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A sustainable energy policy for Slovenia: Considering the potential of renewables and investment costs

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In this paper, Slovenia's current energy policy is analyzed, the potential of renewable energy sources (RES) is evaluated and examined, and new options for the development of an alternative energy policy and the transition of the Slovenian energy industry into a sustainable energy industry are proposed and cross compared. On the basis of current and future electricity consumption, the evaluated RES potentials, and calculated investment prices, options for alternative investment projects and the alternative development of a more sustainable energy policy in Slovenia are identified. These possibilities and the current energy policy are analyzed and cross-compared from the economic and environmental viewpoint, with special emphasis on investment costs. At the end of the paper, the implementation costs of the proposed alternative energy policy investments are evaluated, calculated, and cross-compared, and the advantages and disadvantages of the alternative energy policy are evaluated. The proposed alternatives have significant benefits in comparison to the existing energy strategy, which focuses on a new lignite thermal power plant. Reconstruction of the existing thermal power plant in Šoštanj is a considerably cheaper alternative and a sound transitory solution for Slovenia. Investment in a multiple fuel power plant is also a cheaper and more efficient alternative, which, in addition, enables the usage of local biomass. Another considerably cheaper and more efficient alternative with lower emissions is a gas-steam power plant. The most promising alternative is found to be electricity production from local RES, resulting in a significant reduction of energy related emissions and domestic sources usage. The estimated investment costs for the last alternative are comparable to the costs for the implementation of Slovenia's current energy policy. © *2013 AIP Publishing LLC*. [http://dx.doi.org/10.1063/1.4811283]

I. INTRODUCTION

Pollution, greenhouse gas emissions (GHG), rising energy demand, and high import energy dependency are at the heart of energy problems in both Slovenia and the European Union (the EU) as a whole. Current energy import dependency in the EU and in Slovenia stands at approximately 50% (Government Communication Office[1]). This dependency, which results in economic, political, and social vulnerability within the EU, must be seen as a challenge and opportunity for the sustainable development of energy policy.

Renewable energy sources (RES), which include hydro energy, wind energy, solar energy, biomass, geothermal energy, tidal, and wave energy, are seen as a means to short-term reduction as well as a long-term solution to the problems listed in the first paragraph. The EU is aware of the issues related to conventional energy sources, which include fossil fuels and nuclear energy, and therefore supports the development of RES and sustainable energy policy. Sustainable energy policy means an effective provision of energy in order to meet the needs of the future without compromising the ability of future generations to meet their own needs.

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Sustainable energy comprises two key components: specifically, energy efficiency (EE), i.e., efficient energy consumption and RES. The investments in EE and RES are highly important since RES cause less pollution than fossil fuels and enable the use of local resources. In addition, they decrease import dependency and increase EU competitiveness at the same time. As 80% of all GHG emissions in the EU and in Slovenia are caused by energy production and use (Government Communication Office[1] and EEA[2]), the EU adopted legislation to lower GHG emissions in the energy sector—the so-called climate and energy package. With this regulation the EU intends to lower CO_2eqv emissions by 20%, increase the share of RES to 20%, and decrease the use of primary energy through enhancing EE by 2020. These goals are also known as the 20/20/20 objectives and are included in the Directive on the promotion of the use of energy from renewable sources (Directive 2009/28/EC); they are also mandatory for Slovenia. Slovenia's goal for the RES share is even higher—25% of RES in final energy consumption by 2020. The specific goals for each member state are set individually in accordance with their particular circumstances; they can, therefore, differ significantly from the general objectives. Although the 20/20/20 objectives are appropriately set at the EU level, there is a lack of common strategy for their implementation since implementation strategy remains within the jurisdiction of the individual member state.

In Slovenia, energy strategy is laid out in the National Renewable Energy Action Plan (Ministry of the Economy[3]) and National Energy Programme (IJŠ[4]); however, these documents are not fully consistent with the 20/20/20 objectives because they do not foresee any active increase in the share of RES and EE with regard to long-term energy industry development. Furthermore, the document does not include any implementation measures, which is the most challenging issue in achieving a sustainable energy industry.

Sustainable development is becoming a new development paradigm, important for policy, science, and the general public, and therefore an extremely interesting research topic. Consequently, there has been a considerable increase in studies and research in the field of sustainable energy policy in the last five years. These studies and research have been carried out on global sustainable energy development as well as on sustainable energy development in specific countries or regions. In the first group, the global studies group, we highlight, e.g., the developing of strategies for sustainable energy development, presented by Kaya and Yokobory,[5] the planning of regional energy development concerning RES and environmental constraints (Cormio *et al.*[6]), the Delphi study on the possibilities for future energy development conducted by Wehnert *et al.*,[7] an analysis and modelling of sustainable energy planning (Afgan[8]), a study on facing the world thirst for energy (Combanous and Bonnet[9]), an examination of global trends in clean energy investments carried out by McCrone and Aspinall,[10] etc. In the second group, studies considering sustainable energy development in specific countries or regions, we highlight the modelling of renewable energy in India in 21st century by Iniyan *et al.*,[11] the scenario analysis of energy policy development in Slovenia (Electro-Institute Milan Vidmar[12]), a study on sustainability issues in planning local energy policy (Golc[13]), an assessment of modelling 100% renewable solutions for Denmark by Lund,[14] the elaboration of a new energy development paradigm for Turkey (Saygin and Cetin[15]), an assessment of the impact of renewable energy deployment on local sustainability by del Rio and Burguillo,[16] a study on the possibilities for sustainable energy policy development in Slovenia (Obrecht and Denac[17]), etc.

II. METHODOLOGY

The purpose of this paper is to propose possible strategies and evaluate the potential for the restructuring of the Slovenian energy industry into a sustainable energy industry consistent with the 20/20/20 goals and focused on RES, EE, and reduced energy consumption. By studying the available information and literature, the current situation was assessed, and future energy consumption was forecast. The advantages and disadvantages of the current and alternative energy strategy were also analysed.

The statistical data presented in the study were gathered on the basis of the compilation method. Various independent sources were used, such as statistical offices, national, international, and private studies and analysis, scientific papers, and national energy balances. The data on energy consumption, RES share, exploited and unexploited RES potentials, the barriers to RES exploitation, and all other data were statistically analyzed, evaluated, and cross-compared.

Data on the investment costs of various alternatives—conventional and renewable energy sources—were gathered from the currently available data on past, current, and future energy projects in Slovenia. These data were additionally compared and verified with data from the research included in the preparation of the National Energy Programme and National Renewable Energy Action Plan.

RES potentials were evaluated on the basis of independent research studies and evaluation included in the National Energy Programme and National Renewable Energy Action Plan. Possible strategies for the exploitation of RES are evaluated on the basis of energy demand, technical and economical RES potential, and the intention of the energy sector to invest in such projects. At least one energy company has already shown interest in all of the proposed investments in RES included in alternative No. 4. This means that all of the options presented are feasible and ready for implementation.

The presented calculations on GHG emissions are based on the current emission level—in particular lignite powered facilities and forecast emissions for new power plants currently under construction. Estimates and comparative analysis of the economic aspect are based mainly on investment costs. Production costs are also identified and compared, although not examined in detail.

The survey and analysis of Slovenian RES potentials is based on currently established economic, technological, and environmental acceptability. We assume that technological and economic RES potential will increase in the future due to technological development, internalization of external costs, and the increased price of fossil fuels. The environmental potential will be reduced because of stricter environmental requirements.

III. REVIEW OF THE CURRENT ENERGY POLICY IN SLOVENIA AND IDENTIFICATION OF AVAILABLE ALTERNATIVES

Energy consumption in Slovenia has shown moderate growth in the last ten years. If Slovenia is willing to reach the 20/20/20 objectives, consumption of primary energy must be curbed and reduced. Decreasing the consumption and share of fossil fuels is crucial for all three 20/20/20 objectives because the use of fossil fuels causes high GHG emissions, reduces the need (and possibility) to invest in RES, and accounts for a significant share in total primary energy consumption. The planned reduction in fossil fuel consumption by 2020 will be at least partially compensated by higher electricity consumption; therefore, new power plants must be very carefully planned to ensure that future electricity production is as sustainable as possible and that primary energy consumption will decrease through increased EE.

Electricity consumption per capita and the share of renewables in electricity production in Slovenia are presented in Figure 1. Figure 1 clearly shows that electricity consumption increased dramatically between 2000 and 2005 and remained at almost the same level from 2005 to 2008. After 2008 it has decreased (SURS[19]), mostly due to the economic crisis, as a decrease in economic activities and industrial production also has a negative impact on energy consumption. On the other hand, the share of RES has been fluctuating; in 2009 it was slightly above the 2000 level. However, the RES share increased steadily from 2007 to 2010. The RES share increase is therefore the result of the simultaneous increase in RES and the decrease in energy produced from fossil fuels. Thus, the changes in energy consumption must be considered in the planning of long-term energy strategy, while continued growth of the RES share and a continued decrease in energy use must be planned and implemented.

The current energy strategy is not designed to address reduced and more efficient energy consumption; instead, it aims to fill the gap between supply and demand with a new 600 MW thermoelectric power plant (TPP). Energy strategy should plan for the reduced use of fossil fuels, more efficient energy consumption, and a transition to RES in accordance with the

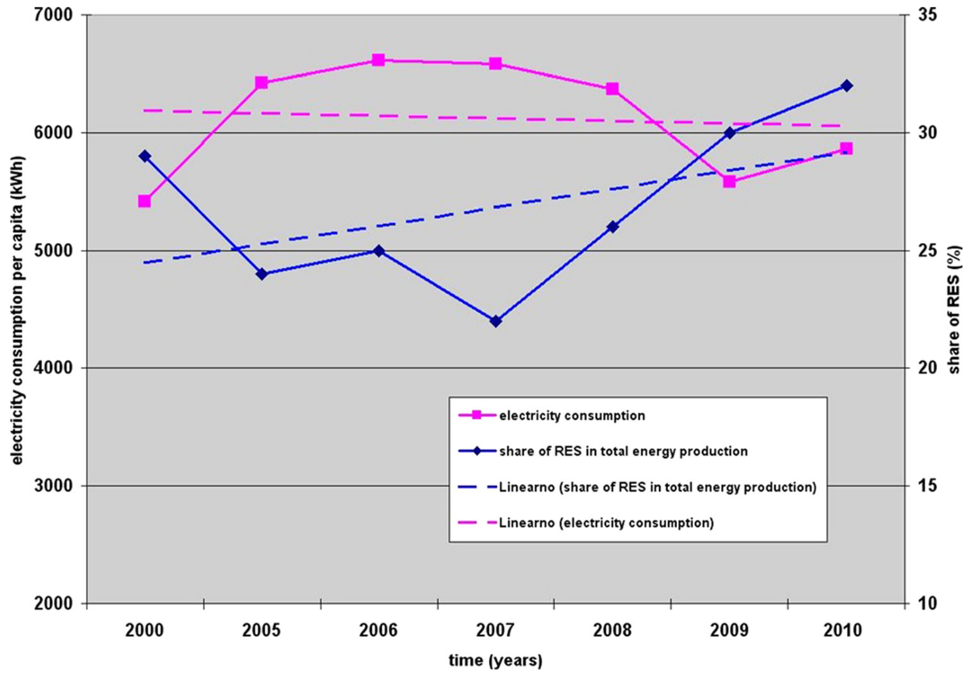

FIG. 1. Electricity consumption and share of RES in total energy production in Slovenia (SURS[19]).

20/20/20 objectives and include, at most, smaller TPPs. Shortcomings should be met with power plants run on local renewables, as proposed hereafter. TPPs are not consistent with the 20/20/20 objectives since they lead to high emissions, cause a reduction in the need for renewables, and reduce available capital for investments in RES. The new TPP block Šoštanj 6, which is to be built by 2015, will undoubtedly strengthen dependence on fossil resources and make the achievement of the 20/20/20 objectives extremely difficult or impossible, since the lignite-fired TPP in Slovenia is responsible for around 31% of total GHG emissions (IJŠ[18]).

The new lignite-powered block will be more efficient and consistent with the Directive for Integrated Pollution Protection and Control (IPPC - Directive 96/61/EC) and its key principle, i.e., best available techniques (BAT). Although it will produce fewer emissions than the current blocks and its efficiency (transformation of potential energy contained in lignite into electricity) will be 43%, as requested by the Directive for Integrated Pollution Protection and Control (the current overall average efficiency is approximately 32.4%), it will nevertheless use a fossil fuel (lignite) as source of energy, which is unsustainable and will also result in high GHG emissions, acid rain, and PM_{10}. The coal dust firing with supercritical parameters technology, which will be used in TPP Šoštanj 6 (BAT for lignite TPP), will result in 3.1×10^6 tons of CO_2 emissions annually. The justification for the investment in TPP Šoštanj 6 is based on its 43% efficiency, which can only be achieved with an at least 600 MW block. 43% efficiency is, through the BAT, a precondition for a European Investment Bank loan. Instead of analyzing and forecasting Slovenia's needs and consumption and developing new jobs in the RES sector, the region's social problems and the fact that they have already accepted pay-outs (more than 540×10^6 euros, according to TPPŠ[20]) are being misused as an argument for TPP Šoštanj 6. 43% efficiency is also at the lower limit of acceptable efficiency for a lignite powered power plant, as requested by BAT.

The investment in TPP Šoštanj 6 (600 MW block) is worth 1.2×10^9 euros (TPPŠ[20]) (i.e., 2×10^6 euros per MW), with additional investment needed for CO_2 capture and storage technology, which has not yet been fully developed. This is why this issue is also an economic one. In addition, the projections of emission allowance prices in the next 40 to 45 years (i.e., the life expectancy of TPP Šoštanj 6) are merely speculative. Time frames for the existing TPP Šoštanj blocks (TPP Šoštanj 4 and TPP Šoštanj 5) closure are also poorly defined. Moreover, with the construction of TPP Šoštanj 6, the existing blocks will become technologically obsolete and environmentally controversial. In other words, the three existing blocks (if still in operation after TPP Šoštanj 6 is constructed) will only increase the total GHG emissions from TPP Šoštanj.

The launch of TPP Šoštanj 6 is planned for 2015, i.e., 3 years after the cut-off date set by the Kyoto Protocol and 5 years ahead of the cut-off date for the 20/20/20 objectives. A fully operational TPP Šoštanj 6, with TPP Šoštanj 4 and TPP Šoštanj 5 as cold reserves, will thus make these objectives almost unattainable. Furthermore, the efficiency increase of TPP Šoštanj 5, planned for during the construction of TPP Šoštanj 6, is also debatable if TPP Šoštanj 5 is to become simply a cold reserve. This indicates that block 5 will not be used in this way, but also as a regularly operating block, which significantly alters the environmental performance of the new TPP Šoštanj as a whole.

Slovenian energy policy should also take into account that TPP Šoštanj 5 and TPP Šoštanj 4 have not yet reached the end of their lifetimes and that their efficiency could be significantly improved in accordance with IPPC (Integrated Pollution Prevention and Control) directive and its essential part - BAT. Even though Slovenian Energy law dictates that energy industry must have sufficient reserve capacities, it is arguable whether Slovenia is building TPP Šoštanj 6 to provide a sufficient amount of energy to cover national needs or simply to profit from electricity exports. Since the future economic situation is highly unpredictable, it would be much better to invest in the reconstruction of the existing TPP blocks and in a new energy production process a few years before the existing blocks reach the end of their operating life cycle. The price of local lignite, CO_2 allowances and decreasing energy consumption bring into question whether TPP Šoštanj 6 will even be able to depreciate itself. The economics of energy projects will undoubtedly change by 2025 (the expected lifetime of the existing TPP blocks in Šoštanj), and as the economics of TPP Šoštanj 6 are already under scrutiny, it is most likely that it will not be feasible then and that new, cheaper, and superior alternatives will be available.

The investment in TPP Šoštanj 6 is based on the predicted increase in electricity use in Slovenia, which is currently debatable, as electricity consumption has remained at the same level or even decreased since 2006 (Fig. 1). The investment in TPP Šoštanj 6 is further supported by the fact that the existing TPP Šoštanj blocks are not entirely efficient and by the move towards national energy independence. Consequently, TPP Šoštanj 6 should bridge the electricity deficit gap until new, sustainable capacities are built. However, while the future of TPP Šoštanj 4 and TPP Šoštanj 5 is questionable, since they should be gradually closed, it is planned that they will remain in cold reserve until 2027. This is regarded as the most difficult issue concerning the blocks, as they will become inefficient and technologically obsolete. A further concern is the adequate supply of lignite for all of the operating blocks. The current Slovenian energy strategy prioritises security and adequate energy production at the expense of environmental costs. Alongside the TPPs, plans are underway for the construction of new hydroelectric power plants (hydro PP), gas-steam power plants (gas-steam PP), and nuclear power plants, as well as small RES power plants. All of these are economically and environmentally more appropriate and sustainable but are currently of secondary importance for Slovenian energy policy.

The production costs of TPP Šoštanj 6 are also arguable. Because the current electricity price on the Leipzig stock exchange stands at approximately 45 EUR/MWh, the production costs of TPP Šoštanj 6 should be lower than this. As the predicted costs of electricity from TPP Šoštanj 6 range between 70 and 80 EUR/MWh (Smrekar-Iskrič and Dakić[21]), TPP Šoštanj 6 will be wholly uneconomical at the very beginning of operation, and taxpayers will be expected to foot the bill for the next 54 years.

Since it is forecast that the global demand for coal is going to rise by up to 50% by 2035 (Likar[22]) mainly because of the economic development of non-OECD countries, especially China and India, and due to the closure of nuclear power plants in Germany, higher supply prices of coal can be expected. This is very important since it is arguable whether Slovenia has enough lignite reserves for the 54-year operation of TEŠ 6. The European Bank for Reconstruction and Development (EBRD) study forecasts that lignite reserves in Slovenia are sufficient for the operation of TEŠ 6 until 2048, which means that Slovenia will have to import lignite or coal for the last 6 years of TEŠ 6 operation.

Unlike most other raw materials and commodities, there is no free-market price formation for the lignite used in power generation. The low calorific value of lignite makes transport uneconomical over longer distances; therefore, the cost of lignite per unit of energy, including transport, would be higher than the cost of hard coal, its main competitor. Hence, a lignite mine cannot offer its product to power plants, which are dislocated.

Similarly, lignite-fired power plants cannot purchase fuel from distant mines. Both producer and consumer co-exist in a captive market. In comparison, the international market for hard coal benefits from a large number of suppliers and customers. For these reasons, it is common to build lignite-fired power plants adjacent to lignite mines (Euracoal[23]). That means that it is extremely difficult to forecast how high the costs of TEŠ operation will be after the Slovenian lignite reserves are exhausted.

The quality of lignite can also differ in time, layers, and deposits. The current calorific value of lignite from the Velenje coalmine (the main supplier of TPP Šoštanj 6) is 11.3 kJ/kg, the ash content is 14%, and the sulphur content is 1.4% (Euracoal[23]). If the quality of lignite decreases or if the production price of lignite from new deposits increases, the economic profile of TPP Šoštanj 6 will be even worse, because more expensive coal will have to be imported to achieve the requested efficiency of the power plant. This is an enormous problem, as the Velenje coal mine is already selling lignite (for 2.6–2.8 EUR/GJ) to TPP Šoštanj below its cost price (2.9 EUR/GJ). The fact that the reference price of lignite in the feasibility studies on TPP Šoštanj 6 was 2.3 EUR/GJ (Malovrh *et al.*[24]) makes the situation even more bizarre.

The existing energy policy is assessed as unsustainable because it is based on the assumption that energy consumption will increase, rather than on achieving reduced and more efficient energy consumption. It gives priority to conventional energy sources, it is not oriented to the 20/20/20 objectives and it does not prioritise RES. Furthermore, it foresees a complete and as such unsustainable use of lignite reserves in Slovenia and lays too little emphasis on environmental costs.

Contrary to Slovenia's current energy policy, sustainable energy policy must be based on reduced energy consumption as a result of increased energy efficiency, as well as on the substitution of conventional energy sources with RES. In other words, the central idea of sustainability is to establish the circular flow and self-regeneration of natural resources, and this cannot be achieved with fossil fuel consumption. The EU energy policy defines sustainability as the combination of (1) the development of competitive RES and all other low-carbon sources of energy carriers by reducing energy demand within the EU; (2) directing collective efforts to halt climate change; and (3) improved local air quality. According to these three criteria, the construction of TPP Šoštanj 6 is inappropriate. In fact, sustainable development must not be perceived as meeting the needs of the present generation at the expense of future generations.

Nonetheless, Slovenia is building TPP Šoštanj 6 and abandoning the construction of new RES, mainly wind power plants and hydroelectric power plants. In general, there is a lack of active fiscal incentives for the construction of small and micro-scale decentralized hydro and wind power plants; however, strong growth can be seen in the biogas and photovoltaic sector. Some RES are not merely environmentally competitive but also cost competitive with conventional energy sources. The electricity generation from RES is additionally supported by the system of feed-in tariffs.

In order to propose alternatives, we decided to examine how competitive RES are from the economic perspective. Through an analysis and comparison of indicative RES investment prices in Slovenia, new possibilities for investments into more sustainable energy projects have been identified:

- Elektro Primorska,[25] for example, indicates that the estimated price of wind power plants at selected locations in Slovenia ranges between 1 and 1.37×10^6 euros per MW, which is, on average, approximately 48% less than the investment in the above mentioned investment in TPP Šoštanj. Production costs of wind power plants are 35-140 EUR/MWh (Obrecht[26]). Although wind power plants are emission-free during the production of electricity and have low operating and maintenance costs, they are completely dependent on the frequency and stability of the wind.

- The investment in hydro PPs varies quite substantially because of the diversity of the environment and the specificity of each project. As a rule, hydro PPs can be divided into large, small, and pump storage hydroelectric power plants. For example, the Avče pump-storage hydroelectric power plant cost 1.54×10^6 euros per MW (Obrecht *et al.*[27]).
- Hydro PP on the Sava River cost 2.63×10^6 euros per MW (Raner and Žebeljan[28]). It is also important to note in regard to hydro PP operations that their minimum costs (approximately 20–30 EUR/MWh - Obrecht[26]), and emission-free energy production have to be taken into account. Because the hydrological potential of Slovenia is rather high, we see great opportunities for hydro PPs.[29]
- Small hydro PPs with a current installed power of 85 MW have an estimated untapped potential of 180 MW. The price for the installed MW in a small hydro is estimated at $1.3–3.0 \times 10^6$ euros (Žumbar[28] and Raner and Žebeljan[28]) and depends on the size of the plant. Such power plants represent a cheap source of RES (with a production price of approximately 30–80 EUR/MWh (Obrecht[26])), but are limited in terms of appropriate locations. Another interesting possibility is also the new technology of hydro PP with vertical axis, which is especially appropriate for slow-flowing waters. These SG/SP (Slovenian Generator/Slovenian Product) devices are already in production but not yet installed; the exact investment costs are therefore not yet available.
- Biogas plants provide a sound alternative to peak energy, with investments in biogas plants standing at around 3.6×10^6 euros per MW of installed power and electricity production prices from 35 to 120 EUR/MWh (Obrecht[26]). The presented calculation is the average for the biogas plants in Styria (LandesEnergieVerein[31]). Additionally, the production of biological waste/raw materials in Slovenia is sufficient for several tens of MW of installed power in a biogas plant (Obrecht and Denac[30]).
- The investment in solar power plants is similar to that of investments in biogas power plants and stands somewhere between $2–4 \times 10^6$ euros per MW (Obrecht *et al.*[27]). The annual solar radiation in Slovenia is at least 1.05 MWh/m^2 (the peak is 1.53 MWh/m^2) (Ref. 32). While the source is sufficient and appropriate, photovoltaic energy is highly dependent on the frequency and stability of solar radiation. Electricity production in photovoltaic systems is practically emission and cost free and is mainly dependent on the investment costs of the photovoltaic system. The production price is approximately 70–200 EUR/MWh (Obrecht[26]).

IV. PROPOSAL OF ALTERNATIVE ENERGY POLICY

To achieve long-term sustainable energy production and consumption as well as to reach the 20/20/20 objectives, we are proposing a new energy policy based on the priorities presented in Fig. 2.

The proposed investments in alternative energy projects are presented on the time axis while the priorities are written from the top down. The facilities in dotted-line cells are only an option if there is a rise in energy needs. The reduction in energy consumption and increased EE consumption must be placed at the heart of sustainable energy policy in Slovenia; this also corresponds with the EU Directive on energy end-use efficiency and energy services (Directive 2006/32/EC) that requires energy savings by 2016 relative to the average of 2001–2005. As electricity consumption declined by 4% in 2008 and by 11% in 2009 and energy consumption in industry also fell, we only have to retain consumption at the current level. This is actually more favourable than reducing energy consumption, as measures aimed at reduced energy use are generally more dramatic and demand larger effort and investment than measures to retain it at the same level. However, electricity consumption increased by approximately 4% in 2010. It is also realistic to expect minor growth in electricity consumption by 2015 due to the economic recovery. In any case, this trend must be limited and reduced as much as possible now, so that future energy consumption will achieve the 20/20/20 objectives on the one hand and reduce the need for new power plants and the resulting environmental impact on energy production in Slovenia on the other.

An improvement in end-use energy efficiency is also required by European legislation. Guided by the 2006/32/EC directive, Slovenia must achieve 9% energy savings by 2016 relative

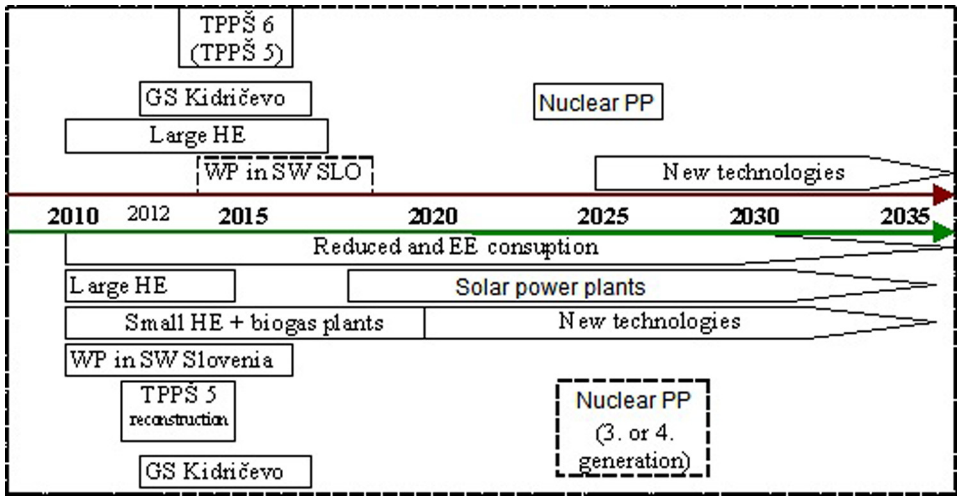

FIG. 2. Estimated development of the Slovenian energy sector over the time: existing and proposed strategy.

to the average of 2001–2005. Therefore, Slovenia should increase subsidies for EE and gradually change consumer habits, as these measures are the best long-term opportunity for smaller and more efficient energy consumption. Household subsidies, such as the installation of heat pumps and the installation of solar collectors for the insulation and renovation of houses, etc., have proven to be a very effective incentive to increase the EE of households, to educate them about the possibilities of increased EE and to promote EE in general. However, the subsidies are unfortunately not appropriate for lowest income households, because even if they can apply for an approximately 20% subsidy for one of the EE measures, they are unable to provide the remaining 80% of the investment. Therefore, subsidies should be increased for less affluent households in particular.

The main proposed change in Slovenia's energy strategy is related to TPP Šoštanj. By closing the existing TPP Šoštanj 3 in 2012 instead of 2014, Slovenia would save up to 4.7×10^6 euros for the Kyoto allowance, i.e., for failure to comply with the Kyoto objectives. The calculation is based on the annual CO_2 emissions from TPP Šoštanj 3 (235 000 tons) and the price of the allowance for CO_2 emitting (EUR 20 per ton of CO_2).

Alternative 1 the reconstruction of TPP Šoštanj (block 5) is a realistic option, since electricity shortages can be replaced by the Avče pump storage hydroelectric power plant and the Sava River hydro PP. The closure of TPP Šoštanj 4 will also be possible after the energy plants presented in Figure 2 are built. Provided that TPP Šoštanj 4 is operational by 2020 (the 20/20/20 objectives), that TPP Šoštanj 5 is operational by 2025, that the investment in the total replacement of the installation and extension of its activities makes economic sense, and on the condition that the new nuclear power plant is opened, TPP Šoštanj CO_2 emissions (including 2010) can be estimated at around 50.5×10^6 tons. This is 75.5×10^6 tons less than the CO_2 emissions produced with the operational TPP Šoštanj 6 by 2054, excluding TPP Šoštanj 5 after 2015. In other words, the annual CO_2 emissions of TPP Šoštanj 4 (317 MW) and TPP Šoštanj 5 (387 MW) are 1.93×10^6 tons and 2.29×10^6 tons, respectively (TPPŠ[33]). The two gas-steam PPs included in TPP Šoštanj and possible CO_2 capturing are not considered in this calculation.

The TPP Šoštanj 5 emissions would also be reduced after its renovation by an estimated 15%, i.e., to the level of TPP Šoštanj 6. Furthermore, an increase of around 50 MW in the installed power as a result of improved efficiency can also be predicted. Studies have proven that investment in renovation or complete replacement of the installation of the existing TPP Šoštanj block is more economical than investment in the construction of a new TPP Šoštanj block, since some of the existing components can be used despite the change of technology.

The reconstruction of TEŠ with a forecast efficiency increase of 3% (consequently also an increase in power of 53 MW) is evaluated at 53×10^6 euros and the production price at 50–60 EUR/MWh (Malovrh *et al.*[24]), which is still higher than the electricity market price, but much lower than the predicted production price in TPP Šoštanj 6. For instance, the total investment in the renovation of two 400 MW blocks and the modernization of the TPP Kostolac mine in Serbia amounted to approximately 860×10^6 euros (Electric Power Industry of Serbia[34])

Alternative 2 for the reorganisation of TPP Šoštanj is the introduction of a power plant using several fuel types. A good example of such a power plant is Danish Avedøre 2, which runs on straw, biomass, coal, and natural gas. The total investment into this plant was approximately 905 000 euros per MW, and the efficiency of the plant is 50% when operating at 300 MW (Tomšič[35]). This kind of technology enables us to use different fuel types at the same time, which is particularly important due to the accessibility of specific local energy sources, such as wood biomass in Slovenia, because of the gradual transition to RES and the ultimate objective of Slovenian energy policy—an emission-free society.

Another alternative to a lignite plant, alternative 3, is a gas-steam power plant (gas-steam PP). An 800 MW gas-steam PP that can replace TPP Šoštanj 6 is planned in Kidričevo, with predicted investment costs of 0.75×10^6 euros per MW (IJŠ[4]). The main advantages of a gas-steam PP are significantly lower emissions than in a lignite-fired TPP, lower investment costs, possible coverage of peak energy consumption, and a more reliable natural gas supply upon the completion of the South Stream and Nabucco pipelines. The essential weaknesses of a gas-steam PP are the dependence on foreign sources of energy and gas price volatility. The price of natural gas does not (yet) follow the price of oil and is therefore totally incompatible with oil price. Although natural gas is a conventional energy source, its use produces lower GHG emissions than other conventional energy sources; for that reason we see gas-steam PPs as an appropriate mid-term technology in the transition to carbon-free energy industry. We can also increase energy production by improving EE of the existing gas-steam PPs and cogeneration plants in Brestanica, Ljubljana, and Maribor.

Even though the price of natural gas on the stock exchange in February 2013 was approximately 2.4 EUR/GJ (Ref. 36), which is comparable to the price of lignite, energy policy must be aware of the volatility of gas price. The peak price in 2008 was approximately 10 EUR/GJ (Ref. 36). Since the majority of energy experts see gas as a very appropriate transitional energy source (for the transition into a more sustainable future), which causes fewer environmental constraints than other fossil fuels, and because investments in gas-powered systems for electricity production are increasing, the demand for gas is rising as well. This means that the price of gas can also significantly increase in the future and strongly influence the economics of selected energy projects concerning gas-powered systems. If the price of gas increases, at least some of these projects would no longer be economical. The high volatility of gas prices can also be seen in the fact that there are only short-term gas contracts. We can even say that gas-steam PPs would be cost-competitive with coal fired PPs only if the gas price decreased or if the efficiency of gas-steam PP increased by 15%.

A nuclear power plant is also a possibility. However, because of the shift by Germany—a leading EU member state—away from nuclear energy, the nuclear disaster in Fukushima, public opposition in Slovenia to a new nuclear power plant and certain technical aspects of power generation in nuclear power plants, for instance, the production of base load power instead of peak power like TPP, we believe that this is not a realistic alternative to TPP Šoštanj at the moment.

However, this paper wishes to propose the 4th and most sustainable alternative to TPP—a change in electricity mix and transition to RES. As there are no wind fields in Slovenia at present, Elektro Primorska has assessed the possibility of building 180 MW of wind power plants on three wind fields. However, such possibilities are limited here because there are few appropriate geographic locations for wind power plants and even those that are suitable lie within the NATURA 2000 area, where any significant change to the landscape is strictly prohibited. Wind power plant construction can impact greatly on the environment. However, Slovenia can achieve synergy with nature through the thoughtful and sustainable positioning of wind power plants, especially in degraded areas near roads. Estimates suggest that Slovenia can ensure 90 MW from wind power plants, while, additionally, a map of appropriate locations for wind power plants in Slovenia has been drawn up including areas with sufficient wind that lie outside NATURA 2000.

The investment into 90 MW wind power plants should amount to approximately 105×10^6 euros. Ideally, a small number of pilot wind power plants would be installed and their subsequent operation examined. The results obtained would facilitate the decisions on new investments in wind power plants, and, furthermore, the criticisms of environmental organisations opposed to wind power plants in Slovenia would thus be thoroughly assessed.

Slovenia has a large water potential, which combined with the high efficiency of hydroelectric power plants, their lengthy operating period (over 100 years), non-emission operations and production of cheap energy, should make investments in new hydro PPs the priority of the Slovenian energy industry. In Slovenia, pump storage hydroelectric power plants are of particular importance in peak energy consumption, the most critical period. New and planned pump-storage hydro facilities will supply 1300 GWh of electricity produced in the peak of consumption (i.e., Avče pump-storage hydro 178 MW and the planned Kozjak pump-storage hydro 440 MW) (Raner and Žebeljan[28]). Therefore, new, suitable locations for the construction of pump-storage hydro PPs must be identified and considered in line with long-term strategy, since they constitute an appropriate, reliable, and clean source of peak energy. The price of investment in the Avče pump-storage hydro was 1.54×10^6 euros per MW (HSE[37]). The investment in the large hydro PP on the Sava River will result in an additional 482 MW of installed power (Raner and Žebeljan[28] and HSE[37]). The average price of hydro PP on the Sava River's lower stream is 2.63×10^6 euros per MW. An additional 118 MW of power installed in the hydro PP on the Soča River (Raner and Žebeljan[28]) is also possible but environmentally highly questionable, excluding the Soča hydro PPs from this study. The total hydro potential of Slovenian rivers is evaluated at app. 9.1 GW. However, only small hydro PPs are included in this study, since large hydro PPs have a greater environmental impact and different economic profiles to small hydro PPs.

Nevertheless, the investments in large and small hydro PPs should, in our opinion, be a priority, as such hydro PPs could constitute Slovenia's largest source of RES and have a significant impact on the mid-term replacement of conventional energy sources. Small hydro PPs with 85 MW of installed power are also very important. The water potential in Slovenia allows for the construction of additional small hydro PPs, which could produce at least 100 MW of electricity (HSE[37] and IJŠ[4]). Small hydro PPs also have a positive impact on the decentralization of the energy industry; moreover, they have an efficiency level of over 90% and cause less environmental strain. They can be built in a variety of locations and require relatively low investment. For that reason, small hydro PPs can also attract private capital. The main hindrances to building small hydro PP are currently the low guaranteed purchase price of electricity, which is not encouraging and is annually adjusted, and the complicated procedures for obtaining the necessary documentation. To popularize small hydro PPs, a few units should be installed on the Ljubljanica River and on some other small rivers in urban areas. These areas are already degraded but as they are accessible and in busy areas, they present an optimal point for presenting these units and educating the public about them, as well as integrating them into the city electricity grid. Small hydro PPs should also be encouraged in rural regions, as they present social benefits for rural development alongside the obvious economic benefits.

Investing in 100 MW of power installed in small hydro would result in the total amount of 215×10^6 euros, when the average price is 2.15×10^6 euros per MW. Of course, these investments are determined primarily by natural conditions. Cost reduction is possible mainly with the development of more efficient or cheaper components or by the purchase of cheaper components. In China and India for example, comparably efficient installations for small hydro PPs cost approximately 0.5×10^6 euros per installed MW.

Biogas plants present the next element of the energy mix in alternative 4, and are an interesting option as they can produce trapezoidal energy. The energy sources used in biogas plants are biological waste, sludge, animal manure and energy crops and the examples from Austria and Germany, where biogas plants are more common, have demonstrated that biogas plants have a positive impact on the development of the countryside and agriculture, too. At the same time, local sources are used and the problems of bio-waste disposal are solved. Second generation biogas plants are particularly appropriate because they primarily use wastes instead of energy crops, which is especially significant, as fields should be used for food rather than energy crop production. Therefore, restrictions on the use of crops in energy production must be drawn-up and implemented. The technology of cogeneration enables us to achieve higher efficiency when we use generated waste heat in industry processes or for household heating. In addition, fertilizer is also a useful by-product.

The study has proven that at least 50 MW of biogas plants can be installed in Slovenia by 2020, with an investment evaluated at approximately 180×10^6 euros. Although biogas plants have social and environmental benefits, they are economical only with the support of a guaranteed purchase price system; nonetheless, we also need to consider the premium for the recovery of bio-waste and revenues from selling heat and fertilizer.

In addition, solar power plants are also potentially interesting because they use the free energy of the sun, but solar panels are not yet efficient enough. At present, investments in installations of solar power plants should be made only in the sunniest areas of Slovenia, bearing in mind their increasing importance and greater exploitation with further development in the coming decades. In accordance with the current growth in solar power plants, due to the relatively high feed-in tariffs, Slovenia can expect 50 MW of solar power plant installations by 2020. The total investment costs are estimated at approximately 110×10^6 euros because the price of solar power plants will decrease by 2020.

However, the variability of wind and solar energy is also an important issue and must be very carefully examined. As the effects of climate change become clearer and the need to find solutions more pressing, the desire to employ such technologies is being felt around the globe. Still, energy policy must ensure the reliability of power to consumers at all times, which is almost impossible for wind and solar power if the new energy storage facilities and a more intelligent electric grid are not developed and implemented.

Finally, the possibilities of thermal energy exploitation in Prekmurje should be explored and examined, too. It could be used primarily as a source of district heating and possibly as a source for peak electricity generation as well. If the geological research and pilot projects are successful, thermal energy exploitation is a sensible option.

Based on the Alternative 4 proposal for the installed powers of various renewables and their average production costs, the evaluated production costs for alternative 4 would be approximately 75 EUR/MW, which is the same as TPP Šoštanj 6 (external costs excluded).

The summarized findings with the advantages and disadvantages of each alternative are presented in Table I.

As presented in Table I, all the proposed alternatives for electricity production in Slovenia are less expensive than the construction of the new lignite powered TPP Šoštanj. All of them also have lower (or app. the same) emissions by 2020. Alternative 1, 2, and 4 also enable the use of local renewable resources, which plays an especially important role in the transition to sustainable energy production and use.

The most important finding is that all the studied alternatives enable softer transition to a sustainable future than the lignite-powered TPP Šoštanj 6 and the achievement of the 20/20/20 objectives. The combination of various alternatives is also an interesting option, with the goal of reducing the need for a large TPP, reducing the environmental impact of energy production, and lowering investment costs. If the new wind power plants, small hydro, biogas plants, and solar power plants, for example, are built as presented in this paper, Slovenia could gain an additional 290 MW of RES power to the value of 510×10^6 euros, which could mean at least a reduction of TPP Šoštanj 6 output to the same level. With an average of 1.75×10^6 euros per MW or approximately 250 000 euros less per MW than planned in TPP Šoštanj 6, this would be less capital-intensive and more environmentally friendly. However, this also means that Slovenia does not need new TPPs for the transitional period by 2025, because energy demand can be sufficiently and reliably covered with the existing TPPs, as their installed power is high enough and would be even higher if renovated.

All the proposed alternatives also have lower investment costs than TPP Šoštanj 6. The lowest investment costs can be seen in alternative 3, followed by alternative 2 and alternative 1. Even alternative 4, a combination of various power plants powered by renewables, has more

TABLE I. Comparison of key findings of proposed alternatives for electricity production in Slovenia.

Alternatives Categories	Alternative 1 Reconstruction of TPP Šoštanj	Alternative 2 Multiple fuels	Alternative 3 Gas-steam PP	Alternative 4 Use of local RES
Investment costs(comparison with TPP Šoštanj 6)[a]	1000 EUR/MW(cheaper-use of existing components)	905 EUR/kW(cheaper)	750 EUR/kW (much cheaper)	1750 EUR/kW(slightly lower)
Electricity price(comparison with TPP Šoštanj 6)[b]	50-60 EUR/MWh(lower, lignite price is the same 2,7 EUR/GJ)	Dependent on fuel mix(lower)	Natural gas price is 2,4 EUR/GJ(currently lower)	75 EUR/MW(approximately the same, dependent on energy mix)
Emission estimation(compared with TPP Šoštanj 6)	Approximately the same	Lower (dependent on fuel mix)	Lower	Close to zero
Efficiency(compared with TPP Šoštanj 6)[c]	2%–3%(lower)	7%(higher)	13%(higher)	Not comparable
Use of local resources	Yes (fossil)	Yes (fossil and renewable)	No	Yes (renewable)
Pros	Low investmentUse of lignite from a local mine	Detachment to a single energy source	Low investmentEasy to implement	Low environmental impactSocial benefits (health and employment) Rural development
Cons	Only a transitory solution	Unfamiliarity with technology	Volatile gas price	Unreliability of wind and solarHard to implement

[a]Investment costs of TPP Šoštanj 6 are 2000 EUR/MW.
[b]Price of electricity produced in TPP Šoštanj 6 is evaluated on 70–80 EUR/MWh.
[c]Efficiency of TPP Šoštanj 6 is 43%.

than 10% lower investment costs. In addition to the lower investment costs, alternative 1, 2, and 3 are also better from the perspective of operating costs that were, however, not studied in detail. The production costs of alternative 4 are highly dependent on the included renewables and local geographic specifics. As calculated, the evaluated production costs for alternative 4 would be approximately the same as TPP Šoštanj 6 production costs. However, the environmental impact of TPP Šoštanj 6 is much higher than the environmental impact of Alternative 4. Therefore, we believe external costs will have a significant influence on the future economics of TPP Šoštanj 6 when included in the production costs.

The transition to renewable energy sources will undoubtedly take some time. At this point, it is most important that we understand how to integrate more sustainable systems that exploit renewable energy into the overall energy infrastructure. The costs of electricity produced from wind and solar sources will more likely continue to decline while the costs of fossil fuels will most likely continue to rise. These price changes have already been clearly visible since 2010, a period in which we have witnessed a huge decrease in the investment costs of solar and wind energy production equipment and a large increase in fossil fuel prices. At some point, renewables will be the cheaper source of power generation, which means that now is the time to ascertain how to integrate them into the grid and establish which storage solutions will set us on the path to reliable and secure all-day, year-round power supply.

V. CONCLUSION

As examined and presented in the paper, there are many alternatives to the current energy strategy. The research has shown that some of the alternatives are much more appropriate from the environmental perspective, since they produce fewer GHG emissions, require smaller use of imported fossil fuels and enable the increased use of local renewable resources.

The short-term losses of electricity that could result from the proposed transition to more sustainable energy production and consumption should be replaced with possible short-term energy imports or less exports. We evaluate that the short term importing of energy is, due to reduced energy use, possible and rational. More sustainable energy production and use has other benefits as well, such as lower environmental costs, less pollution, smaller penalties for failure to meet the Kyoto targets, the achievement of 20/20/20 objectives, additional income from the sale of emission allowances, the use of local resources, sustainable economic and social development, etc.

As calculated in the paper, if TPP Šoštanj 6 were not realized, the reduction of GHG emissions that Slovenia could reach with the implementation of the proposed energy policy is estimated at 1.7×10^6 tons of CO_2eqv per year over the next 44 years. The calculation has also shown that the estimated energy production in the existing blocks of TPP Šoštanj and the new block (TPP Šoštanj 6) by 2020 is approximately the same. This means that the Slovenian energy sector would remain self-sufficient also if the proposed energy strategy were applied, but at lower cost and with fewer environmental constraints.

Another of the presented calculations has shown that TPP Šoštanj operating at its current capacities with existing block 4 and 5 would produce 43 TWh of energy and 50.5×10^6 tons of CO_2eqv emissions by 2025. The construction of TPP Šoštanj 6 would increase production to 52 TWh of energy by 2025 and result in 49.5×10^6 tons of CO_2eqv emissions. Thus, the difference in the amount of CO_2eqv emissions is only 1×10^6 ton. However, the total costs for allowances are much lower if the proposed energy strategy is realised without TPP Šoštanj 6, because Slovenia can sell it after 2025 when block 5 ceases operations. This means that we have discredited the argument that TPP Šoštanj 6 will reduce GHG emissions concerning lignite combustion by 30%, as presented in TPP Šoštanj 6 documentation. The annual level of GHG emissions will be lower, but the total GHG emissions will be much higher, because TPP Šoštanj 6 would be operating for a much longer period and with higher installed power (from 2020 to 2025 - after closure of block 4). The gap in energy production should be filled with other RES, as proposed.

We ascertained that this is the result of (1) the closure of some of the existing blocks of the existing TPP Šoštanj and (2) the annual reduction of TPP Šoštanj 5 emissions (387 MW or approximately 435 MW after reconstruction) after 2020, as they would annually be 0.8×10^6 tons lower than the emissions of the new TPP Šoštanj 6. However, approximately 9 TWh less energy is produced without TPP Šoštanj 6. This gap should be filled with other RES, as proposed.

In this paper, we have demonstrated that the competitive possibilities for investing in more sustainable renewables exist in Slovenia, mainly in the form of hydro PPs. From the trapezoidal energy consumption aspect, pump-storage hydro PPs are the most suitable, while small hydro PPs are the most suitable from the environmental and social point of view. In other words, the latter impact minimally on the environment and facilitate the development of rural areas alongside the exploitation of unused water sources. However, large hydro PPs still remain the largest energy producers from RES in Slovenia.

Moreover, this paper has proven that if the output of the new large hydro PP and gas-steam PP is added, the new TPP Šoštanj block is unnecessary and inadequate from the environmental, economic and social perspectives. It is also socially inappropriate, as there is much more scope for new jobs in the renewable energy industry than in the coal industry and the use of RES can minimize or even completely solve the social and societal issues of the Šaleška Valley.

We can conclude that the development and transition of the Slovenian energy industry into a more sustainable one is cost competitive and sensible. At a time when we are beginning to fully grasp the global environmental constraints, we are still basing our development on a quantitative increase in the use of raw materials and energy. We have to move away from restrictive assumptions and change our patterns of thinking with regard to the energy sector and to our everyday lives, as this is the only way to a sustainable energy policy. A fundamental change is needed in the mindsets of the energy policy planners as well as of the public. Therefore, energy policy development and energy consumption should be founded on the promotion of reduced and efficient use of energy and on the awareness that increasing consumption will undoubtedly exceed sustainable development.

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