Sustainable Electricity Options for Kosovo

Noah Kittner[1, 2], Hilda Dimco[3], Visar Azemi[3], Evgenia Tairyan[3], and Daniel M. Kammen[1, 2, 4 *]

[1] Energy and Resources Group, University of California, Berkeley

[2] Renewable and Appropriate Energy Laboratory, University of California, Berkeley

[3] Kosovo Civil Society Consortium for Sustainable Development (KOSID)

[4] Goldman School of Public Policy, University of California, Berkeley

* Address correspondence to: Professor Daniel M. Kammen at:

* E: kammen@berkeley.edu, URL: http://rael.berkeley.edu/kosovoenergy

Abstract (word count: 125):

We have developed an analytic platform to analyze the electricity options, costs, and impacts for Kosovo, a nation that is a critical part of the debate over energy access and the role of fossil fuels versus cleaner electricity options to meet growing demands for power. We find that a range of alternatives exists to meet present supply constraints all at a lower cost than constructing a proposed 600 MW coal plant. The options include energy efficiency measures, combinations of solar PV, wind, hydropower, and biomass, and the introduction of natural gas. A $30/ton shadow price on carbon increases costs of coal generation by at least $330 million USD. The results indicate that financing a 600 MW coal plant is the most expensive pathway to meet future electricity demand.

1. Introduction

Kosovo faces serious energy challenges, and is a critical test case for the future financing of new coal-fired power plants by the World Bank and the U.S. government. More than 95% of electric power generation comes from lignite coal in Kosovo. This dependence on lignite places it among the highest rates of CO_2 emissions per Euro GDP, with estimates at twice the average level for EU countries, despite a low rate of total CO_2 emissions per capita. The UNDP estimated 0.84 tons CO_2/Euro GDP in Kosovo compared to 0.4 tons CO_2/Euro GDP for the rest of the EU (Kabashi et al., 2011; UNDP, 2013). The scheduled decommissioning of Kosovo A coal-fired power plant in 2017 prompted the international lending and donor community to consider providing a loan guarantee for a new coal-fired power plant to replace expected future missing electricity supply. But the power sector in Kosovo continually experiences electricity supply shortages and technical losses, warranting a systematic analysis of the options that exist to meet electric generation needs in addition to a proposed coal-fired power plant. The alternative pathways that Kosovo could pursue to meet future electricity supply needs have expanded significantly since this project was first discussed over a decade ago due to technological, market, and policy innovations. This analysis examines a suite of alternatives and provides both an operational and financial basis for comparison with the coal-intensive proposals.

In 2013, the World Bank issued a policy underscoring its commitment to cease financing new coal projects unless no financially feasible alternatives exist. Because Kosovo represents a case where new preliminary assessments suggested that financially feasible alternatives may exist (Kammen, Mozafari, and Prull, 2012), the decision by the World Bank to finance a new plant in Kosovo could set a precedent for future projects that will test the pledge to cease development lending for new coal-fired power plants in other countries. Since the initial plans for a coal-based future energy scenario for

Kosovo were announced, the US Department of the Treasury has also announced an end for U.S. support of public financing for new overseas coal projects as part of President Obama's Climate Action Plan (CAP) with the exception of "very limited circumstances" (US Department of the Treasury, 2013). Additionally, the European Bank for Reconstruction and Development (EBRD) policy requires that the infrastructure being financed is the least carbon-intensive of the realistically available options, keeping in line with other multilateral development banks (EBRD, 2014). Future coal-fired generation in a proposed 600 MW coal plant will undermine the pledges by the US Department of Treasury and the World Bank without fully understanding the feasible alternatives to meet Kosovar power generation challenges.

We find that a range of technically and economically viable clean electricity paths exists to meet Kosovo's near and long-term electricity needs. The scenarios that emphasize a variety of renewable electricity resources – notably solar, wind, and hydropower, in concert with judicious use of fossil fuels that are employed with a clear end game of a decarbonized and reliable electricity grid – afford Kosovo with an array of advantages. Significant in the cases examined is the consistently estimated lower overall cost relative to the business-as-usual fossil fuel pathway. In addition, each scenario emphasizing renewable energy provides more energy than the forecast demand, opening the door for regional power trading and exports, which have significant capacity to build security, regional prosperity, and peace, as well as bringing Kosovo's carbon emissions closer to the EU standard.

2. The Energy Supply and Demand Picture for Kosovo

Kosovo's power sector currently is not meeting the needs of its population due to frequent blackouts, price fluctuations, and electricity supply shortages that have required the import of electricity from neighboring countries to serve demand. Figure 1 details the mismatch between electricity generation and demand in Kosovo from 2000-2012. Historically, Kosovo resorted to importing electricity to meet electricity demand needs, therefore placing emphasis on ensuring energy supply security in the future.

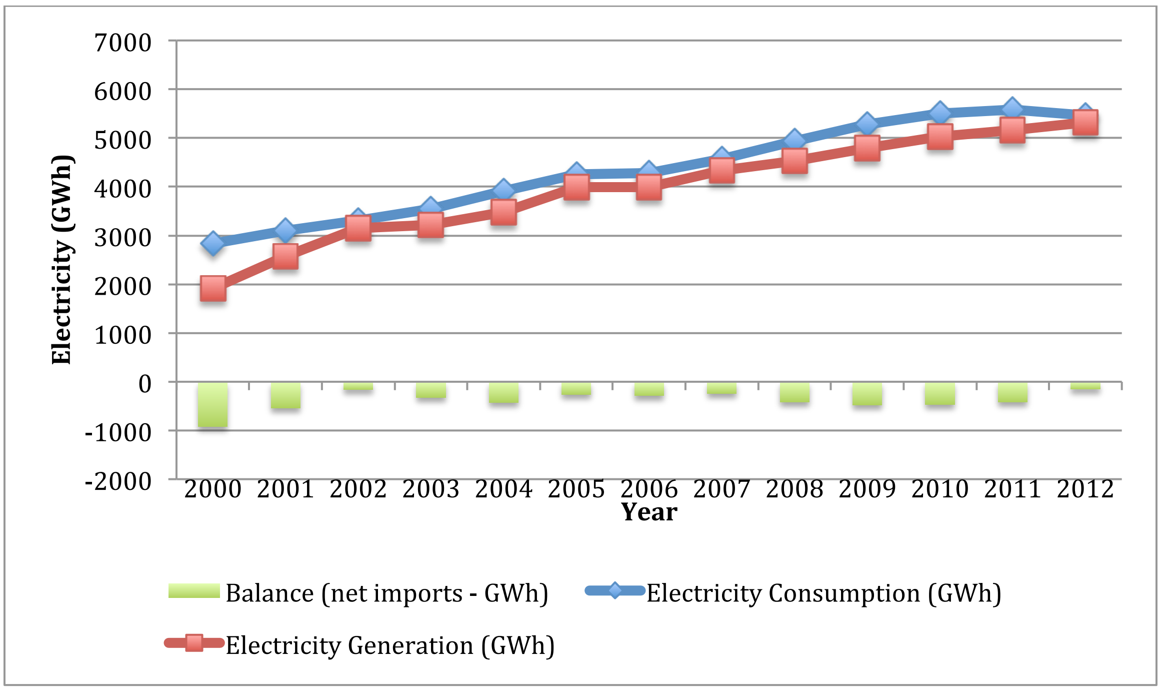

Figure 1. Electricity generation and demand from 2000-2012 (Energy Regulatory Office, 2013).

Furthermore, the combination of the existing resource and technology mix, and the high levels of lost or diverted energy means that the future supply and efficiency measures will not be sufficient to meet the country's projected energy demand. The heavy dependence on lignite coal for power generation is coupled with outdated and insufficient transmission and distribution infrastructure. The reduced cost of solar PV and wind power over the past five years combined with the widely abundant solar resource in Kosovo has expanded the range of options available to meet energy supply needs (Fraunhofer, 2013). This situation requires a fresh look at the energy mix for Kosovo. International perspectives on energy security and job creation have changed. Energy efficiency programs have been augmented by resource and technology improvements. The combination of improvements to energy efficiency programs, the declining cost of renewable energy alternatives, and the potential inclusion of natural gas as a coal substitute have added richness to the technical and policy landscape.

As an example of the key role of technological change, the declining cost of renewable energy, including solar PV and wind power, provides an alternative development pathway for Kosovo's electricity grid and economy, by meeting the electricity demand in a way that creates jobs and lowers the risk for public health disaster (Zheng and Kammen, 2014). This report demonstrates the viability of solar PV, wind, biomass, and hydroelectric resources to generate increased shares of electricity in Kosovo at a lower cost than constructing a new 600-MW coal-fired power plant by 2017, by updating an initial assessment (Kammen et al., 2012). The study addresses the need for adequate dispatchable supply, capacity requirements, and reserve margins by modeling the energy supply and demand on an hourly resolution.

3. Regional Trends in the Cost of Energy

Across Southeastern Europe, the cost of solar PV and wind electricity generation has declined dramatically, with real-world costs falling by up to 70% over the past five years, increasing the cost competitiveness of solar PV and wind when compared with conventional energy sources. Furthermore, small rooftop PV systems are expected to become cost-competitive with all forms of coal power in the next decade due to the consolidation and progress in the PV marketplace. According to the Fraunhofer Institute, the LCOE of PV power plants dipped as low as 0.078 Euro/kWh in 2013, and reached parity with grid electricity in Germany (Fraunhofer, 2013). Learning in wind power development also has contributed to lower costs for intermittent renewables, motivating a new push to use renewables as a transition toward EU integration. The high cost of meeting environmental regulations as part of the proposed Energy Community Treaty for new coal-fired power plants inhibits their future competitiveness to provide low-cost and reliable electricity, especially considering the ambient air quality directive.

Given renewable energy's slow start in Kosovo, many have posed the question of whether it is realistic to expect that the situation will change in the next few years. A 2013 GIZ study found that there is at least 290 MW of confirmed wind capacity in Kosovo spread across at least seven sites (GIZ, 2013). Furthermore, a 2014 study by Economic Consulting Associates and Energy Institute Hrvoje Pozar has cited 246 MW of wind planned for 2020 (KOSTT, 2014).

An External Expert Panel to the World Bank estimated the LCOE of a new coal power plant in Kosovo at approximately €81.42/MWh (Beer et al., 2012). By the time of completion this cost level will be uncompetitive with renewable generation and the price that electricity is traded within neighboring power exchanges, as electricity traded in the Coordinated Auction Office in Southeast Europe (SEE CAO) hovered between €10-60/MWh during 2013 and 2014. Figure 2 highlights the base market spot prices for electricity traded in the Southeast Europe market, which represents a realistic option since Kosovo is part of the Energy Community and a shareholder in SEE CAO. If electricity in Austria is traded at €35-40/MWh, it will pressure Kosovar producers to stay at this price level to remain competitive. An open regional market could allow for trading of electricity at significantly less than the LCOE of coal based on historical prices in 2013 and 2014.

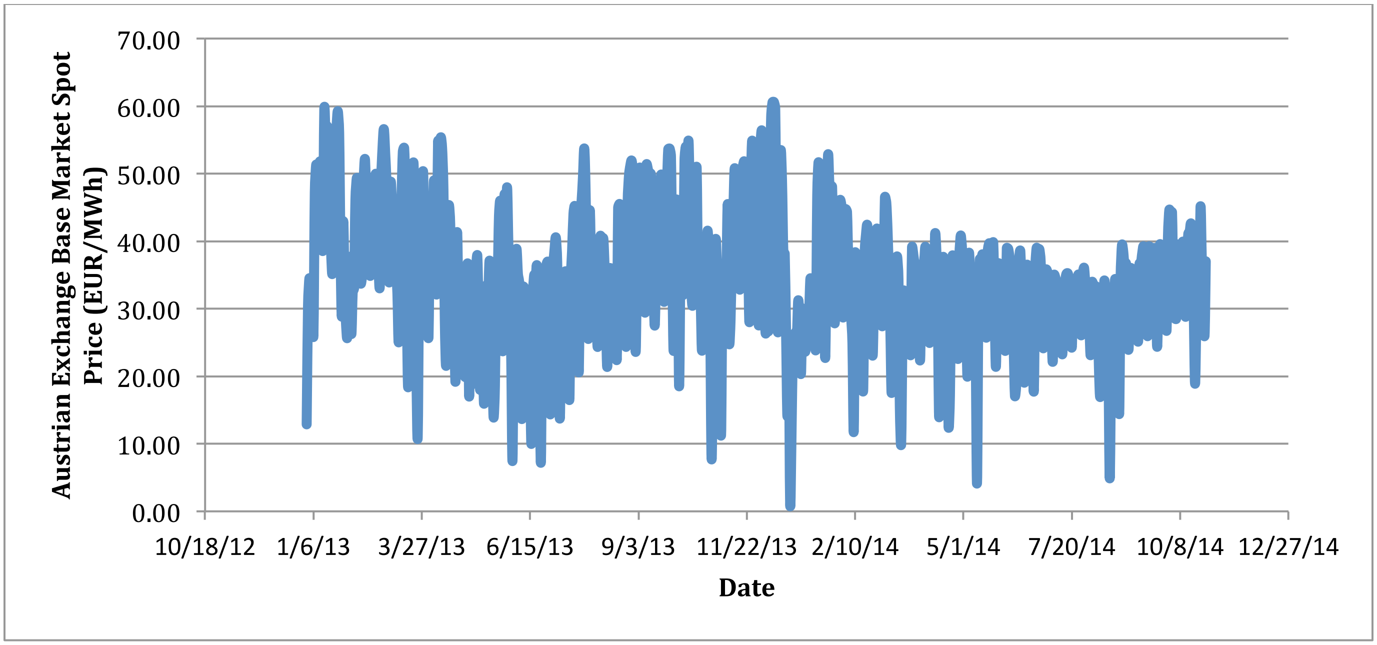

Figure 2. Base Electricity Market Spot Prices for Austrian Energy Exchange in 2013 and 2014 (Energy Exchange Austria, 2014).

Assuming that Kosovo's aspiration is joining the EU, Kosovo will likely move into an emerging open regional power market, where it would become part of the European integrated energy market. In fact, KOSTT is already a shareholder in the Coordinated Auction Office for South East Europe and a part of the Energy Community Treaty, furthering the rationale for moving toward a single market for energy within the EU (Prange-Gstohl, 2009). The existing and planned grid interconnections position Kosovo to become a regional power market player. Significant opportunities exist in the region for electricity trading due to differences in resource portfolios and the potential for intertemporal substitution of electricity from various sources (Hooper and Medvedev, 2009). The market however will expose the financial uncompetitiveness of the proposed power plant. Kosovo runs a serious risk to end up with a significant stranded asset that will either drain public resources through government subsidies or restrict the integration of the country within the broader European energy system.

4. Data

There has been little empirical work studying the power sector in Kosovo and the Southeast Europe region. Few studies have undertaken detailed resource assessments for renewable energy resources due to regional conflict (Kammen et al., 2012). Because the power sector faces pressing informational needs due to rising demand, power generation challenges, and future regional grid integration, providing reliable and secure electricity remains a critical development challenge. The data for this study represent the best available information given the limitations of resource availability assessments in the region, yet provide useful information that can inform electricity capacity planning efforts. The decreased capital cost of key renewable technologies including solar PV and wind within Southeastern Europe provides insights into the cost of developing renewable energy in Kosovo, especially as the Government of Kosovo prepares to seek accession into the European Union. The European Commission has enacted stricter greenhouse gas emission reduction targets along with increased energy efficiency, renewable generation goals, and plans for expanding regional interconnections. Joining the EU – a goal expressed publicly by a range of Kosovar leaders -- would be a major driver of change in the energy mix to meet the standards imposed by the Industrial Emissions Directive. Additionally, Kosovo would need to follow the 20-20-20 targets, which stipulate a 20% reduction in greenhouse gas emissions from 1990 levels, raising the share of renewable energy generation to 20%, and a 20% improvement in energy efficiency (EU, 2015a; EU, 2015b).

4.1 Study area

This study models the cost of building new generation capacity within the power sector in Kosovo. We locate all generation and construction projects within Kosovo and we also investigate the opportunities to participate in an open regional market via a power-trading scheme that would include Albanian-Kosovar joint projects and imported electricity from Romania. The World Bank designates

Kosovo as a Lower Middle Income country with a GDP in 2013 of approximately $6.96 billion USD and a population of 1.824 million (World Bank, 2013). The country spans an area of approximately 10,908 square kilometers within the Balkan region.

4.2 Resource Availability

4.2.1 Coal Reserves

There is an estimated potential of 10.9-12.5 billion tonnes of domestic lignite coal reserves. However, despite this available resource, lignite coal has the lowest carbon content, highest amount of moisture, and lowest energy density compared to other types of coal. Significant health and environmental problems arise from its continued use (Treyer et al., 2014). Even the process of converting lignite from mining and extraction into a usable form is more energy intensive than other types of coal production. It's unlikely the proposed power plant, "New Kosovo," would utilize the best available technologies for pollution control and carbon capture and storage due to the proposed subcritical boilers (World Bank, 2011).

4.2.2 Solar resource availability

We use regional resource estimates to estimate solar PV generation. The annual incoming solar radiation ranges from 1550 kWh/m^2/year to 1650 kWh/m^2/year at 35° inclination (European Commission, 2008). There is not much regional variation across the country (less than 10%), so we use an average of 1600 kWh/m^2/year to estimate the generation as shown in Figure 3. There is more solar resource available in the southwest toward Prizren, however the differences within the country differ by less than 10%. We include a capacity factor of 18% for solar photovoltaic installations. We assume that the plant operated at 13% efficiency at STC including an AC derating factor of 87%.

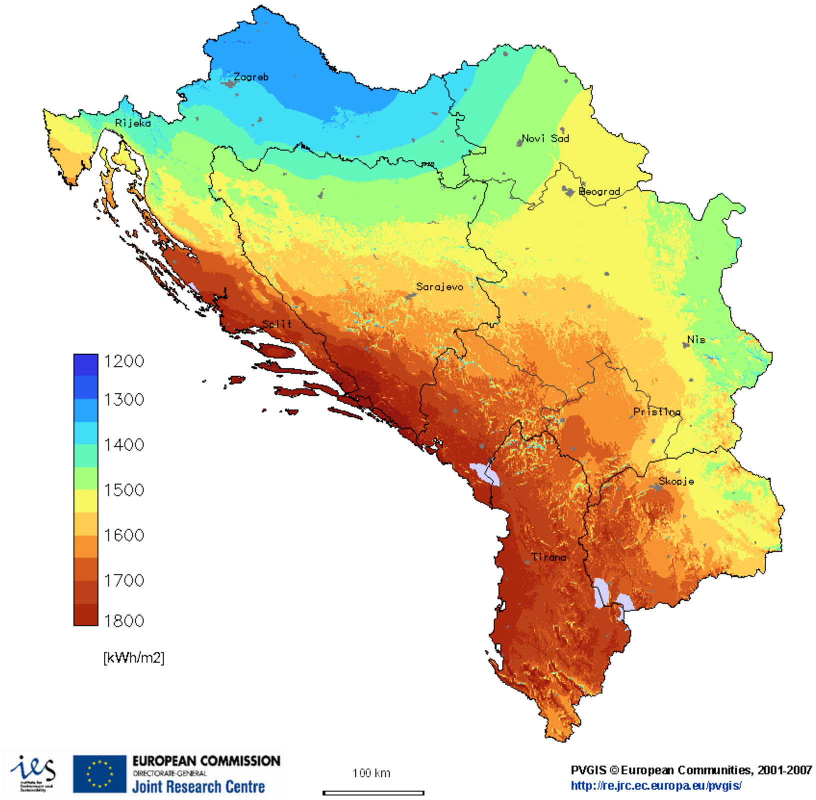

Figure 3. Solar radiation across Balkan region, with 35 degree inclination, facing south.

4.2.3 Hydroelectric power

We separate hydropower into two different classifications. We treat reservoir-based traditional hydropower as large-scale hydropower projects and we investigate run-of-river small-scale mini-hydropower projects.

4.2.3.1 Large-scale hydropower projects

This analysis explores scenarios where a major proposed hydropower project, Zhur is built and when it is not constructed. The proposed location of Zhur is between Prizren and Dragash. The plans for Zhur have been modified as original documentation proposed a 305 MW facility with annual production of approximately 400 GWh. However, we do not model scenarios with a 305 MW facility as we expect Zhur to be approximately 45 MW in capacity if it is built (Ministry of Energy and Industry, *personal communication*). This large-scale hydropower facility would be the only one of its type. As a reservoir-based large-scale hydropower facility, Zhur could provide peaking support to accommodate the variability in the current grid, which is not reliable. This facility would also support the development of intermittent renewables by providing a dispatchable, load-balancing generation source. The hydropower portfolio matches well with coincident demand in Kosovo, which could provide peaking support in the absence of or combined with natural gas.

4.2.3.2. Run-of-river hydropower projects

There is an aggregated potential to develop approximately 63 MW of small-scale, run-of-river, mini-hydropower projects across Kosovo due to the presence of many rivers with sufficient resources ranging from 3-21 meters of gross head and greater than 4 cm^3/s of flow based on a feasibility study carried out across Kosovo's water resources (Kammen et al., 2012). This resource could provide nearly 300 GWh of electric generation per year. Even more supportive of hydropower development, the Energy Regulatory Office (ERO) in Kosovo expects 140.3 MW of run-of-river capacity by 2020.

4.2.4 Wind resource

The wind resource data comes from meteorological data from 10 potential project sites. The estimated average annual wind-speed from Budakova at 38 meters is approximately 6.9 m/s. Figure 4 exhibits the monthly average wind resource at Budakova. We use the log law to extrapolate wind speed at commercial hub of 90 meters to 7.4 m/s using a roughness class of 1 based on the European Wind Atlas classification. The mountainous terrain of Kosovo provides many available sites located near municipalities with potential for wind power generation. Wind projects in the pipeline include the development of 140 MW of wind by NEK Umwelttechnik, a Swiss firm, beginning with the Zatric wind farm project with a capacity of up to 45 MW. The other projects include the Budakove wind farm and Cicavices, which could come online by 2016 (NEK, 2013).

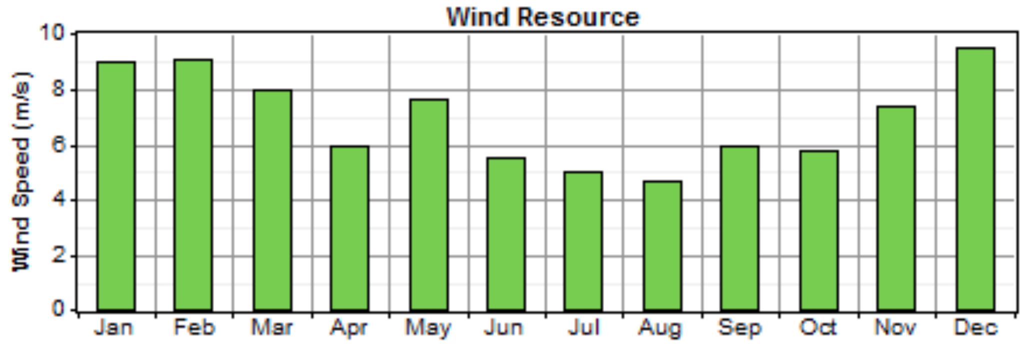

Figure 4. Annual wind speed (m/s) in Budakova.

4.2.5. Biomass

The theoretical potential for electricity generation from biomass sources in Kosovo comes from three main types of biomass—wood, livestock waste, and agricultural straw. We estimate approximately 6600 GWh/yr of theoretical annual energy from biomass resources available in Kosovo. Furthermore, a household survey on biomass recently estimated that 1.6 million cubic meters of biomass are harvested annually (Waschak et al., 2013). Even though this represents a 300,000-400,000 cubic meters above the recommended levels of wood harvesting, improved forest management policies and practices could enable a sustainable biomass resource for electricity consumption (NFG, 2012). This would facilitate the development of more promising, lower-cost renewables including solar PV and wind. An important area for further study is the potential in Kosovo to aggregate and utilize biomass as both a dispatchable renewable energy resource, but also potentially as a means to technologically leapfrog and include a net carbon negative energy component. Recent studies in other regions (Sanchez, *et al.*, 2015) open the door for further studies that have additional benefits of strong job creation potential (Wei, Patadia, and Kammen, 2010).

4.2.6. Waste-to-energy projects

Another resource explored in this study is waste incineration. The Government of Kosovo (GoK) estimates annual urban waste of 192 kg per capita, which represents approximately 384,000 tons/year (GoK, 2012). This study assumes that 1 ton of waste is equivalent to 670 kWh of electricity generation, and 10% of the electricity generated is lost to waste recycling. This type of technology is based on landfill cogeneration and Kosovo has the advantage of using central heating. Incineration or burning of waste by advanced technologies could contribute to a small portion of overall electricity generation.

4.2.7 Energy efficiency measures

Energy efficiency is a critical resource for planning Kosovo's future electric grid. Currently, Kosovo represents a "non energy-efficient" country, however, this sector must improve to meet European Union integration requirements. The World Bank already approved a $31 million USD loan to establish the Kosovo Energy Efficiency and Renewable Energy Project.

Transmission and distribution inefficiencies along the grid account for significant technical energy losses. Approximately 33% of electricity generated is lost through the transmission and distribution system. Technical losses within the distribution system alone accounted for 14% of electricity generated and 16% were unaccounted commercial losses. The remaining losses occurred in the transmission system. Upgrading transmission and distribution infrastructure would greatly address electricity generation concerns. Neighboring Albania recently transitioned from a similar level of technical and commercial losses in the distribution system improving from 38% total losses to less than 21% in 2014 with a goal of 15% in 2015 by integrating better meters (Ministry of Energy and Industry, *personal communication*).

Demand-side management emerges as one strategy that could alleviate theft within the distribution system and improve systems operability. The distribution company, KEK, has deployed over 30,000 smart meters, but this lags considerably behind the customer base of 400,000 individuals.

4.2.8 Natural gas development

Kosovo has no domestic natural gas resources for electricity generation. Currently, gas consumption and supply is limited to bottled liquefied petroleum gas. However, there are plans underway to construct the Trans Adriatic Pipeline (TAP) to deliver natural gas supply. We study the option of including natural gas by regional trade. Natural gas plants can facilitate the growth of solar PV and wind on the grid by providing peaking services in a cleaner and more efficient way compared to coal backup generation. Additionally, natural gas can diversify fuel supplies, and engage the country in regional markets. If combined with Kosovo's existing, but not yet implemented feed-In tariff policy, this use of gas, including biogas, can provide a scalable backstop resource that supports an overall path to expand the role of renewable energy deployment (Sitzmann, 2013).

4.3 Data for Cost Estimates

The cost data for this study comes from the latest estimates in Southeast Europe for the levelized cost of energy by leading market research firms (Fraunhofer, 2013). The global reductions over the past five years in the LCOE of renewables open the door for a wide variety of alternative scenarios to investigate further. The cost of generation in our analysis captures capital investment costs, fixed and variable operation and maintenance (O&M) costs, and also the cost of fuel (for coal and natural gas).

4.3.1.The Cost of Renewables

The cost of solar has reduced drastically over the past five years, due to photovoltaic-specific learning in the manufacturing sector. In Germany, for instance, the LCOE reached between 0.078 and 0.142 EUR/kWh. This represents an example lower-bound cost estimate based on electricity infrastructure improvements financed by KfW, the German development bank. We use the analysis from Fraunhofer, which applies an 85% learning curve to the levelized cost of solar electricity.

Run-of-river mini-hydropower is estimated to generate electricity at 0.04 Euro/kWh, and the levelized cost of large-scale hydropower from Zhur is assumed at 0.10 Euro/kWh based on construction estimates (IEA, 2015). Domestic, on-shore wind and biomass projections are assumed to be 0.05 Euro/kWh and 0.06 Euro/kWh respectively (Fraunhofer, 2013). The cost of energy efficiency is derived from World Bank estimates as part of the Energy Efficiency and Renewable Project. We apply a 90% learning curve to wind and energy efficiency costs per year.

5. Methods

We created a spreadsheet model to estimate the cost of annual generation and supply over 8760 hours. We incorporate previous analyses and parameters of Kosovo's power sector. These scenarios provide a framework to investigate the cost and generation of Kosovo's power sector. The data are from the latest levelized cost of energy projections determined by Fraunhofer and represent prices within Southeast Europe. Investment and capital costs are included in this calculation, as the LCOE comprises total capital cost, fixed and variable O&M, fuel price, and construction time.

$$LCOE = \frac{\{capital\ investment\ cost * capital\ recovery\ factor + fixed\ O\&M)}{8760 * capacity\ factor} + (fuel\ cost * heatrate) + variable\ O\&M$$

We base capacity factors for different technologies on previous reports that estimate resource availability for renewable technologies and historical generation from existing power plants using information from KOSTT. We simulate 8760 hours of electricity generation for each technology type and the cost to build each scenario using capital fixed costs and operating costs and amortize until 2025. Each scenario represents a different alternative pathway that highlights the numerous opportunities for development in the region. The base case presents a business as usual approach if the World Bank approves financing for Kosovo C. Additionally we estimate the cost difference from the base scenario when introducing a $30/ton shadow price of carbon when using coal. Lignite coal is one of the lowest quality types of coal and could release 5.8 million tons of CO_2/year in Kosovo's electricity sector (Kammen et al., 2012). In multiple scenarios, Kosovo B must close down by 2017, as it will approach its end-of-life unless we apply retrofit investments. The base case scenario continues operation of Kosovo B beyond 2025.

5.1 The Scenarios

Each scenario is explored to consider the range of options and costs to meet power generation demands using different technologies as summarized in Table 1. We explore different technologies to understand the cost of the options available and the various ways Kosovo could improve its power sector.

The scenarios have been selected to represent plausible renewable energy options that meet Kosovo's power sector needs. There is uncertainty whether the government will build natural gas pipelines, and many of the scenarios could occur due to differing policy directions. The cost of solar has decreased remarkably during the past five years explaining the SunShot solar scenario (Zheng and Kammen, 2014). We explore demand-side reductions through aggressive energy efficiency measures because the World Bank has committed funding toward energy efficiency projects, and the existing state of the electricity sector remains inefficient. The storage penalty case investigates a more conservative case on the costs of expanding solar electricity. We explore gas and importing electricity as a transition scenario to meet electricity supply needs at lower investment costs.

5.1.1 The Base case

The base case scenario considers the construction of Kosovo C, a 600 MW coal-fired power plant in 2017 to meet the generation gap induced by the closing of Kosovo A. The base case includes the continued operation of Kosovo B, including retrofits to extend its life-span beyond 40 years. We assume a 3% yearly improvement in transmission and distribution losses. The base case scenario includes imported electricity to continue due to reliability concerns. Recent explosions and technical problems at Kosovo A have severely limited production and forced Kosovo to increase imported electricity, therefore it is considered in this analysis. The cost of importing electricity is approximately 40 EUR/MWh, well within the range of Figure 1. The base case scenario is highlighted in Figure 2.1. We project consumption based on estimated population and GDP growth, which is currently around 3% according to the World Bank.

5.1.2 Solar prices reduce to SunShot levels ($1/watt)

The second scenario considers the situation if the cost of solar PV reaches $1/W by 2020. The US Department of Energy established a program called SunShot solar power that strives to achieve this target. The progress so far indicates this is potentially viable and therefore we consider this an upper-bound scenario on the generation from solar photovoltaics. Reaching SunShot levels reduces the cost of solar to approximately 0.05 USD/kWh. This scenario also features the decommissioning of Kosovo A by 2017, and the expiration of Kosovo B by 2024 as it will reach 40 years of sustained use. The SunShot solar price scenario includes wind, electricity imports, biomass, the construction of Zhur, and run-of-river mini-hydropower. By 2020, this model reaches 325 MW of solar PV capacity.

5.1.3 Aggressive energy efficiency measures to reduce end-use consumption

The third scenario incorporates increased energy efficiency and a reduction in generation capacity due to reduced end-use consumption, meeting the Government of Kosovo's target of 9% improvement of energy efficiency by 2018. We apply a linear improvement in energy efficiency and assume that 1 kWh of energy conservation displaces 1 kWh of coal-fired generation from the baseload. There is great potential for energy efficiency measures across public buildings especially if considering the benefits of a nationwide building insulation campaign. The scenario, detailed in Figure 2.3, reduces consumption to nearly 5000 GWh by 2015. Also, this scenario considers significant investment and improvement in the transmission and distribution infrastructure to reduce losses by 50% from their current levels.

5.1.4. Introduction of natural gas

The natural gas scenario assumes that natural gas pipelines will facilitate the adoption of natural gas as a potential electricity generation source by 2018. While natural gas may only show modest improvement over lignite coal in terms of climate impacts, natural gas has significant advantages for grid operation in the presence of intermittent renewables. First, natural gas is more flexible to the variability of solar PV and wind. Secondly, the construction of natural gas facilities could potentially provide electricity without the magnitude of the public health costs associated with lignite coal. Natural gas prices in this scenario are based on Fraunhofer Institute projections of the fuel price to 2020 of 0.03 Euro/kWh. The inclusion of 600 MW of new gas capacity in 2019 could remove the need to extend Kosovo B beyond its current lifespan. This scenario includes the option for Kosovo to become a net exporter of electricity an in energy poor region, producing surplus electricity generation.

In an open regional market, this could be a boon for the economy since Southeast Europe as the region remains energy poor.

5.1.5. Including storage cost for solar at high deployment levels

In this scenario, we apply a cost penalty for solar PV to add energy storage. This cost is attributed as 10% of the total system cost of generation and added to the cost for all solar PV. We add this to better represent the external costs that increased distributed solar resources may bring to the grid for balancing and flexibility. The storage penalty raises the cost of solar to reflect more conservative estimates. In this scenario pictured in Figure 2.6, we estimate far less solar PV developed compared to the scenario pictured in Figure 2.2. Additionally, we include expanded electricity imports to account for the difference in generation. The costs are detailed in Table 2 and the Appendix. The storage penalty scenario also includes natural gas to highlight the complementary role of natural gas as a flexible generator that fills in for intermittent renewables. The combination of flexible natural gas with solar PV, wind, and additional costs associated with energy storage presents an alternative that could satisfy electricity demand and create a net energy producing scenario.

5.1.6. Including a carbon shadow price

Adding a price on carbon changes the energy picture in several ways. First, we apply a shadow price of $30 USD/ton CO_2-eq as practiced by the World Bank. This represents the price that World Bank uses to evaluate projects; therefore, we estimated our model using this level. Recent research into the social cost of carbon indicates that the full social cost of climate damages could even reach levels as high as $220 USD/ton CO_2-eq (Moore and Diaz, 2015). We assume that low-carbon electricity generation sources including solar PV, wind, hydropower, and imports will not receive any price on carbon. Imported electricity is excluded because we only count a carbon price within Kosovo. We apply this analysis in two ways. First we look at the additional cost of carbon added to the base case scenario when the generation mix consists predominantly of coal. The second application is applying the cost to coal and modeling a scenario where the carbon shadow price influences decisions to expand existing capacity. This scenario, pictured in Figure 5.6 requires the import of electricity to meet electricity demands in the later years. We would expect that a carbon shadow price further increases the gap between investing in future coal generation and alternative energy pathways.

5.1.7. Excluding gas and Zhur, but including a power exchange, and waste-to-energy

The final scenario is included in the appendices. This alternative removes the possibility of including natural gas in the energy portfolio for Kosovo by 2018. The missing generation comes from participating in an open regional market and investing in new transmission line capacity. This more conservative estimate also explores the possibility that construction delays for Zhur could prevent this hydroelectric source from coming online. This scenario relies on the continuation of Kosovo B beyond its expected lifespan.

5.2 Further details

We annualize the cost of generation each year in a net present value calculation to estimate the cost of the different scenarios until 2025. Appendix 1 details these cost figures.

The information on the potential for small hydropower developments comes from a previous feasibility study that highlights the potential for 63 MW of projects with projected annual production of nearly 300 GWh. The ERO office within Kosovo also foresees development of small-scale hydropower projects that could total up to 140 MW beyond 2020. We include this within our scenarios. We also analyze the potential construction of Zhur, where the development is proposed between Prizren and Dragash. However, we scale back the capacity of Zhur from the previous analysis due to the concerns over feasibility and include a scenario with an operation Zhur at 45 MW, which is 15% of the originally proposed capacity of 305 MW.

We introduce natural gas as one scenario by including the construction of the Trans Adriatic Pipeline (TAP) by 2018. Though natural gas remains politically questionable, it remains an important energy source globally and could become a large regional player given the supply shortages from other sources and regional market plans to trade gas. Additionally, recently the EU Energy Commission proposed an Energy Community Gas Ring, which would enable natural gas to play a role in the power sector and displace coal-generation. Regionally, in Albania, the conversion of a diesel plant to gas opens up the opportunity for future natural gas development in the region. Therefore, we investigate natural gas as a scenario for analysis among a range of alternatives.

The proposed construction of increased regional transmission capacity allows for future energy imports and exports and we also consider the potential for an open regional market via a power exchange. We include the construction of a 400 kV transmission line between Albania and Kosovo financed by the German Development Bank (KfW) in each scenario. The line is expected to be 241 km and cost approximately 75.5 million euros or 94.2 million USD (1 EUR = 1.25 USD). We use the cost of the expansion of transmission capacity in our estimation of the open regional market.

We estimate transmission losses based on the USAID energy efficiency reports and figures from KOSTT, the Kosovar transmission system operator. The KOSTT system already interconnects with Montenegro (400 kV line), Macedonia (400 kV line), Albania (220 kV line), and Serbia (400 kV, 220 kV, and 110 kV) allowing transit, imports and exports of electricity. The existing interconnections provide key opportunities for future electricity trading in an open regional market situation.

The demand forecasts are based on KOSTT information. The future expected demand incorporates projected population growth and economic growth by using GDP. We assume 3.2% growth in GDP per annum. This version of the model does not incorporate seasonal fluctuations for hydropower or demand requirements on peak time scales. However, it provides a picture of different ways Kosovo could meet demand, especially given severe supply constraints.

We use energy efficiency costs from the most recent USAID report and the newly funded Kosovo Energy Efficiency and Renewable Energy project funded by the World Bank that aims to reduce energy consumption in public buildings (USAID, 2013). The household and services (public and private) building sectors account for approximately 48% of final energy consumption in Kosovo (World Bank, 2013). The Government of Kosovo's energy efficiency target of 9% reductions by 2018 falls short of the EU's 20% reduction requirement. Our energy efficiency scenario considers meeting the Government of Kosovo's energy efficiency target of 9% improvement by 2018. If Kosovo seeks accession to the EU, the energy efficiency targets would need to increase to reflect EU directives on energy, the environment, and market competition (USAID, 2013).

Kosovo experiences severe losses across the distribution system, which is now privatized and operated by a Turkish consortium called "Limak-Calik." Koorporata Energjetike e Kosoves (KEK), the previous company that maintained the distribution system is only responsible for energy production. Technical losses on the distribution system have ranged as high as 16% in one year due to outdated equipment, a lack of maintenance, and network inefficiencies.

Furthermore, including a price on carbon widens the difference in cost between the studied scenarios because of the carbon intensity of lignite coal. Therefore a shadow price on CO_2 emissions further pushes the base case scenario from the range of alternatives in terms of total estimated cost.

6. Results

The results indicate a wide range of options that meet electricity generation requirements at a lower cost than the base case scenario. Table 1 summarizes the scenarios and cost estimates. The Energy Strategy for Kosovo established specific goals for capacity expansion for renewables.

We estimated the cost of different renewable energy technologies and the amount of electricity generated based on different capacities for each technology in Table 1.

Scenario	Name	Notes
1	**Base Case (coal)**	TPP C built in 2017
2	Solar prices reduce to SunShot levels ($1/watt)	Solar at $1/W by 2020
3	Aggressive energy efficiency measures to reduce consumption and T&D losses along with expanded open regional market via a power exchange	1 kWh energy avoided displaces 1 kWh coal-fired generation
4	Introduction of natural gas via TAP by 2018 with aggressive energy efficiency measures	Solar at $2/W by 2020
5	Storage penalty for solar at $200/kWh along with introduction of natural gas via TAP and aggressive energy efficiency measures	Solar at $2/W by 2020 and storage is $200/kWh
6	Including a carbon shadow price at $30/ton of CO_2	Carbon price commensurate with World Bank policy
7	Excluding gas and Zhur, but including a power exchange, and waste-to-energy	Solar at $2/W by 2020 and excess generation from Albania is sold on Kosovar market

Table 1. A selection of the multiple pathways examined in this paper that economically and reliably meet Kosovo's projected future electricity demand.

The cost assumptions influenced the capacity deployed of each technology in different years. Using resource availability data, we calculated the estimated annual generation from each type of electricity and the associated cost, annualized over a twelve-year period. The base case scenario, Figure 5.1, assumes Kosovo C is built in 2017 and 98% of Kosovo's electricity generation comes from brown lignite coal. Figure 5.2 highlights the scenario where solar prices reduce to SunShot levels of $1/W by 2020, TPP A ceases production by 2017 and we assume a 3% yearly improvement in transmission and distribution losses. Albanian-Kosovar joint projects and small hydropower reserves balance the system and provide flexibility to accommodate intermittent solar as a part of an open regional market. We added a storage penalty to account for the intermittency of solar PV, by appending 10% of system costs per kWh to each kWh of solar generated in Figure 5.5 (Gur et al., 2012).

The estimated grid consumption data comes from projections by the Ministry of Economic Development along with expected population growth. Figure 5.2 exhibits the increased ability of solar PV to meet electricity needs, ramping up in magnitude starting in 2020 if the price of solar reduces to $1/W, a current policy goal of the US government under the SunShot pricing program. These prices are reasonable because of the global competitiveness of the solar PV market and remain consistent with projections for the cost of solar PV in southeast Europe. An aggressive energy efficiency scenario, detailed in Figure 5.3, exhibits the potential to curtail growth in peak energy consumption to 5000-7000 GWh. Figure 5.4 introduces natural gas to Kosovo's electricity portfolio by 2018 and gas quickly facilitates a rise in solar PV deployment due to the ability to serve as a fast-ramping, flexible generator that compensates for the variability of solar PV due to cloudiness. Given that bringing TAP or IAP is an official policy of the Government of Kosovo, a scenario incorporating natural gas should be analyzed. With the introduction of gas, the demand for all coal generation disappears by 2022. The final scenario, not pictured here, introduces low-cost energy imports from an open regional market, which allows solar to develop along with available hydropower resources. A waste-to-energy program could supplement the grid in the final scenario, providing a potential of nearly 257 GWh per year assuming the availability of 384,000 tons per year of landfill material. The results highlight the wide variety of options Kosovo has to meet its future electricity demand at lower cost than building Kosovo C and the opportunities for Kosovo to become an energy hub by exporting electricity to neighboring states.

In Figure 5.6, we test the sensitivity by including a shadow price of $30/ton of CO_2, as World Bank President Jim Kim has suggested should be accounted for when planning new World Bank projects. We estimate that the construction of Kosovo C could add up to 11.5 million tons of CO_2 per year, adding an additional amortized cost of $330 million to the construction of Kosovo C.

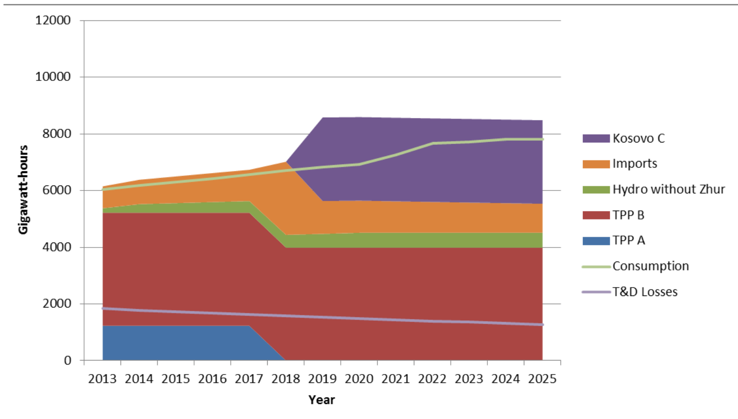

Figure 5.1. Base Case (Kosovo C built in 2017)

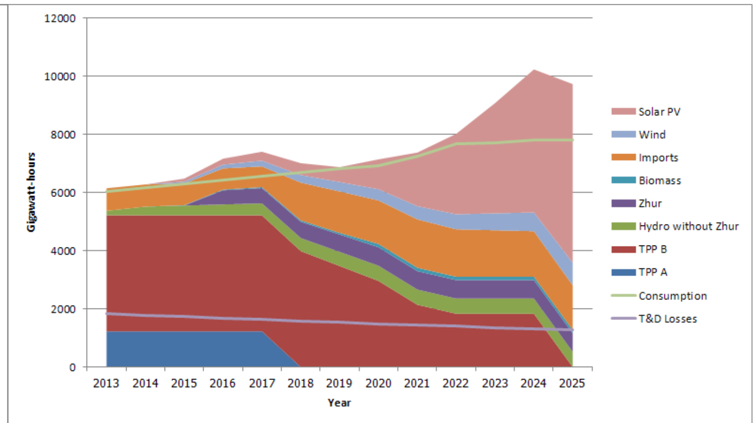

Figure 5.2. Solar reaches SunShot Prices ($1/W) by 2020.

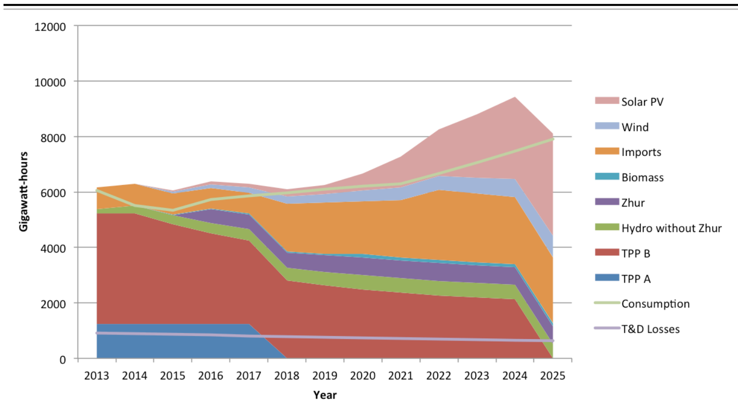

Figure 5.3. Aggressive energy efficiency measures to reduce consumption and T&D losses along with an open regional market via a power exchange.

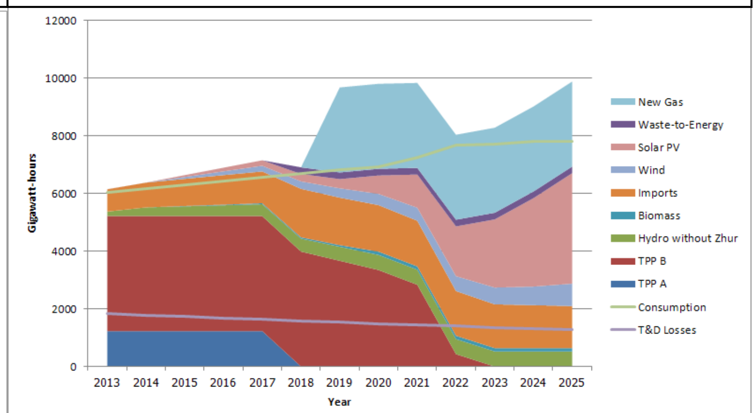

Figure 5.4. Introduction of natural gas via TAP by 2018 with aggressive energy efficiency measures.

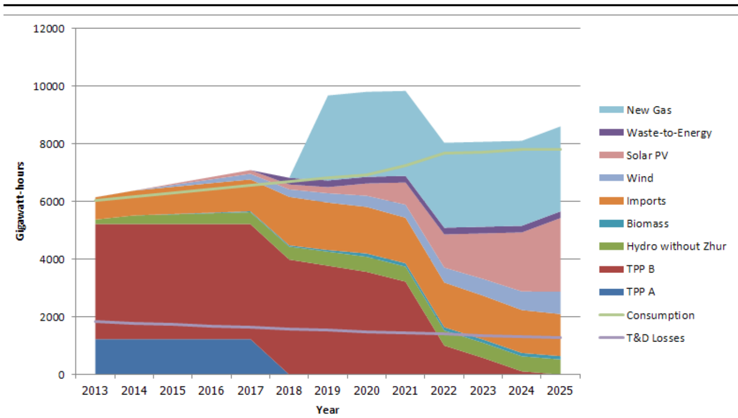

Figure 5.5. Storage penalty for solar at $200/kWh along with introduction of natural gas via TAP and aggressive energy efficiency measures.

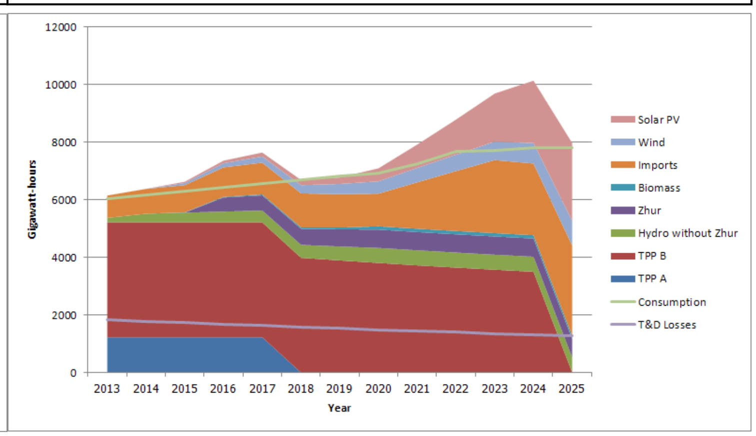

Figure 5.6. Carbon Shadow Price of $30/ton CO_2

Scenario	Name	Notes	Estimated Cost[*]	Figure
1	**Base Case (coal)**	"New Kosovo" built in 2017	**$2.17 billion USD**	Figure 5.1, Appendix Table A.1, A.1.1
2	Solar Prices Reduce to SunShot Levels	Solar at $1/W by 2020	$1.85 billion USD	Figure 5.2; Appendix Table A.2
3	Aggressive energy efficiency measures to reduce consumption and T&D losses along with open regional market via a power exchange	1 kWh energy avoided displaces 1 kWh coal-fired generation	$1.73 billion USD	Figure 5.3; Appendix Table A.3
4	Introduction of natural gas via TAP by 2018 with aggressive energy efficiency measures	Solar at $2/W by 2020	$1.71 billion USD	Figure 5.4; Appendix Table A.4
5	Including storage cost for solar at high deployment levels	Solar at $2/W by 2020 and storage penalty at $200/kWh, representing 10% of system generation costs	$1.74 billion USD	Figure 5.5; Appendix Table A.5
6	Including a carbon shadow price	$30/ton of CO_2 added to cost of coal generation	$1.97 billion USD	Figure 5.6; Appendix Table A.6
7	Excluding gas and Zhur, but including a power exchange, and waste-to-energy	Solar at $2/W by 2020 and excess generation from Albania is sold on Kosovar market	$1.94 billion USD	Not pictured; Appendix Table A.7

Table 2. Total cost estimates of each scenario including business-as-usual case. Technology costs are based on current operating costs (BAU), and renewable energy technology costs as estimated by the Global Energy Assessment (2012) project.

[*] See Appendix A for detailed annualized cost estimation.

Each of the different non-Kosovo C scenarios will provide electricity until at least 2025 at a cost of less than $1.7-$1.9 billion dollars. This is significantly less than an estimated cost of $2-2.2 billion dollars to build a 600 MW coal fired power plant. Ongoing international discussions around the Kosovo C option have focused on installing two 330 MW coal-fired subcritical boilers (~ 37% thermal efficiency) which indicates that a) the cleanest conventional coal plants are not being considered, largely due to cost concerns, and b) the human and environmental health impacts of the baseline coal project will be significantly higher than the most recent epidemiological studies on higher ranking bituminous and anthracite coal (Epstein et al., 2011; Treyer et al., 2014). Selection of these less socially damaging coal options, which international safeguards would warrant, would increase the price gap between the clean energy cases and the coal scenario further. The alternative pathways presented could save the Kosovo Energy Corporation (KEK) between $200-500 million USD before considering health, job creation, or societal benefits of a more resilient system. This upper-bound estimate does not include any externalities. If we apply a shadow price of $30/ton of carbon, the difference between each scenario and the base case could double. This is based on estimated costs of capacity expansion only and therefore does not model power flow across the grid. We caveat the results that the costs are based on expanding generation capacity.

7. Discussion

Particularly important in this work is the observation that there are multiple, economically realistic scenarios that can provide reliable, low-carbon electricity for Kosovo. Technical and political preferences may lead different analysts to prefer different energy mixtures, but the diversity of viable cases leads directly to three very clear conclusions:

- There is no shortage of low-cost, low-carbon paths that Kosovo and international investment and development partners could follow;
- As a result of the above, a coal-dominated future is neither an economic nor political necessity. In ongoing work, the job creation and both human and environmental health benefits of these non-coal scenarios will be further detailed, which makes the case for a multi-billion dollar coal-based pathway unnecessary.
- A diversity of low-carbon pathways requires further discussion and action; the range of options presented, in fact, may make the pathway to a decision challenging in a contentious environment.

Due to capital constraints within the region, the $200-500 million difference in costs per scenario is not trivial. The health costs of lignite in terms of particulate and sulfur emissions would increase the gap between options that reduce coal generation. Further work will examine: 1) regional interconnections; 2) the job benefits of clean energy scenarios; and 3) health, agricultural and political benefits of a clean energy sector. Each of these assessments will increase the value of the clean energy path for Kosovo, Europe, and the international partners engaged in pro-growth sustainable regional development. Preliminary estimates for job creation indicate that the clean energy scenarios examine here all have the potential for greater number of long-lasting jobs than the coal intensive pathway.

7.1 Developing a Smart Grid

The development of smart grids could leverage under-utilized resources in Kosovo. Currently Kosovo's distribution system experiences approximately 34% losses including technical and non-technical losses. Given the Ministry of Finance's revised renewable energy targets of 29.4% by 2020, the development of smart grid infrastructure for both improved efficiency and communications could greatly aid the reduction of technical losses on the system and improve system performance. With the Energy Regulatory Office already approving 67 MW in small-scale hydropower and 30 MW of wind in December, the improvement of existing infrastructure and information and communication technology on the transmission and distribution system becomes increasingly important.

7.2 Expanding Regional Cooperation

The potential for Kosovo's participation in the existing and future regional markets (notably around gas and hydropower) remains an under-studied opportunity for economic development and expanding regional cooperation. Each scenario features surplus generation of electricity in the future that could be sold on an open regional market. At the same time, excess hydropower capacity from Albania can be purchased to secure balancing reserves and enable a more resilient power grid to accommodate temporal and seasonal mismatches in energy availability. Enhanced regional cooperation will facilitate the transition to renewables and will improve overall system efficiency in contrast to building a new coal-fired power plant.

8. Conclusions and policy implications

As demonstrated through the range of alternative energy pathways, the opportunity cost of building a new 600-MW coal-fired power plant is high. The policy implications of the proposed coal plant are pervasive throughout the economics of coal, multi-lateral development bank finance policy, and energy security as a national development strategy. The scenario results provide a framework to evaluate policy risk from multiple stakeholders, including the Government of Kosovo, the World Bank, and the US Government as a direct benefactor of energy lending to multi-lateral development banks. The results of this work have the potential to influence policy within Kosovo and on an international scale. The decision to build a coal plant in Kosovo could create a ripple effect for other proposed coal projects in emerging economies like India and Pakistan that sets a precedent for the interpretation of financially feasible alternatives. For Kosovo, coal is not cost competitive even before considering external environmental and health costs.

Previous studies have analyzed the full-scale costs of coal across the entire life cycle and externalized these values into economic terms for policy analysis (Epstein et al., 2011). Given the scale of the need for reliable and efficient electricity in Kosovo, there is a heightened risk for public health and the environment. Financing a new coal plant would lock-in the commitment to sustaining a coal industry for more than forty years, which enables path dependencies. We find that the difference of $100-$400 million USD is not considered significant within the multi-lateral development banking sphere, but represents a significant chunk of Kosovo's GDP and would substantially alter Kosovo's development path.

Multi-lateral development banking policy has emerged at the global forefront of the energy debates regarding the future of coal as a source for baseload electricity generation. Inevitably, development banks will finance Kosovo's future, therefore the policy choice from the banking institution will have long-term implications. The nameplate policy by the World Bank to cease the financing of coal-fired power plants unless no financially feasible alternatives exist is a critical step toward shifting energy finance in the direction of low-carbon renewables and energy efficiency measures. However, by potentially moving forward with a coal plant in Kosovo, the World Bank would disregard the alternative pathways discussed in this analysis that remain financially viable without considering social or external costs of the proposed Kosovo C facility.

Given the enormous existing losses from the transmission and distribution system, the results indicate a potential outlet to promote energy efficiency policy in Kosovo. Emphasizing improvements in the transmission and distribution system alone could replace the need to continue operating Kosovo A beyond 2017. The diversion of available loan guarantees from coal projects toward efficiency measures would enable the investment in transmission upgrades including the potential for FACTS devices, power electronics and distribution-system upgrades including voltage regulators, capacitor banks, and smart meters that would alleviate wasted energy.

In the US, new analyses have documented the rapidly declining cost of saved energy through demand-side management measures. For some states in the US, the cost of saved energy has declined as low as 2.3 cents per kWh (LBNL, 2014). These opportunities for policy intervention include national-scale building insulation campaigns, audits, retrofits, and appliance standards. Even though the alternative pathways do not recommend a particular set of technologies over another, the advantages of instituting energy efficiency policies remain certain. Building a new coal plant as opposed to directing money toward efficiency campaigns, codes, and standards would create a negative cost situation for the Government of Kosovo where they would spend at least an additional $100-$400 million USD without considering social costs. The added cost of CO_2 at $30 USD/ton would further burden the coal facility with an estimated $330 million of external carbon costs.

Energy security has emerged as an important policy goal within Southeast European countries. The different pathways presented in this paper fall within different energy security policy packages including expanding generation capacity within Kosovo and access to electricity and simultaneously responding to looming threats of global climate change. Coal specifically poses certain security challenges including the tradeoff of being plentiful, yet finite in supply. The resource curse of coal could constrain Kosovo's future economic development, as diversity and availability of resources remain key components of any national energy security plan (Sovacool & Brown, 2010; Sovacool &

Saunders, 2014). The alternative pathways detailed in this analysis highlight the range of security options and domestic renewable resources that would reduce governmental debt. A focus on managing risk through diversification of resources, where Kosovo currently relies on 98% lignite could reduce the recent price surges consumers have faced due to unreliable generation capacity from Kosovo A and Kosovo B. Decentralized and domestic run-of-river hydropower, solar electricity, and biomass resources open up opportunities for regional power trading. An open market could enable Kosovo to become an energy producer of surplus electricity and sell to neighboring countries, since nearly all countries in the region (Albania, Bulgaria, Serbia, and Macedonia) suffer from energy supply shortages on a frequent basis.

The policy options discussed would set the World Bank and multi-lateral lending institutions on a dangerous precedent if they choose to continue coal-based lending from a global climate perspective. The ripple effects of decisions on Kosovo's power sector will hold a large influence over the future debates to construct new coal-fired power plants in sub-Saharan Africa, India, and Pakistan. The lending policy opens the conversation for how constrained an economy must be to qualify for the exception in the World Bank's policy, as technically Kosovo resembles a middle-income country (officially classified as IDA/Blend) compared to other countries that may lack significantly more economic resources.

Many options exist for Kosovo's future electricity system, however one certainty is the ability for different combinations of renewable energy to provide reliable electricity at a greatly reduced cost compared to building a 600 MW coal-fired power plant. Under a range of scenarios with the current and projected cost of solar electricity, coal consistently remains a more expensive option for the country's electric grid. Moreover, aggressive energy efficiency and future ability to import electricity from Albania would facilitate more solar PV development beyond the base case scenario, which indicates the feasibility of using alternative energy to improve Kosovo's electric grid. This report highlights that Kosovo's energy future will not depend on the economy or technology, yet will remain a policy choice with significant implications for the electricity sector, public health, and the environment.

Acknowledgments

We thank the many dedicated partners working on energy scenarios for discussions leading to this work. Maryam Mozafari and Dan Prull provided key foundational analyses as part of the RAEL team. Justin Guay of the Sierra Club and Julian Popov of the European Climate Foundation have been invaluable colleagues in this assessment effort, along with colleagues at the Harvard School of Public Health. We thank the Zaffaroni Family, the Karsten Family Foundation, the Rockefeller Brothers Fund, and the NSF SAGE-IGERT program at the University of California, Berkeley for their support.

References:

Beer, J., Mielczarski, W., Taylor, D. (2012). Kosovo: Kosovo Power Project Report of the SFDCC External Expert Panel to the World Bank. http://siteresources.worldbank.org/INTENERGY2/Resources/Kosovo_Power_Project_Expert_Panel_Report.pdf Last Accessed 20 January 2015.

Epstein, P. R., Buonocore, J. J., Eckerle, K., Hendryx, M., Stout III, B. M., Heinberg, R., ... & Glustrom, L. (2011). Full cost accounting for the life cycle of coal. *Annals of the New York Academy of Sciences*, *1219*(1), 73-98.

EU (2015a). The Industrial Emissions Directive. <http://ec.europa.eu/environment/industry/stationary/ied/legislation.htm> Last Accessed 20 January 2015>.

EU (2015b). The 2020 Climate and Energy Package. http://ec.europa.eu/clima/policies/package/index_en.htm Last Accessed 20 January 2015.

European Commission (2008). European Commission Liaison Office to Kosovo – Kosovo Ministry of Energy and Mining, June 2008.

Fraunhofer Institute for Solar Energy Systems (2013). *Levelized cost of electricity: Renewable Energy technologies study*. Last accessed 7 October 2014.

URL: http://www.ise.fraunhofer.de/en/publications/veroeffentlichungen-pdf-dateien-en/studien-und-konzeptpapiere/study-levelized-cost-of-electricity-renewable-energies.pdf>

Government of Kosovo (2012). Strategy of the Republic of Kosovo on Waste Management 2012-2021. Ministry of Environment and Spatial Planning. URL: http://mmph.rks-gov.net/repository/docs/+SRKMM_Ang_270038.pdf Last Accessed: 20 January 2015.

GEA (2012) *Global Energy Assessment - Toward a Sustainable Future,* Cambridge University Press, Cambridge, UK and New York, NY, USA and the International Institute for Applied Systems Analysis, Laxenburg, Austria. http://www.globalenergyassessment.org

GIZ (2013). Renewable energy as an opportunity for economic development in Kosovo. Last accessed 20 October 2014. URL: *http://www.nek.ch/windenergie-geothermie-e/publikationen/dokumente/2013.05.30_GIZ_Study_english_final_16012013.pdf*

Gur, I., Sawyer, K., & Prasher, R. (2012) "Searching for a better thermal battery," *Science,* **335** (6075), 1454-1455.

Hooper, E., & Medvedev, A. (2009). Electrifying integration: Electricity production and the South East Europe regional energy market. *Utilities Policy*, *17* (1), 24-33.

International Energy Agency (2015). World Energy Outlook – Investment Costs. Last accessed 23 March 2015. http://www.worldenergyoutlook.org/weomodel/investmentcosts/

Kabashi, S., Bekteshi, S., Ahmetaj, S., Kabashi, G., Najdovski, D., Zidanšek, A., & Šlaus, I. (2011). Effects of Kosovo's energy use scenarios and associated gas emissions on its climate change and sustainable development. *Applied Energy*, *88* (2), 473-478.

Kammen, D. M. (2012) "Kosovo counting on the U.S. for energy leadership" *San Francisco Chronicle*, A10 (Tuesday, March 27).

URL: http://www.sfgate.com/cgi-bin/article.cgi?f=/c/a/2012/03/27/EDKM1NR08K.DTL#ixzz1qNlTka16

Kammen, D. M., Mozafari, M., & Prull, D. (2012). RAEL Report. Sustainable Energy Options for Kosovo: An Analysis of Resource Availability and Cost. *University of California, Berkeley*. http://rael.berkeley.edu/kosovoenergy

KOSTT (2014). Western Balkans Sustainable Energy Direct Financing Facility: Institutional Capacity Building. Last Accessed 20 October 2014. URL: http://www.kostt.com/website/images/stories/Komunikate_per_Media/EBRD_W_Balkans_-Kosovo_Wind_Task_1-_Draft__-_Eng.pdf

LBNL (2014) The Total Cost of Saving Electricity Through Utility Customer-Funded Energy Efficiency Programs. http://emp.lbl.gov/cost-saved-energy

Ministry of Energy and Industry (2015). *Personal Communication with Ilir Bejtja*. 23 March 2015. Tirana, Albania.

Moore, F. C., & Diaz, D. B. (2015). Temperature impacts on economic growth warrant stringent mitigation policy. *Nature Climate Change* 5 (127-131).

NEK, 2013. Kosovo's first wind farm takes shape. Last Accessed 15 November 2014<www.nek.ch/windenergie-geothermie-e/publikationen/dokumente/2013.03.08_EIEE_Kosovo_080313.pdf>

NFG, Norwegian Forestry Group, and Ministry of Agriculture, Forestry, and Rural Development (2012). The second Kosovo national forest inventory: Resources remain stable. <http://www.nfg.no/userfiles/file/Kosovo/NFI%20Kosovo_folder_201113_final.pdf>

Prange-Gstöhl, H. (2009). Enlarging the EU's internal energy market: Why would third countries accept EU rule export?. *Energy Policy*, *37*(12), 5296-5303.

Sanchez, Daniel L., Nelson, James H., Johnston, J., Mileva, A., and Kammen, D.M. (2015) "Biomass Enables the Transition to a Carbon-negative Power System Across Western North America", *Nature Climate Change*, in press. DOI: 10.1038/NCLIMATE2488

Sitzmann, B. (2013). Feasibility analysis for renewable energy for farming in Kosovo. *Initiative for Agricultural Development of Kosovo.* Available online at: http://www.iadk.org/Portals/0/2013/Feasibility%20analysis%20for%20alternative%20energy%20in%20farming%20in%20Kosovo.pdf

Sovacool, B. K., & Brown, M. A. (2010). Competing dimensions of energy security: An international perspective. *Annual Review of Environment and Resources*, *35*, 77-108.

Sovacool, B. K., & Saunders, H. (2014). Competing policy packages and the complexity of energy security. Energy, 67, 641-651.

Statement of Security of Supply for Kosovo (Electricity, Natural Gas and Oil) July 2013. Available online at: https://www.energy-community.org/portal/page/portal/ENC_HOME/DOCS/2422181/Statement_of_Security_of_Supply_for_Kosovo_(Electricity_Gas, and Oil)_Final_Eng.pdf

Treyer, K., Bauer, C., & Simons, A. (2014). Human health impacts in the life cycle of future European electricity generation. *Energy Policy*. [doi: 10.1016/j.enpol.2014.03.034]

UNDP (2013). Support for low emission development in Kosovo. http://www.ks.undp.org/content/kosovo/en/home/operations/projects/environment_and_energy/support-for-low-emission-development-in-kosovo.html. Last Accessed 20 January 2015.

USAID (2013). USAID Affirmative Investigation: Kosovo coal-fired power plant project trip report.

US Department of Treasury. (2013). Guidance for U.S. Positions on MDBs Engaging with Developing Countries on Coal-Fired Power Generation. Last Accessed 19 October 2014 at

<http://www.treasury.gov/resource-center/international/development-banks/Documents/CoalGuidance_2013.pdf>

Waschak, M.R., English, A., Myderrizi, A., Halili, B., Hasaj, B. (2013). Wood fuel consumption in Kosovo households. RIT/AUK Center for Energy and Natural Resrouces Final Report.

Wei, M., Patadia, S. and Kammen, D. M. (2010) Putting renewables and energy efficiency to work: How many jobs can the clean energy industry generate in the U. S.? *Energy Policy*, **38**, 919 - 931.

World Bank (2011). Kosovo: Kosovo Power Project: Terms of Reference for the SFDCC Expert Panel.

World Bank (2013). National Building Energy Efficiency Study for Kosovo. Last Accessed 5 December 2014 at: <http://www.worldbank.org/content/dam/Worldbank/Feature%20Story/ECA/kosovo/Kosovo%20Eptisa%20Final%20Report_2013.04.13.pdf>

World Bank (2013). World Development Indicators. Last Accessed 1 November 2014 at <http://data.worldbank.org/country/kosovo>

Zheng, Cheng and Kammen, Daniel (2014) "An Innovation-Focused Roadmap for a Sustainable Global Photovoltaic Industry," *Energy Policy,* **67**, 159–169.

Appendix A. Detailed annualized costs for each scenario.

Technology	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	Net Present Value $USD 2014, 2%
KSA3	-123514248	-4428857.109	-4428857.109	-4428857.109	-4428857.109	-4428857.109	0	0	0	0	0	0	0	($135,894,172.89)
KSA4	-41171416	-4428857.109	-4428857.109	-4428857.109	-4428857.109	-4428857.109	0	0	0	0	0	0	0	($57,472,428.13)
KSA5	-13723805.33	-4428857.109	-4428857.109	-4428857.109	-4428857.109	-4428857.109	0	0	0	0	0	0	0	($31,331,846.54)
KSB1	-156212096	-13286571.33	-13286571.33	-13286571.33	-13286571.33	-13286571.33	-13286571.33	-12622242.76	0	0	0	0	0	($221,543,840.92)
KSB2	-199298569.9	-13286571.33	-13286571.33	-13286571.33	-13286571.33	-13286571.33	-13286571.33	-12622242.76	0	0	0	0	0	($262,578,577.99)
"New Kosovo", no renewables, BAU	0	0	0	0	-1.4E+08	-1.4E+08	-1.3E+08	-1.7E+08	-1.8E+08	-1.9E+08	-2E+08	-2E+08	-3.3E+08	($2,171,546,287.47)

Table A.1. "New Kosovo" is built with business-as-usual growth.

Technology	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	Net Present Value $USD 2014, 2%
KSA3	-123514248	-4428857.109	-4428857.109	-4428857.109	-4428857.109	-4428857.109	0	0	0	0	0	0	0	($135,894,172.89)
KSA4	-41171416	-4428857.109	-4428857.109	-4428857.109	-4428857.109	-4428857.109	0	0	0	0	0	0	0	($57,472,428.13)
KSA5	-13723805.33	-4428857.109	-4428857.109	-4428857.109	-4428857.109	-4428857.109	0	0	0	0	0	0	0	($31,331,846.54)
KSB1	-156212096	-13286571.33	-13286571.33	-13286571.33	-13286571.33	-13286571.33	-13286571.33	-12622242.76	0	0	0	0	0	($221,543,840.92)
KSB2	-199298569.9	-13286571.33	-13286571.33	-13286571.33	-13286571.33	-13286571.33	-13286571.33	-12622242.76	0	0	0	0	0	($262,578,577.99)
"New Kosovo", no renewables, BAU	0	0	0	0	-1.4E+08	-1.4E+08	-1.3E+08	-1.7E+08	-1.8E+08	-1.9E+08	-2E+08	-2E+08	-3.3E+08	($2,171,546,287.47)
CO_2 priced at $30/ton	-27000000	-27000000	-27000000	-27000000	-34000000	-34000000	-34000000	-34000000	-34000000	-34000000	-34000000	-34000000	-34000000	($332,907,500.62)

Table A.1.1. "New Kosovo" is built with business-as-usual growth and we introduce a shadow price of \$30/ton of CO_2.

Technology	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	Net Present Value $USD 2014, 2%
PV array 18% cf	0	0	-5329584	-5329584	-5329584	-5329584	-5329584	-26647920	-42636672	-47966256	-53295840	-58625424	-63955008	($193,619,049.18)
Wind turbines	-89737.44	0	-6670483.04	-6715351.76	-6715351.76	-6715351.76	-6715351.76	-6715351.76	-6715351.76	-6715351.76	-6715351.76	-6715351.76	-13475572.24	($54,226,345.98)
Hydro turbine	-16300327.68	-15213639.17	-3803409.792	-3803409.792	-3803409.792	-3803409.792	-3803409.792	-3803409.792	0	0	0	0	0	($46,833,487.66)
KSA3	-123514248	-4428857.109	-4428857.109	-4428857.109	-4428857.109	-4428857.109	0	0	0	0	0	0	0	($135,894,172.89)

KSA4	-41171416	-4428857.109	-4428857.109	-4428857.109	-4428857.109	-4428857.109	0	0	0	0	0	0	0	($57,472,428.13)
KSA5	-13723805.33	-4428857.109	-4428857.109	-4428857.109	-4428857.109	-4428857.109	0	0	0	0	0	0	0	($31,331,846.54)
KSB1	-312424192	-13286571.33	-13286571.33	-13286571.33	-13286571.33	-13286571.33	-13286571.33	-12622242.76	-11991130.62	-11391574.09	-10821995.39	-10280895.62	0	($397,092,477.65)
KSB2	-265731426.6	-13286571.33	-13286571.33	-13286571.33	-13286571.33	-13286571.33	-13286571.33	-12622242.76	-11991130.62	-11391574.09	-10821995.39	-10280895.62	0	($352,623,177.23)
Imports	-40281482.18	-39475852.53	-38686335.48	-37912608.77	-37154356.6	-67611269.46	-74059044.08	-77777863.19	-86622305.93	-84889859.81	-83192062.62	-81528221.36	-79897656.94	($567,980,661.04)
Biomass	0	0	-1352894.4	-1352894.4	-1352894.4	-1352894.4	-1352894.4	-6764472	0	0	0	0	0	($9,891,227.12)
Total	-813236635.2	-54689491.7	-54510310.71	-53781452.72	-53023200.55	-83480113.42	-15621188.03	-40740336.75	-6424441.69	-82659831.57	-129879294.4	-132212641.1	-141339485.2	($1,846,964,873.42)
Renewables Cost	-56671547.3	-54689491.7	-54510310.71	-53781452.72	-53023200.55	-83480113.42	-89927888.03	-115047036.7	-125315161.7	-127579903.6	-129879294.4	-132212641.1	-141339485.2	($824,146,008.68)

Table A.2. Solar reaches SunShot Prices ($1/W) by 2020.

Technology	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	Net Present Value $USD 2014, 2%
PV array 18% cf	0	0	-1332396	-1332396	-1332396	-3108924	-1776528	-8882640	-14212224	-15988752	-17765280	-19541808	-21318336	($64,436,902.01)
Wind turbines	-179474.88	0	-6670483.04	-6715351.76	-6715351.76	-6715351.76	-6715351.76	-6715351.76	-6715351.76	-6715351.76	-6715351.76	-6715351.76	-13475572.24	($54,311,810.21)
Hydro turbine	-16300327.68	-15213639.17	-3803409.792	-3803409.792	-3803409.792	-3803409.792	-3803409.792	-3803409.792	0	0	0	0	0	($46,833,487.66)
KSA3	-123514248	-2214428.555	-2214428.555	-2214428.555	-2214428.555	-2214428.555	0	0	0	0	0	0	0	($126,763,395.02)
KSA4	-41171416	-2214428.555	-2214428.555	-2214428.555	-2214428.555	-2214428.555	0	0	0	0	0	0	0	($48,341,650.25)
KSA5	-13723805.33	-2214428.555	-2214428.555	-2214428.555	-2214428.555	-2214428.555	0	0	0	0	0	0	0	($22,201,068.67)
KSB1	-312424192	-13286571.33	-13286571.33	-13286571.33	-13286571.33	-13286571.33	-13286571.33	-12622242.76	-11991130.62	-11391574.09	-10821995.39	-10280895.62	7729576.224	($392,993,318.35)
KSB2	-265731426.6	-13286571.33	-13286571.33	-13286571.33	-13286571.33	-13286571.33	-13286571.33	-12622242.76	-11991130.62	-11391574.09	-10821995.39	-10280895.62	0	($352,623,177.23)
Import	-	-	-	-	-	-	-	-	-	-	-	-	-	($612,249,8

s	34574938.87	33883440.09	33205771.29	32541655.86	31890822.75	74586339.62	79594612.83	82336053.91	89355999.5	109235546.2	107050835.2	104909818.5	102811622.2	83.99)
Biomass	0	0	-1352894.4	-1352894.4	-1352894.4	-1352894.4	-1352894.4	-6764472	0	0	0	0	0	($9,891,227.12)
Total	-813236635.2	2210508.3	-31351748.15	-50794673.98	-50277662.94	-55547914.37	-59623737.02	-94784541.33	-106509620.5	-114832028.3	-122628856.1	-129999242.5	-143784610.8	($1,730,645,920.50)
Renewables Cost	-16390065.12	-15213639.17	-18488767.23	-18533635.95	-18533635.95	-18533635.95	-18533635.95	-50593133.55	-60011191.76	-66673171.76	-141374359.1	-146675555	-158764187	($464,538,800.32)

Table A.3. Aggressive energy efficiency measures to reduce consumption and T&D losses along with open regional market via a power exchange

Technology	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	Net Present Value $USD 2014, 2%
PV array 18% cf	0	0	-4885452	-3108924	-3997188	-3997188	-3997188	-19985940	-31977504	-35974692	-39971880	-43969068	-47966256	($145,250,825.74)
Wind turbines	-179474.88	0	-6670483.04	-6715351.76	-6715351.76	-6715351.76	-6715351.76	-6715351.76	-6715351.76	-6715351.76	-6715351.76	-6715351.76	-13475572.24	($54,311,810.21)
Hydro turbine	-16300327.68	-15213639.17	-3803409.792	-3803409.792	-3803409.792	-3803409.792	-3803409.792	-3803409.792	0	0	0	0	0	($46,833,487.66)
KSA3	-123514248	-123514248	-123514248	-123514248	-123514248	-123514248	0	0	0	0	0	0	0	($626,920,288.77)
KSA4	-41171416	-41171416	-41171416	-41171416	-41171416	-41171416	0	0	0	0	0	0	0	($208,973,429.59)
KSA5	-13723805.33	-13723805.33	-13723805.33	-13723805.33	-13723805.33	-13723805.33	0	0	0	0	0	0	0	($69,657,809.86)
KSB1	-312424192	-312424192	-312424192	-312424192	-312424192	-312424192	74306700	74306700	0	0	0	0	0	($1,482,666,909.14)
KSB2	-265731426.6	-265731426.6	-265731426.6	-265731426.6	-265731426.6	-265731426.6	-265731426.6	-265731426.6	0	0	0	0	0	($1,717,478,746.72)
Gas	0	0	0	0	0	0	-	-	-	-	-	-	-	($733,299.9

							176857.5203	196508.3559	178822.6039	157206.6847	157206.6847	157206.6847	157206.6847	6)
Imports	-80562964.35	-89351705.06	-97964670.96	-106405377.5	-114677270	-143583724.6	-140712050.1	-137897809.1	-135139852.9	-132437055.9	-129788314.7	-127192548.4	-124648697.5	($1,101,501,109.97)
Biomass	0	0	-1352894.4	-1352894.4	-1352894.4	-1352894.4	-1352894.4	-6764472	0	0	0	0	0	($9,891,227.12)
Total	-853607854.8	-104565344.2	-114676910.2	-121385957.5	-130546113.9	-159452568.5	-82274194.05	-100860282.7	-54941988.68	135524398.9	-176475546.5	-177876968.2	-186090525.7	($1,707,873,465.46)

Table A.4. Increased energy efficiency measures alongside the introduction of natural gas via TAP by 2018 and phase out of coal by 2022.

Technology	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	Net Present Value $USD 2014, 2%
PV array 18% cf	0	0	-4885452	-3108924	-3997188	-3997188	-3997188	-19985940	-31977504	-35974692	-49971880	-53969068	-57966256	($175,250,825.74)
Wind turbines	-179474.88	0	-6670483.04	-6715351.76	-6715351.76	-6715351.76	-6715351.76	-6715351.76	-6715351.76	-6715351.76	-6715351.76	-6715351.76	-13475572.24	($54,311,810.21)
Hydro turbine	-16300327.68	-15213639.17	-3803409.792	-3803409.792	-3803409.792	-3803409.792	-3803409.792	-3803409.792	0	0	0	0	0	($46,833,487.66)
KSA3	-123514248	-123514248	-123514248	-123514248	-123514248	-123514248	0	0	0	0	0	0	0	($626,920,288.77)
KSA4	-41171416	-41171416	-41171416	-41171416	-41171416	-41171416	0	0	0	0	0	0	0	($208,973,429.59)
KSA5	-13723805.33	-13723805.33	-13723805.33	-13723805.33	-13723805.33	-13723805.33	0	0	0	0	0	0	0	($69,657,809.86)
KSB1	-312424192	-312424192	-312424192	-312424192	-312424192	-312424192	74306700	74306700	0	0	0	0	0	($1,482,666,909.14)
KSB2	-265731426.6	-265731426.6	-265731426.6	-265731426.6	-265731426.6	-265731426.6	-265731426.6	-265731426.6	0	0	0	0	0	($1,717,478,746.72)
Gas	0	0	0	0	0	0	-	-	-	-	-	-	-	($733,299.9

							176857.5203	196508.3559	178822.6039	157206.6847	157206.6847	157206.6847	157206.6847	6)
Imports	-80562964.35	-89351705.06	-97964670.96	-106405377.5	-114677270	-143583724.6	-140712050.1	-137897809.1	-135139852.9	-132437055.9	-129788314.7	-127192548.4	-124648697.5	($1,101,501,109.97)
Biomass	0	0	-1352894.4	-1352894.4	-1352894.4	-1352894.4	-1352894.4	-6764472	0	0	0	0	0	($9,891,227.12)
Total	-853607854.8	-104565344.2	-114676910.2	-121385957.5	-130546113.9	-159452568.5	-82274194.05	-100860282.7	-54941988.68	135524398.9	-176475546.5	-177876968.2	-186090525.7	($1,737,873,465.46)

Table A.5. Increased energy efficiency measures alongside the introduction of natural gas via TAP by 2018 and storage cost of $200/kWh.

Technology	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	Net Present Value $USD 2014, 2%
PV array 18% cf	0	0	-8793813.6	-8793813.6	-8793813.6	-8793813.6	-8793813.6	-43969068	-70350508.8	-79144322.4	-87938136	-96731949.6	-222776611.2	($381,652,059.23)
Wind turbines	-98847.84	0	-7347689.44	-7397113.36	-7397113.36	-7397113.36	-7397113.36	-7397113.36	-7397113.36	-7397113.36	-7397113.36	-7397113.36	-14843650.64	($59,731,558.77)
Hydro turbine	-16300327.68	-15213639.17	-3803409.792	-3803409.792	-3803409.792	-3803409.792	-3803409.792	-3803409.792	0	0	0	0	0	($46,833,487.66)
KSA3	-123514248	-4428857.109	-4428857.109	-4428857.109	-4428857.109	-4428857.109	0	0	0	0	0	0	0	($135,894,172.89)
KSA4	-41171416	-4428857.109	-4428857.109	-4428857.109	-4428857.109	-4428857.109	0	0	0	0	0	0	0	($57,472,428.13)
KSA5	-13723805.33	-4428857.109	-4428857.109	-4428857.109	-4428857.109	-4428857.109	0	0	0	0	0	0	0	($31,331,846.54)

KSB1	-312424192	-13286571.33	-13286571.33	-13286571.33	-13286571.33	-13286571.33	-13286571.33	-12622242.76	-11991130.62	-11391574.09	-10821995.39	-10280895.62	0	($397,092,477.65)
KSB2	-265731426.6	-13286571.33	-13286571.33	-13286571.33	-13286571.33	-13286571.33	-13286571.33	-12622242.76	-11991130.62	-11391574.09	-10821995.39	-10280895.62	9766850.837	($347,443,607.71)
Imports	-40281482.18	-44675852.53	-48982335.48	-53202688.77	-57338635	-61391862.3	-60164025.05	-58960744.55	-57781529.66	-56625899.07	-55493381.08	-54383513.46	-53295843.19	($501,373,082.69)
Biomass	0	0	-1352894.4	-1352894.4	-1352894.4	-1352894.4	-1352894.4	-6764472	0	0	0	0	0	($9,891,227.12)
Total	-813245745.6	-59889491.7	-70280142.71	-74549919.92	-78685866.15	-82739093.45	-68224684.87	-108272564.9	-123538021.2	-131775760.7	-140006635.1	-148231680.8	-281149254.2	($1,968,715,948.37)

Table A.6. Scenario with Solar at \$2/W by 2020 and shadow price of \$30/ton of CO_2 for coal generation.

Technology	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	Net Present Value $USD 2014, 2%
PV array 18% cf	0	0	-4885452	-3108924	-3997188	-3997188	-3997188	-19985940	-31977504	-35974692	-39971880	-43969068	-47966256	($145,250,825.74)
Wind turbines	-179474.88	0	-6670483.04	-6715351.76	-6715351.76	-6715351.76	-6715351.76	-6715351.76	-6715351.76	-6715351.76	-6715351.76	-6715351.76	-13475572.24	($54,311,810.21)
Hydro turbine	-16300327.68	-15213639.17	-3803409.792	-3803409.792	-3803409.792	-3803409.792	-3803409.792	-3803409.792	0	0	0	0	0	($46,833,487.66)
KSA3	-123514248	-4428857.109	-4428857.109	-4428857.109	-4428857.109	-4428857.109	0	0	0	0	0	0	0	($135,894,172.89)
KSA4	-41171416	-4428857.109	-4428857.109	-4428857.109	-4428857.109	-4428857.109	0	0	0	0	0	0	0	($57,472,428.13)
KSA5	-13723805.33	-4428857.109	-4428857.109	-4428857.109	-4428857.109	-4428857.109	0	0	0	0	0	0	0	($31,331,846.54)
KSB1	-156212096	-13286571.33	-13286571.33	-13286571.33	-13286571.33	-13286571.33	-13286571.33	-12622242.76	0	0	0	0	0	($221,543,840.92)

KSB2	-199298569.9	-13286571.33	-13286571.33	-13286571.33	-13286571.33	-13286571.33	-13286571.33	-12622242.76	0	0	0	0	0	($262,578,577.99)
Waste	0	0	0	0	0	-57910500	-57910500	-57910500	-57910500	-57910500	-57910500	-57910500	-57910500	($293,264,349.73)
Imports	-80562964.35	-78951705.06	-77372670.96	-75825217.54	-74308713.19	-72822538.93	-71366088.15	-69938766.39	-68539991.06	-67169191.24	-65825807.41	-64509291.27	-63219105.44	($681,529,311.37)
Biomass	0	0	-1352894.4	-1352894.4	-1352894.4	-1352894.4	-1352894.4	-676447 2	0	0	0	0	0	($9,891,227.12)
Total	-853607854.8	-104565344.2	-114676910.2	-121385957.5	-130546113.9	-159452568.5	-82274194.05	-100860282.7	-54941988.68	135524398.9	-176475546.5	-177876968.2	-186090525.7	($1,939,901,878.28)

Table A.7. Affordable imports from Albania, Solar @ $2/W, national waste-to-energy program, no gas, and limited hydropower availability (not pictured).