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HOW WILL THE CZECH REPUBLIC ACHIEVE THE EU CLIMATE AND ENERGY TARGETS?

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Introduction

The Czech Republic has been a large exporter of electricity in recent years. In 2014, for example, it was the third largest exporter of electricity in Europe, exporting approximately 19 percent or 16 terawatt hours (TWh) of the 86 TWh of gross electricity generated. The country used coal to produce nearly half of its power in 2014, as it has regularly done since 2005 ("Yearly Report …2014," p. 7). Upon joining the European Union (EU) in 2004, the Czech Republic committed to supporting the EU's goals to fight climate change, which included reduction of greenhouse gas (GHG) emissions, international connection of electricity grids, and increased use of renewable energy sources (RES) ("Energy Union and Climate"). In terms of emissions, combustion of coal in the Czech Republic produced 65.8 million metric tons of CO_2 or 65.1 percent of the total CO_2 emissions from combustion ("CO_2 Emissions …," pp. 48, 51). Thus, the country's proportion of energy sources used to generate electricity must change to meet the EU's goal to reduce GHG emissions.

In addition to the EU's goals, the top three long-term strategic energy objectives for the Czech Republic are security, sustainability, and competitiveness. The country achieves a secure energy supply if it continues to be self-sufficient with diversified energy sources. Sustainability in the country means that it converts energy sources into electricity with the lowest level of emissions possible. Lastly, it desires competitive energy sources in terms of low final electricity prices.

In this article, I seek to determine the most efficient and economical way to meet both the energy targets established by the EU and the strategic energy objectives of the Czech Republic. Initially I explain the EU's goals, targets established to meet those goals, and the strategic energy objectives of the Czech Republic. Next, I examine how nuclear, wind, and solar power help meet the EU targets and the country's objectives in detail.[1] My analyses show that wind power is the optimal RES as it is the most efficient and economical with the least initial investment. It can generate up to 22 TWh annually or 31 percent of gross electricity consumption in 2014. Replacing 22 TWh of coal power with 22 TWh of wind power could save as much as 22 million metric tons of CO_2, bringing CO_2 emission levels to about 47.1 percent below 1990 levels ("CO_2 Emissions …," pp. 48, 51, 66).[2] Wind power has the second lowest cost of producing electricity at about $146 per megawatt hour (MWh), compared to the cost of other renewables, such as solar, at about $393 per MWh. My analysis shows that only increasing wind power, instead of the Czech Republic's target of increasing all RES, would save $23.68 billion in initial investment costs. Finally, I discuss the serious lack of capacity in the country's electricity grid, which cannot receive any increase in electricity generation.

Background on European Environmental Goals

In October 2005, the European Council approved a mandatory and comprehensive European energy policy that was published in January 2007. The European energy policy outlined five goals. The first goal was to increase competition in internal markets and interconnection between country electricity grids. The second goal required a diversified energy mix and better systems to respond to a crisis. Thirdly, the EU desired to decarbonize the economy by reducing GHG emissions. Furthermore, the EU required existing energy supplies to be used more efficiently while increasing RES commercialization. Lastly, the EU energy policy increased funding for new energy technologies ("Energy Union Factsheet").

[1]In this article, I do not discuss hydropower, gas power, and biomass power because the Czech Republic is a landlocked country with limited and exhausted water sources, gas is projected to contribute minimally to EU targets, and biomass will be primarily used to achieve EU RES heating targets.

[2]Assuming the 2040 target is a 60 percent reduction in CO_2, solar and/or biomass power would be necessary to achieve 2040 targets.

The specific measurable goals were established in a second agreement issued in March 2007. In this second agreement, the EU set three climate and energy targets to be accomplished by 2020 that aligned with its five energy goals. The targets were to reduce GHG emissions by 20 percent as compared to existing conditions in 1990, to increase RES consumption to 20 percent, and to increase energy savings by 20 percent ("2020 Climate & Energy Package"). The first target addresses the reduction in GHG emissions, which are gases that trap radiation that cause an increase in the earth's temperature, of which CO_2 is a significant contributor. The second target requires that 20 percent of the EU's energy consumption come from RES, such as solar, wind, biomass, or hydropower. The RES 20 percent consumption target includes consumption from heating and cooling, electricity, and transportation. The third target, to increase energy savings by 20 percent, is an increase in energy efficiency by using less energy to achieve the same output.

Each EU member state created a National Action Plan that established legally binding targets for energy savings and RES consumption by 2020. RES targets vary for each member state depending on how much RES had already been developed in the member state. For example, the RES target for Malta is 10 percent whereas Sweden's is 49 percent. The Czech Republic's overall national RES target is 14 percent with a minimum of 13 percent. The proportional mix of RES for heating and cooling, electricity, and transportation is 15.5 percent, 13.5 percent, and 10.8 percent respectively ("National Renewable…," 2012, p. 13).

But the EU's energy targets do not end in 2020. The EU increases energy savings targets to 27 percent by 2030. Furthermore, 27 percent of final energy consumption should come from RES, and GHG emissions should be 40 percent less than 1990 levels. The GHG emissions target will continue to increase until the EU reaches the 2050 target of an 80–95 percent reduction in GHG emissions compared to 1990 levels. The increased reductions in GHG emissions can be achieved by increasing renewable energy. In this article, I focus my analysis only on the EU's GHG emissions and

RES targets as they relate to the generation of electricity within the power sector.

Strategic Energy Objectives of the Czech Republic

In addition to the Czech Republic's commitment to the EU's energy targets, in December 2014 the country released its State Energy Policy, administered by the Ministry of Industry and Trade. The State Energy Policy provides three strategic energy objectives: security, sustainability, and competitiveness. Energy security is extremely important because the Czech Republic has been a net exporter of electricity since 2005 ("Yearly Report…2014," p. 8).[3] The country wants to continue to be a net exporter. Additionally, it wants to generate electricity at the lowest level of emissions possible to remain sustainable. It must also continually decrease CO_2 emissions to align itself with the EU's 2050 goal. Lastly, in the long run, the Czech Republic desires competitive (affordable) energy sources. As electricity grids and markets become more interconnected in accordance with EU's energy policy, its power industry will face increasing competition from other countries. Competitive prices are crucial for the country to maintain its high levels of exports in the future.

In the next section, I examine how each potential energy source at the disposal of the Czech Republic fares in terms of security, sustainability, and competitiveness. I measure energy security as the total potential electricity that a specific power source can generate. The total potential electricity generated by a power source is estimated using capacity factors and available limitations, such as wind speeds, landscape ruggedness, and other resource restrictions. I then measure the sustainability of an energy source as the reduction in CO_2 achieved by replacing coal as a source of power. I use 2013 CO_2 emission data as a base year of comparison to measure the CO_2 reduction. Lastly, I measure competitiveness as the levelized cost of electricity (LCOE). LCOE is the per-kilowatt-hour cost of building and operating a power plant over the assumed life span of the plant.

[3]The Czech Republic has exported about 15 to 20 percent of electricity generated yearly since 2005.

Analysis of Energy Sources in the Czech Republic

Currently, the Czech Republic's electrical generation depends approximately 50 percent on coal power and 35 percent on nuclear power. The long-term goal is to change the proportion, in general, to 20 percent reliance on coal power and 50 percent reliance on nuclear power because of the EU's goal of an 80–95 percent reduction in CO_2 by 2050 and diminishing coal reserves ("2014 Country Reports Czech Republic," p. 51). The unaccounted for percentage is distributed among various other sources of power. In this section, I describe the different energy sources that the Czech Republic may consider developing, and I compare the security, sustainability, and competitiveness of each of these energy sources.

The first energy source I discuss is nuclear power, since it does now and will continue to contribute significantly to electrical generation. Nuclear power does not produce any CO_2 emissions. It can replace coal power, helping to achieve the EU's CO_2 reduction targets. However, nuclear power is not an RES because the reactor's spent fuel is dangerously radioactive. Thus, nuclear power will not contribute at all to the EU's RES targets. In addition, the bidding, licensing, constructing, and inspections process of a new nuclear reactor takes an estimated 15 years to complete (Vlček and Černoch, p. 145)[4]. Thus, the CO_2 reduction from nuclear then will not contribute to the EU 2020 targets and possibly not even to the 2030 targets. The Czech Republic must consider RES to help achieve the EU 2020 targets of 20 percent reduction in CO_2 emissions and the 14 percent increase in use of renewable energy. In this section, I explore how nuclear power, solar power, and wind power help meet the EU's 2020 and 2030 targets as well as the Czech Republic's strategic

[4]From 2009 to 2014, CEZ, a Czech power company, began the bidding process for two new 1,200-MWe reactors at Temelin ("Nuclear Power in Czech Republic"; Vlček and Černoch p. 144). The project ended in April 2014 when the Czech Republic government refused to guarantee electricity prices for the nuclear power plant.

energy objectives.

Nuclear Power

As of 2016 in the Czech Republic, there are four nuclear reactors at Dukovany and two nuclear reactors at Temelin. Combined, the nuclear reactors generate approximately 30 TWh or 35 percent of the total gross electricity generated. However, as Table 1 shows, the licenses for all the reactors are due to expire within seven years after 2020 ("Nuclear Power in Czech Republic"). Originally, all four plants at Dukovany had a 30-year life span, but each was extended by ten years through updates costing $560 million between 2009 and 2015.[5] This means that current nuclear power plants need the licenses extended or a new reactor constructed. The State Energy Policy plans to extend all four reactors at Dukovany by another 10 to 20 years with licenses to expire in 2030 or 2040.

Additionally, two new nuclear reactors are scheduled to be operational between 2030 and 2035 which would add an estimated 10 TWh ("State Energy Policy of the Czech Republic," p. 117), increasing nuclear power to 50 percent of the Czech Republic's gross electricity generation. Nuclear power will dominate the electricity mix in 2030–2040 because it is the best power source that meets most of the EU targets and the Czech Republic's strategic energy objectives.

Nuclear power is a secure, sustainable, and competitive source of power that will contribute to the EU targets. It is secure because it is more reliable than RES. Solar and wind power production depends on weather conditions, making it difficult to forecast output, whereas nuclear power is easily predicted because nuclear power production is determined (up to a fixed capacity) by an operator. In addition, nuclear power requires substantially less installed capacity to generate the same output as renewable energy. As shown in Table 2, to generate an annual 5 TWh, nuclear power requires only 707 MW as compared to 1,214 MW for biomass power and 4,756 MW for solar power.

[5]I assume a conversion ratio of $1 = CZK 25.

Unlike coal power, nuclear power produces no CO_2 during electricity production. The Czech Republic's planned expansion of nuclear power in 2035 would replace coal power, which would further reduce CO_2 emissions. I assume that the additional 10 TWh of nuclear power would replace 10 TWh of coal power. The estimated reductions in CO_2 are displayed in Table 3. In each energy source case, I assume that the total potential power in Table 2 would replace an equal amount of power from coal, and the reduction of CO_2 emitted from replacing coal is displayed in Table 3.

Finally, compared to RES, nuclear power is the cheapest (and therefore most competitive) way to produce power. Table 4 displays the LCOE of each power source. LCOE is the per-kilowatt-hour cost of building and operating a power plant over the assumed life span of the plant. Table 4 also displays the investment, decommission, fuel, carbon, and operation and maintenance (O&M) costs associated with each power source which are the components that are used to determine LCOE.

Nuclear power is a reliable, inexpensive, and CO_2-free power source, which meets the three Czech Republic strategic energy objectives. However, it will not help achieve the EU's 14 percent increase in RES target and 20 percent short-term CO_2 reduction target. For this reason, the country must consider alternative energy sources to meet EU GHG emissions reduction targets in the short term and increased use of RES.

In the next section, I examine the alternative energy sources of wind and solar power, utilizing the Czech Republic's strategic energy objectives of security, sustainability, and competitiveness to determine the best energy sources to achieve the EU's targets.

Wind and Solar Power

From 2005 to 2011, solar capacity in the Czech Republic increased greatly, from 464.4 MW to 1,971 MW because of favorable government incentives. At the end of 2011, the rapid increase in solar power incentives cost end consumers approximately $560

Table 1
Czech Republic Nuclear Power Plants

Reactor	Net MWe*	First Power	License Expiration Year
Dukovany 1	468	1985	2025
Dukovany 2	471	1986	2026
Dukovany 3	468	1986	2026
Dukovany 4	471	1987	2027
Temelin 1	1023	2000	2020
Temelin 2	1003	2003	2022
Total (6)	3904		

*MWe (electric MW) is the actual power output in megawatts.
Source: "Nuclear Power in Czech Republic."

Table 2
Energy Source Security

Energy Source	Capacity Factor (%)*	Total Potential (TWh)	Percent of 2014 Total Gross Generation	Percent of 2014 Total Gross Consumption	Required Capacity for 5 TWh (MW)
Biomass	47	21.10	25	30	1,214
Solar	12	39.44	46	57	4,756
Wind	20	21.90	25	31	2,854
Hydro	20	2.53	3	4	2,854
Nuclear	81	10.00	12	14	705

*Capacity Factor = gross electricity generated/(installed capacity × 365 days × 24 hours);
Required Capacity for 5 TWh = 5,000,000 MWh/(capacity factor × 365 days × 24 hours); and
total electricity generated and consumed in 2014 is approximately 86 TWh and 69.6 TWh, respectively.
Source: "Yearly Report on the Operation of the Czech Electricity Grid: 2014."

million (Chvalek et al., p. 4).[6] The government mitigated increasing costs with retroactive taxes against RES ("Is the Czech Republic on Track?" p. 32). On January 1, 2014, the government abolished incentives for all RES projects ("Promotion in Czech Republic"; "Is the Czech Republic on Track?" p. 32). At the end of 2014, RES accounted for 10.7 percent of total gross electricity generated or 13.17 percent of total gross consumption of electricity. Although the Czech Republic is close to the EU's 2020 target of 13.5 percent of electricity consumed from RES, the EU's 2030 targets will require still further increases in the use of RES. Therefore, it is crucial that the country select the most efficient and economical RES to avoid unexpected increases in end consumer costs that had occurred with solar power from 2005 to 2011. I examine wind and solar power together because of their similar fluctuations in power generation.

Wind power offers a large supply of

[6]I assume a conversion ratio of €1 = $1.40.

secure electricity. Jaroslava Orságová, from Brno University of Technology, has estimated the total area suitable for wind power based on wind speeds and other land restrictions (Orságová et al.).[7] Orságová and colleagues use weight factors to account for landscape ruggedness, wooded areas, and urban areas to reduce available area further. The calculated available area for wind capacity is about seven percent of the total area of the Czech Republic. They then use 2.2 W of capacity per meter squared to calculate an available capacity of 12.5 gigawatts (GW) of wind power. Based on the 20 percent capacity factor in Table 2, the estimated annual potential of wind power is about 22 TWh, or 25 percent of total gross electricity output in 2014.[8] Wind power would easily surpass the EU RES consumption target of 13.5 percent, with total gross consumption of wind power alone being 31 percent in 2014.

Turning to solar power, I use the same methodology used to calculate the total potential power for wind power. For comparison purposes, I assume that the same seven percent of the Czech Republic that is viable for wind power is also viable for solar power. I assume that 6.7 W of capacity is installed per meter squared of area (Bryce). I use the capacity factors from Table 2 to estimate the total solar power capacity as 37.52 GW, which yields a total annual power generation of about 39.44 TWh.[9] Solar power could account for 46 percent of total gross generation or 57 percent of total gross consumption in 2014, which easily surpasses the EU target of 13.5 percent of electricity consumed from RES.

Both solar and wind power are clean and readily available sustainable energy sources. Unlike coal, nuclear, natural gas, and biomass, wind and solar power do not produce harmful byproducts or emissions when generating electricity. Lignite (brown coal) for instance, which is the Czech Republic's main fuel source for coal power plants, produces about 2.17 pounds of CO_2 per kWh of electricity ("How Much Carbon…"). In 2013, combustion of coal produced 65.8 million metric tons of CO_2, which is 65.1 percent of the total 101.1 million metric tons of CO_2 emitted from fuel combustion in the Czech Republic ("CO_2 Emissions…," pp. 48, 51). Assuming that 22 TWh of wind power would replace 22 TWh of coal power in 2013, CO_2 emissions from coal power would decline by 22 million metric tons or decrease to about 47.08 percent relative to 1990 in CO_2 emission levels. Again, assuming that 39.44 TWh produced by solar power replaced 39.44 TWh of coal in 2013, CO_2 emissions would decrease by a maximum of about 38.82 million metric tons, or decrease to about 58.56 percent relative to 1990 CO_2 emissions. Solar and wind would easily surpass the EU target of CO_2 emission reduction by 20 percent by 2020 and 40 percent by 2030.

So why is wind power better than solar power? The answer has to do with the LCOE. Wind power has a more competitive LCOE, at $145 per MWh compared to solar power at $393 per MWh, as seen in Table 4. A major reason for the disproportionally high LCOE for solar power is the initial investment costs for engineering, procurement, and construction, which originally were artificially low due to government incentives. In addition, wind power has a higher capacity factor of 20 percent, compared to solar power at 12 percent. A higher capacity factor means that wind power would require less installed capacity to generate the same amount of gross electricity as solar power. For example, to generate an extra 5 TWh of gross electricity annually, wind power would require 2,918 MW, while solar would require 4,869 MW as shown in Table 2. The higher the required installed capacity, the higher the initial investment costs. Therefore, wind power is the more competitive resource as it has the higher capacity factor and lower LCOE.

Wind power is a secure, sustainable, and competitive RES that can meet the EU's GHG emissions and RES targets. Wind power would

[7]Other land restrictions include protected landscape areas and national parks, military areas, airports, reserved airspace lower than 300 feet, roads, motorways, railways, population centers, oil and gas pipelines, high-voltage lines, and historical and natural monuments.

[8]Annual electricity generated from wind power was calculated as follows: 22 TWh = 20 percent capacity factor × 12.5 GW of capacity × 365 days × 24 hours/10^3.

[9]Assuming the total area of the Czech Republic is approximately 80 billion m^2, the annual electricity generated from solar power is calculated as follows: 80 billion m^2 × 7 percent × 6.7 W/m^2 × 365 days × 24 hours × 12 percent capacity factor = 39.44 TWh.

Table 3
Energy Source Sustainability

Energy Source	Million Metric Tons of CO_2 from Coal Replaced	New 2013 CO_2 Levels	EU Emission Target 2013 Percentage Less Than 1990 Levels
Biomass	20.77	80.33	46.55
Solar	38.82	62.28	58.56
Wind	21.56	79.54	47.08
Hydro	2.49	98.61	34.39
Nuclear	9.84	91.26	39.28

1990 CO_2 emissions: 150.3 million metric tons.
2013 CO_2 emissions: 101.1 million metric tons (32.7 percent less than 1990 levels).
The million metric tons of CO_2 saved from replacing coal is calculated as follows:
total potential power (in Table 2) × 10^3 gigawatt hours (GWh)/TWh × 2.17 pounds of CO_2 per kWh × 0.000454 metric tons per pound.
Source: "CO_2 Emissions from Fuel Combustion Highlights."

Table 4
Energy Source Competitiveness

Energy Source	$ per kW Investment	$ per MWh				
		Decommission	Fuel	Carbon	O&M	LCOE
Nuclear	6,392.00	0.22	9.33	0	14.74	69.74
Coal	5,654.83	0.19	19.25	13.04	11.35	88.98
Biomass*	5,548.50	0.19	28.95	12.29	12.07	98.15
Gas	2,359.00	0.15	63.37	5.39	4.98	95.07
Wind	3,502.00	1.15	0	0	21.92	145.85
Small hydro	12,918.00	0.08	0	0	6.97	156.05
Large hydro	21,302.00	0.13	0	0	6.39	231.63
Solar	7,958.00	3.25	0	0	29.95	392.88

*Costs are a combination of biomass and coal.
Decommission refers to the costs of replacing and or disposing of the energy source.
Fuel refers to the costs of fuel required to generate electricity, such as coal, biomass, gas, or nuclear material.
Carbon refers to the costs associated with emitting CO_2 per MWh of electricity generated.
O&M refers to the operating and maintenance costs for generating 1 MWh of electricity.
Source: "Projected Costs of Generating Electricity."

reduce CO_2 emissions from coal power plants by 22 million metric tons or 47.08 percent of 1990 levels. It can supply as much as 25 percent of power or 31 percent of total consumption of power in 2014. Lastly, wind power is the most efficient and cost-effective renewable energy. Other RES, besides solar, may align with both the Czech Republic's strategic energy objectives and EU targets; however, due to their limitations, they are not viable alternatives.

Analysis of Results

Having examined wind power and solar power to determine how each meets the Czech Republic's strategic energy objectives of security, sustainability, and competitiveness, I conclude that wind power is the optimal RES for expansion. Wind power can generate 25 percent of the total gross electricity generated and 31 percent of the total gross electricity consumption in 2014, which surpasses the EU target of 13.5 percent. Wind power also has the second lowest LCOE. Nuclear power produces dangerous byproducts and will not be producing power for many years. Solar power has a very high LCOE, making it uneconomical. As I explain in the next section, the initial investment costs to increase reliance on wind power further support my conclusion that wind power is the optimal RES for expansion.

Initial Investment Costs of Electricity Generation Mixes

The Czech Republic's State Energy Policy specifies a target electricity mix (in proportion to the total gross annual amount of electricity generated) by 2040. Table 5 shows its target electricity mix as well as my own proposal for an electricity mix. In both the Czech Republic's target and in my proposal, the changes in gross electricity generated from coal power, natural gas power, nuclear power, and overall RES remain the same. I assume that its target electricity mix will meet future EU 2040 CO_2 reduction and increased RES targets. The difference between the country's target and my proposed electricity mix is the proportion of each RES. In my proposed electricity mix, wind power is the only electricity source that increases, in contrast with the Czech Republic's target electricity mix, which has all RES increasing.

I next examine the initial investment costs of the Czech Republic's target compared to the costs of my proposal. Using the capacity factors in Table 2, the electricity generated by each electricity source in Table 5, and the investment costs for each electricity source per kilowatt in Table 4, I calculate the required installed capacity and initial investment costs of each plan. The results are presented in Table 6. The data demonstrate that my proposed electricity mix, which emphasizes an increase in wind power, is $23.68 billion less than the country's targeted electricity mix in initial investment costs.

But before any increase in power to meet the EU's progressive targets for reduction of GHG emissions and increased consumption of RES can be considered, it is critical that the Czech electrical grid be expanded to increase its capacity to accept the increased power production as well as to transport it to where it is needed.

Adequacy of the Electrical Grid

The capacity of the Czech Republic electricity grid is the major obstacle to implementing nuclear, solar, or wind power. Each power source requires specific expansions of the grid to be successful. In this section, I briefly explain the necessary power lines for nuclear power, the costs associated with the unexpected expansion of solar power, and the limitations of available capacity for expanding wind power.

Nuclear Power

From 2009 to 2014, CEZ, a Czech power company, began the bidding process for two new 1,200-MWe reactors at Temelin ("Nuclear Power in Czech Republic"; Vlček and Černoch, p. 144). The expected additional nuclear power generated would have required two additional 400-kV power lines to be installed between Kocin and Mirovka. The estimated timeline and cost of construction of a high-voltage line is from 7 to 10.5 years and $323.2 million (Vlček and Černoch, p. 183). The Czech government owns the electricity grid, but CEZ

Table 5
Electricity Generation Mix

Electricity Source	2014 (%)	C.R. Target 2040 (%)	My Proposal 2040 (%)
Brown/black coal	50.00	19.10	19.10
Natural gas	4.00	9.30	9.30
Nuclear	35.30	48.80	48.80
RES	10.70	22.80	22.80
Biomass power	5.40	10.50	5.25
Hydropower	2.20	3.00	2.14
Wind power	0.60	2.70	12.99
Solar power	2.50	6.60	2.43
Total electricity generated (TWh)	86	88.5	88.5

C.R., Czech Republic.
Source: "State Energy Policy of the Czech Republic."

Table 6
Investment Cost Comparison

RES Electricity Source	Capacity (GW)		Investment In $ Billions	
	Target	Proposal	Target	Proposal
Biomass power	1.13	—	6.29	—
Hydropower*	0.43	—	7.39	—
Wind power	1.09	6.41	3.83	22.43
Solar power	3.59	—	28.61	—
Total investment costs			46.11	22.43

*The average $ per kW investment cost for small and large hydropower in Table 4 was used to calculate the investment cost of hydropower in Table 6.
The required capacity for each RES in gigawatts was calculated as follows:
[(2040 percentage projected in Table 5 × 88.5 TWh) – (2014 percentage in Table 5 × 86 TWh)] × (10^3 GWh/TWh)/(365 days × 24 hours × capacity factor in Table 2).
The total investment cost for each RES was calculated as follows:
gigawatt capacity in Table 6 × $ per kW investment costs in Table 4 × 10^3 kW/GW.
Table 6 used exact values to determine the gigawatt capacity and investment cost. The numbers presented in previous tables were rounded.

will own the new nuclear power plants. Also, the government owns 70 percent shareholder in CEZ ("CEZ Cancels Temelin Expansion Tender"), and it is therefore unknown whether the investors of CEZ, the government, or final consumers would have covered most of the costs of installing the new power lines. The nuclear expansion project, however, was cancelled in April 2014. As a result, the country's proposal to expand nuclear power by 2030 to 2040 would still require additional powerlines to be constructed, and who would cover the costs is still unknown.

Solar Power

The unexpected rapid expansion of installed solar capacity from 2005 to 2011 and an inadequate grid caused grid transmission and distribution costs to increase greatly. In 2010, ČEPS, the Czech Republic grid operator, expected solar power installed capacity to reach about 1,650 MW and 1,695 MW by 2020 ("National Renewable…," 2010, p. 13). In 2010, the installed capacity increased by almost 1,500 MW. By the end of 2010, the total installed capacity was 1959.1 MW ("Yearly Report…2014," p. 23). The unexpected increase in installed capacity cost the grid operator about $2 billion for ancillary services (Vlček and Černoch, p. 184). The enormous increase in installed solar power capacity forced the grid operator to refuse grid connection for solar power. The distribution system operator argued that the unexpected power increase from solar could damage the grid due to lack of grid capacity ("Is the Czech Republic on Track?" p. 32).

Wind Power

Inadequacy of the grid is also the largest limiting factor for wind expansion. Orságová and colleagues (p. 4) determined the total capacity suitable for wind power to be 12,500 MW. Based on the available network capacity, though, they determined that only 1,780 MW of the 12,500 MW of wind power could be installed. Using the capacity factor of 20 percent in Table 2, the total potential electricity from wind power based on available capacity is about 3.12 TWh annually, or 3.6 percent of total gross electricity in 2014. Furthermore, in 2014 the Czech Republic's installed wind capacity was only 278 MW ("Yearly Report … 2014"). It is crucial for the Czech Republic to invest in upgrading the capacity of its grid. Without an increase in capacity, it will be impossible to use wind energy sources to meet EU targets.

International Connectivity

In addition to the difficulties encountered by the development of Czech Republic RES to meet EU targets, the first of the five goals of the European energy policy is the initiative to increase competition in the internal markets and to increase interconnection between electricity grids. The implementation of this goal has threatened the safe operation of the country's electricity grid due to unexpected electricity in-flows from neighboring countries. At the end of 2014 and beginning of 2015, Germany's large wind and solar parks have placed the Czech Republic electricity grid in immediate danger. In 2010, Germany began to shift toward a renewable energy–driven economy. By 2035, Germany plans to have as much as 60 percent of its power generated from renewable energy (Morison). From December 1, 2014, to January 10, 2015, Germany experienced several days of strong winds which generated almost 30,000 MW, the equivalent of 30 Temelin reactors. In response to the incoming surge of electricity, the Czech Republic had to shut down its most expensive power sources to prevent grid failure ("Critical Situation …," p. 5).

The inadequacy of the Czech Republic electricity grid is a major barrier hindering the country's expansion of solar, wind, or nuclear power. The EU goal of interconnecting electricity grids with neighboring countries threatens to overload the Czech Republic grid and cause damage. Without immediate investment to improve the capacity of its grid, the country will have a difficult time meeting both current and future EU targets as well as the country's own strategic energy objectives.

Conclusion

The Czech Republic is committed to the EU 2020 energy targets of decreasing CO_2

emissions by 20 percent compared to 1990 and increasing RES to 14 percent of final electricity consumption. These targets will continue to increase in the EU such that in 2030 energy targets will be 27 percent of final energy consumption of RES and a 40 percent reduction in GHG emissions until the EU achieves its 2050 goal of an 80 to 95 percent reduction in CO_2 compared to 1990 levels.

It is clear from my analysis that wind power is the Czech Republic's optimal RES to meet the EU's targets for renewable energy from electricity and for CO_2 reduction and the country's strategic energy objectives. As of 2014, wind power can generate as much as 25 percent of the total gross electricity generation or 31 percent of the total gross electricity consumption. Wind power can potentially replace 21.56 million metric tons of CO_2 from coal power and reduce CO_2 emissions to a level that is 47 percent below 1990 levels. It is also the second cheapest RES in producing electricity. Furthermore, my proposed 2040 electricity mix indicates that wind expansion could save $23.68 billion in initial investment costs as compared to the Czech Republic's target electricity mix. But the largest barrier preventing the Czech Republic from meeting its own strategic energy objectives or the EU targets is the significant lack of capacity of its electricity grid to absorb and transmit the electricity generated by wind. Extensive expansion of the grid is critical for supporting the changes coming to the electricity infrastructure.

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