biomass, hydro, PV and wind) and the fossil fuel based electricity generation (coal, heavy fuel oil (HFO), lignite, natural gas (NG) and waste to electricity (WtE) are calculated for each electricity provider using the shares from the reference numerical model of the Slovenian grid mix (SI-MIX) and the publically available data for electricity providers.

Table 1. The share of the electricity generation sources and input data for the LCA model for the three typical providers in Slovenia

	Provider A [%]	Provider B [%]	Provider C [%]	SI hydro [%]
Biogas	0.6	0.2	0.7	0.0
Biomass	0.5	0.1	0.6	0.0
Hard coal	1.3	4.4	3.8	0.0
HFO	0.0	0.1	0.1	0.0
Hydro	21.9	5.7	22.8	100.0
Lignite	14.4	48.2	42.0	0.0
Nat. gas	1.6	5.5	4.8	0.0
Nuclear	58.5	35.5	24.3	0.0
PV	1.0	0.3	1.0	0.0
Wind	0.0	0.0	0.0	0.0
WtE	0.0	0.1	0.1	0.0

As the publically available data for the electricity providers do not include all 11 technologies/sources for electricity generation (see Figure 3), they are determined by recalculation from available data (see Figure 2) and the known data in the Gabi database, [15].

2.3 *Numerical models*

The Numerical models are set up in the Gabi Thinkstep software, [14]. Figure 4 presents the numerical model for Provider A.

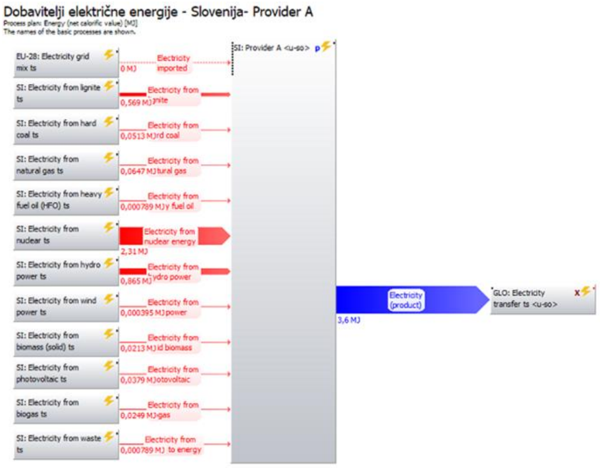

Figure 4. Gabi numerical model for electricity Provider A

The numerical model for each electricity provider is set up according to its share of energy sources/technologies. The data given in Table 1 are used. In the numerical model presented in Figure 4 the EU 28 electricity generation source ‘’EU28-Mix’’ process represents the imported electricity. Finally that process is set to zero in all cases as there is no data available of the electricity imported by the providers. After setting up the numerical models, the mass, energy and environmental balances are calculated.

3 RESULTS AND DISCUSSION

The results are presented according to the life cycle impact assessment (LCIA) CML 2001 methodology (CML 2001, Jan. 2016), [16]. Results are presented in terms of the absolute (Table 2) and normalized values to the maximum values in radar shaped diagrams.

At the first glance it seems Provider A has the best electricity generation fuel source mix according to the most mid-point impact indicators, because it has the lowest absolute values for the nine out of the twelve environmental indicators. Provider A has the second highest RES share in its grid mix, the biggest share of the nuclear fuel generated electricity and a relatively low share of the fossil fuel generated electricity. Provider B with the biggest share of fossil fuels in its portfolio has the maximum values in eight of the twelve environmental indicators that confirm the relatively bad environmental impact of the fossil fuel generated electricity. Provider C is somewhere in the middle, it has an almost equal share of RES as provider A, but a much lower share of nuclear energy that is replaced with fossil fuel generated electricity. The environmental impact compared with the hydro energy, we can easily conclude that of the hydro energy has much lower environmental impact, except one, which is abiotic depletion (AD). High AD impact is due to lowering of non-living (abiotic) resources affected by a high share of RES in the grid mix, [17]. That is the reason why the AD indicator of the 100 % hydro generated electricity is the biggest.

Table 2. The Absolute values for each environmental indicator of the CML 2001 methodology.

	Provider A	**Provider B**	**Provider C**	**SI hydro**
AD elements, [kg Sb-Eq.]	1.21E-07	4.40E-08	1.16E-07	2.27E-07
AD fossil, [MJ]	2.21E+00	7.18E+00	6.26	0.0308
GW 100 years, [kg CO$_2$-Eq.]	0.232	0.755	0.660	0.00587
GW 100 years, ex. bio. Car. [kg CO2-Eq.]	0.232	0.755	0.660	0.00588
OD, [kg R11-Eq.]	4.47E-12	2.72E-12	1.89E-12	1.14E-15
A, [kg SO$_2$-Eq.]	5.14E-04	1.52E-03	0.00136	1.19E-05
FAET inf., [kg DCB-Eq.]	0.00107	0.000903	0.000704	3.81E-06
MAET inf., [kg DCB-Eq.]	1.29E+01	1.67E+01	18.8	0.284
E, [kg PO$_4$-Eq.]	6.41E-05	1.74E-04	0.000159	1.45E-06
HT inf., [kg DCB-Eq.]	0.0113	0.0207	0.0184	0.000373
POC, [kg C$_2$H$_4$-Eq.]	3.39E-05	1.00E-04	8.95E-05	7.46E-07
TET inf., [kg DCB-Eq.]	0.000164	0.000561	0.000484	1.06E-05

In the next sections environmental impact indicators will be discussed in terms of their global, regional and local individual environmental impact.

3.1 Global environmental impact indicators

In the CML 2001 methodology the global indicators are AD elements, AD fossil, global warming (GW 100 years and GW 100 years excluding biogenic carbon) and ozone depletion (OD). Among those indicators, the most popular is the GW, despite showing only the intensity of using the fossil fuels in a certain technology/process. So, using more fossil fuels indicates a higher GW, [18].According to the EU legislation CO_2 is not a pollutant. It is therefore important to analyse other indicators more thoroughly. AD indicates depletion of the resources on the earth and is a very important indicator of sustainability of the used technology. On other hand, OD indicates the extent of the damaged ozone layer that protects us and the environment against harmful radiation.

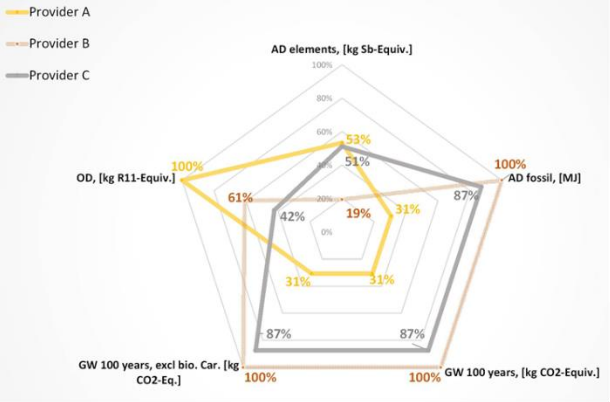

Figure 4. Relative comparison for the global impact indicators for a 1 kWh of the electricity generated by the considered providers.

In Figure 4, the global impact indicators are presented for three providers. There is no, 100% hydroelectricity, because of its low environmental impact of which only AD could be seen on the diagram. The share of fossil fuel generated electricity of Provider B is the biggest making GW and AD fossil indicators the highest. The OD share of Provider A is the biggest, thus increasing the nuclear energy share in the provider portfolio. Ozone layer depletion (OD) refers to the thinning of the stratospheric ozone layer by chlorofluorocarbons (CFCs), which results in an increased UVB radiation to the earth surface. Figure 5 shows a relative comparison between different technologies in the OD CML 2001 environmental impact indicator for a 1 kWh of the generated electricity and also three considered providers. Despite the ban of CFCs under the Montreal Protocol, some OD substances are still manufactured in various non-signatory countries for the use in the signatory countries, [19]. As such, OD is still an open issue. Nuclear power emits around 0.55 µg of CFC-11 equiv./kWh, most of which is normally attributable to mining and milling, although the figures can also vary widely depending on the enrichment technology used, [20]. For PV, 3.6–25.2 µg/kWh is emitted. In the PV life cycle, this impact is mainly due to the manufacture of tetrafluoroethylene, the polymer of which (Teflon) is often used in solar cell encapsulation, [21].

The 100 % hydroelectricity has the highest impact on the AD elements. It comes from a big environmental impact when building hydro power plants. AD is the only indicator among all the 12 indicators which is the highest for 100% electricity generated form hydro power plant compared with providers A, B and C. Analysing the reasons for that shows (see Figure 6) that electricity generated with higher RES share has bigger AD indicator compared with e.g. lignite based generated electricity. The reason is that there is lot of lignite available in the world and the impact of 1 kWh of the lignite generated electricity is low as far as depletion of this source is concerned. On other hand, in the PV technology there are several critical materials used that are not available in large quantities in the world, this is why depletion of those sources is quite severe.

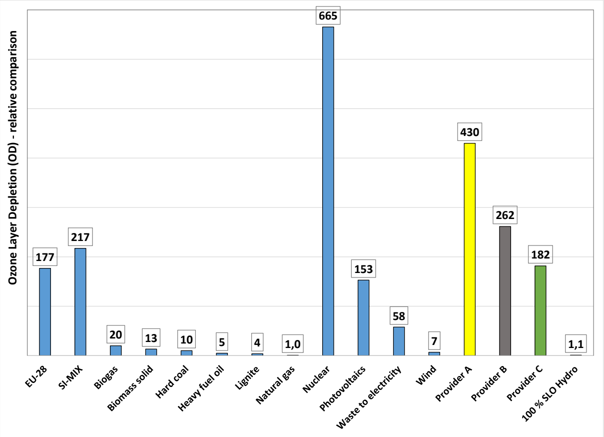

Figure 5. Relative comparison of OD for a 1 kWh of electricity generated from different sources in Slovenia and the three considered providers plus a 100 % hydroelectricity.

It is particularly in PV that AD is very high this is primarily due to depletion of silver and tellurium during manufacturing the metallization pastes required for the silicon cell production (thought the copper and silver components used in capacitors also contribute to this impact), [21]. The wind turbine depletes 5.39 mg Sb eq./kWh of abiotic elements, 99% of this is incurred in the manufacturing stage due to the depletion of molybdenum used for steel production. The depletion of fossil fuels is estimated at 1.15 MJ/kWh. This is again in the manufacturing stage which contributes 85.5% to the total consumption of fossil fuels due to the energy used for steel manufacture, [22].

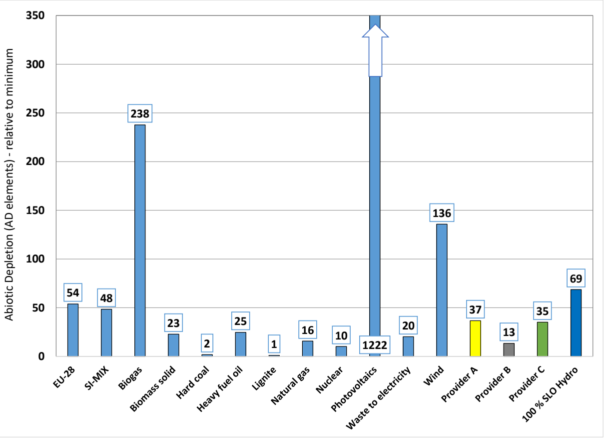

Figure 6. Relative comparison of AD for a 1 kWh electricity from different sources and the three considered providers plus 100 % hydroelectricity.

3.2 *Regional environmental impact indicators*

In the category of regional indicators, acidification (A), fresh water eco toxicity (FAET) and marine water eco toxicity (MAET) are discussed.

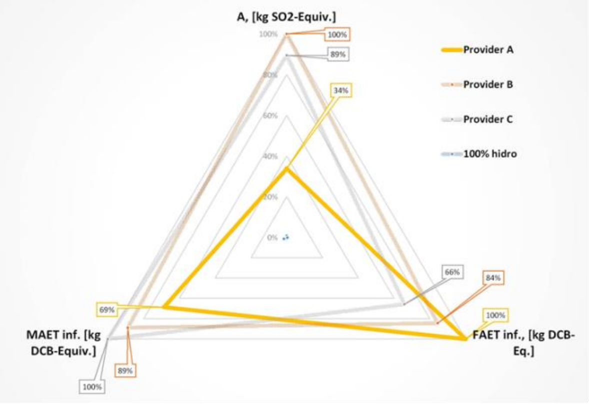

Figure 7. Relative comparison for the regional impact indicators for a 1 kWh electricity of the considered providers and hydroelectricity.

Provider A has the lowest values for two of the three regional environmental indicators, but the highest value of FAET (see Figure 7). In the provider A portfolio, the share of the nuclear electricity is almost 60 % (see Figure 3) and the nuclear source generated electricity has the third largest value of the FAET indicator along all the electricity generation technologies (see Figure 8). In the case of the FAET local environmental indicator, the technology the most impacting the fresh water is the HFO generated electricity that has a ten times higher impact than any other technology (see Figure 8), that is mainly due to heavy oil metals. Mining process (within nuclear fuel) is the main contributor with more than 99% of the potential impact on the eco toxicity. Vanadium is the main contributor to the eco-toxicity (80%). It is followed by molybdenum (10%) and uranium (2.5%), [23].

The provider B portfolio has the highest share of the fossil fuel generated electricity, this being the reason for the highest A compared to the all considered providers. Provider C is similar to Provider B with a small difference in FAET, the highest MAET and a very high A. For A environmental indicator the biggest negative impact comes from the electricity generated from heavy fuel oil, lignite (the biggest share is in the Provider B portfolio) and black coal (see Figure 9).

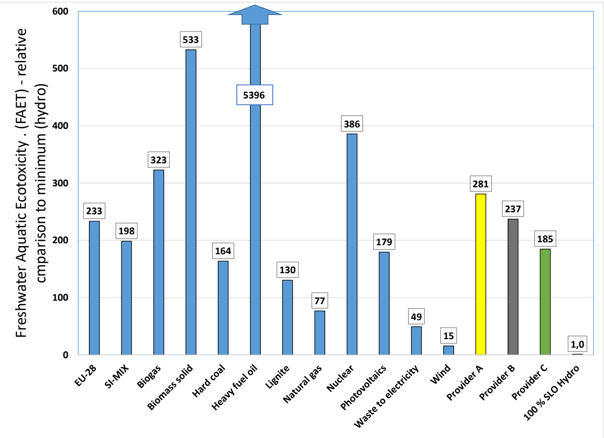

Figure 8: Relative comparison for the FAET impact indicator for a 1 kWh of electricity generated by using different technologies for the considered three providers and hydroelectricity.

Interestingly, the biogas and biomass generated electricity also has a large A indicator, but in Slovenia such electricity generation is scarce, [5].

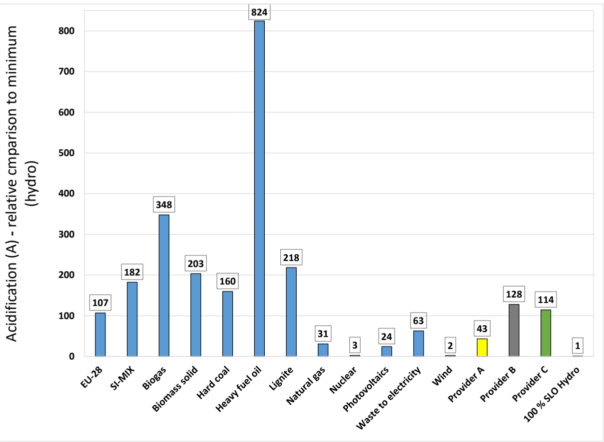

Figure 9. Relative comparison for A for a 1 kWh of electricity generated using different technologies for the considered providers and hydroelectricity.

We can conclude that the provider A has the smallest average environmental impact in the regional impact criteria. Jet, compared to pure hydroelectricity, the hydro energy is by far the best solution. The A environmental impact of hydroelectricity is by 99.2 % smaller than for provider B and for FAET, it is by 99.6 % less than for provider A, and for MAET it is by 88.5 % less than provider for C.

3.3 Local environmental impact indicators

In the category of local environmental impact indicators, eutrophication (E), human toxicity (HT), photochemical ozone creation (POC) and terrestrial eco toxicity (TET) are discussed.

The comparison given in Figure 10 shows that hydroelectricity is by far the best option also locally wise. In average, each of the four indicators is by 98.7 % lower than for provider B that has the highest local environmental impact indicators. Provider B is the one having the biggest share of the fossil fuel based generated electricity (58.22 %), 35.47% of the nuclear power plant generated electricity and just 6.31 % of the RES generated electricity. Provider C that has a bit lower values of local environmental indicators than provider B, and provider C also has a bit lower share of fossil fuel generated electricity than provider B (50.7 % for provider C and 58.22 % for provider B). Provider A with just a 17,42 % share of fossil fuel generated electricity has an average by 61 % lower values of the local environmental indicators than provider B and an average by 50 % lower than provider C.

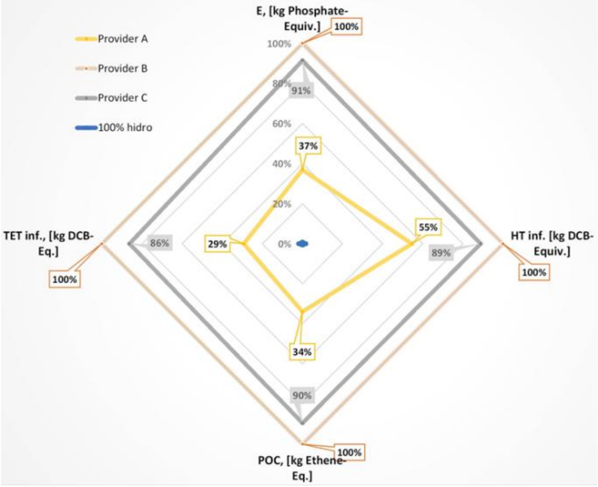

Figure 10. Relative comparison for the local environmental impact indicators for a 1 kWh of generated electricity

To better understand the reasons for each local environmental indicator either high or low, the technologies for each local environmental impact indicator should be compared. For eutrophication the biogas generated electricity is the most impacting. This followed by biomass and fossil fuels (see Figure 11). Provider A has the lowest value of E indicator because of the low share of biogas, though having a small share in the Slovenian grid mix, biomass and fossil fuels compared to other two providers. The share of biogas and biomass is small. This is the reason why fossil fuels do not significantly affect this indicator. On other hand, the impact of the hydro energy source on E indicator is negligible. The photochemical oxidation, very often defined as summer smog, is the result of reactions that take place between nitrogen oxides (NO_X) and volatile organic compounds (VOC) exposed to UV radiation.

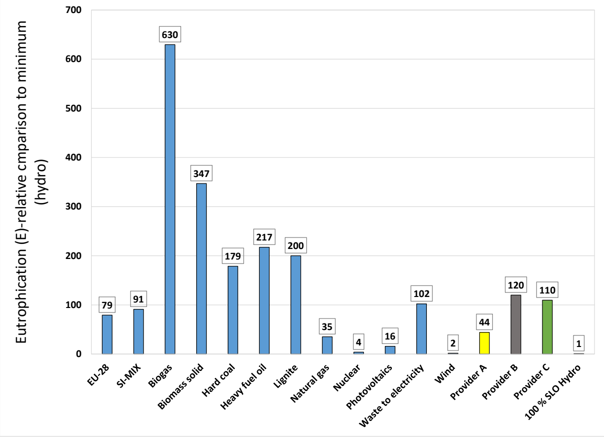

Figure 11: Relative comparison for the E environmental impact indicator for a 1 kWh of electricity generation from different technologies, providers A, B, C and hydroelectricity.

According to the POC definition, the highest values of this indicator come from the fossil generated electricity (HFO, Hard coal, Lignite) and RES (Biogas and Biomass). Provider B and C have high POC values. They are followed by the provider A which has a low share of the key sources for POC (see Figure 12).

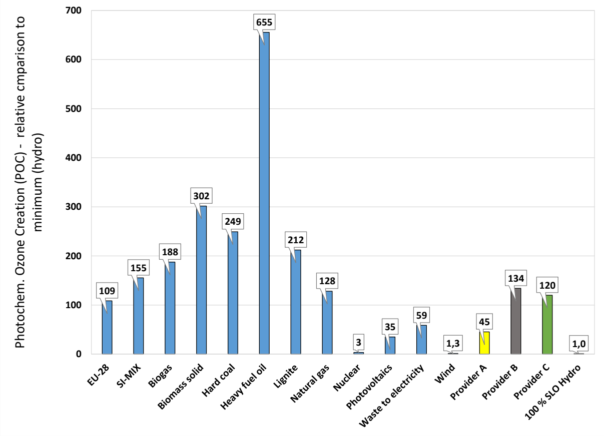

Figure 12. Relative comparison for the POC impact indicator, for a 1 kWh of electricity generation using different technologies, providers A, B, C and hydroelectricity.

4 CONCLUSIONS

The Environmental impact of a 1kWh of the generated electricity for three typical electricity providers in Slovenia is analysed using the LCA method. The LCA models are set up using the Gabi Thinkstep software. The results are evaluated with the midpoint life cycle impact assessment method CML 2001. The LCA results are compared with the 100% of the hydro generated electricity. It is shown that besides evaluating the global warming impact indicator it is very important to evaluate also other environmental indicators to determine the overall environmental impact of different electricity generation technologies used by the electricity providers. The conclusions drawn from our study are:

- By far the best is electricity generation by hydro power plants. The only questionable indicator is AD, which is higher than AD of the three considered providers. The other environmental indicators are an average by more than 99 % lower than the highest values of a specific indicator.
- The least environmentally impacting is provider A for nine of the twelve assessed environmental impact indicators. Nevertheless, OD, AD and FAET environmental impact indicators of provider A are very high, because of its highest share of the nuclear energy (OD, FAET) and relatively high share of RES (AD).
- Analysing the global environmental impact indicators shows that provider A, which has in general the most environmentally sound portfolio, has the highest OD that comes from its high nuclear energy share.
- Analysing the regional environmental impact indicators show that provider A is a good choice, but it has the highest value of the fresh water eco toxicity that comes from uranium mining.
- Analysing local environmental impact indicators shows that provider A is much better than the other two providers, but cannot be compared to the 100% hydroelectricity.

To sum up, to lower the environmental impact of electricity generation in Slovenia, it is crucial to maintain and further develop the RES based electricity from hydro sources. Furthermore, to get better insight in the environmental impact of a particular electricity generation technology the deeper LCA analysis should be done rather than being focused on one environmental impact indicator, such as the global warming impact, alone.

REFERENCES

[1] Evropska komisija: Energija Trajnostna, zanesljiva in cenovno dostopna energija za evropske prebivalce 2014. doi:10.2775/61086.

[2] Brizmohun R, Ramjeawon T, Azapagic A. Life cycle assessment of electricity generation in Mauritius. J Clean Prod 2015;106:565–75. doi:10.1016/j.jclepro.2014.11.033.

[3] Hammons TJ. Integrating renewable energy sources into European grids. Electr Power Energy Syst 2008;30:462 – 475.

[4] Eltigani D, Masri S. Challenges of integrating renewable energy sources to smart grids: A review. Renew Sustain Energy Rev 2015;52:770–80. doi:10.1016/j.rser.2015.07.140.

[5] Agencija Republike Slovenije za energijo: Seznam dobaviteljev električne energije n.d. http://primerjalnik.agen-rs.si/index.php?/kalkulatorelektrika/kalkulator/action/dobavitelji/ (accessed June 20, 2017).

[6] Thinkstep. Life Cycle Impact Assessment (LCIA) methods: GaBi Software 2018. http://www.gabi-software.com/uk-ireland/support/gabi/gabi-5-lcia-documentation/life-cycle-impact-assessment-lcia-methods/.

[7] International Organisation for Standardisation (2006a) ISO 14040: Environmental management - Life cycle assessment - Principles and framework. 2006. doi:10.5594/J09750.

[8] International Organisation for Standardisation (2006b) ISO 14044: Environmental management - Life cycle assessment - Requirements and guidelines. 2006.

[9] Schuller O. Energy modelling in GaBi 2017 edition. 2017.

[10] PE International. Handbook for Life Cycle Assessment (LCA) Using the GaBi Education Software Package. 2010.

[11] Atilgan B, Azapagic A. Renewable electricity in Turkey: Life cycle environmental impacts. Renew Energy 2016;89:649–57. doi:10.1016/j.renene.2015.11.082.

[12] García-Gusano D, Garraín D, Dufour J. Prospective life cycle assessment of the Spanish electricity production. Renew Sustain Energy Rev 2017;75:21–34. doi:10.1016/j.rser.2016.10.045.

[13] Atilgan B, Azapagic A. Life cycle environmental impacts of electricity from fossil fuels in Turkey. J Clean Prod 2015;106:555–64. doi:10.1016/j.jclepro.2014.07.046.

[14] Baitz M, Makishi C, Kupfer T, In JF-, Schuller O, Kokborg M, et al. GaBi thinkstep Database & Modelling Principles. PE Int 2017:1–178.

[15] Gabi Professional Database; PE international 2016.

[16] CML - Department of Industrial Ecology. CML-IA Characterisation Factors - Leiden University 2016. https://www.universiteitleiden.nl/en/research/research-output/science/cml-ia-characterisation-factors (accessed April 21, 2017).

[17] Suwanit W, Gheewala SH. Life cycle assessment of mini-hydropower plants in Thailand. Int J Life Cycle Assess 2011;16:849–58. doi:10.1007/s11367-011-0311-9.

[18] Turconi R, Boldrin A, Astrup T. Life cycle assessment (LCA) of electricity generation technologies: Overview, comparability and limitations. Renew Sustain Energy Rev 2013;28:555–65. doi:10.1016/j.rser.2013.08.013.

[19] Luxembourg: Office for Official Publications of the European Communities. The Montreal Protocol. 2007.

[20] Stamford L, Azapagic A. Sustainability indicators for the assessment of nuclear power. Energy 2011;36:6037–57. doi:10.1016/j.energy.2011.08.011.

[21] Stamford L, Azapagic A. Life cycle environmental impacts of UK shale gas. Appl Energy 2014;134:506–18. doi:10.1016/j.apenergy.2014.08.063.

[22] Greening B, Azapagic A. Environmental impacts of micro-wind turbines and their potential to contribute to UK climate change targets. Energy 2013;59:454–66. doi:10.1016/j.energy.2013.06.037.

[23] Poinssot C, Bourg S, Ouvrier N, Combernoux N, Rostaing C, Vargas-Gonzalez M, et al. Assessment of the environmental footprint of nuclear energy systems. Comparison between closed and open fuel cycles. Energy 2014;69:199–211. doi:10.1016/j.energy.2014.02.069.

Dr. Mitja Mori received his PhD Degree in Mechanical Engineering in 2008 from the Faculty of Mechanical Engineering, University of Ljubljana, Slovenia. Currently, he is an assistant professor at the same faculty. His main field of interest are life cycle assessment (LCA) of new technologies, particularly the new hydrogen technologies and their integration in large scale energy systems. He is also involved in heat transfer research, numerical system modelling and process analyses. He has participated in several national, commercial and European projects.

Rok Stropnik received his Engineering Degree (Energy and Process Engineering) in 2014, from the Faculty of Mechanical Engineering, University of Ljubljana, Slovenia. He is a researcher at the Department for Heat and Power and is pursuing his PhD Degree in the field of energy engineering. His main research focus is on life cycle assessment (LCA) of hydrogen technologies and RES in the future energy supply. He is also involved in various EU projects in the field of LCA and energy modelling. From 2017, he has been a teaching assistant in the field of power engineering.