Research Paper for Capstone Project Fall 2016

Lifecycle Greenhouse Gas Emissions from Power Generation:

A Comparative Analysis Between the United States and the European Union and its Implication for Developing Economies Using the Example of China

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I. Introduction

Energy generation, either from utilizing fossil fuels or renewable energy sources, is certainly one of the biggest sources of greenhouse gas emissions. 30 percent of the total emissions of the United States were caused by electricity generation (EPA, 2016). The constantly increasing demand for energy, limited energy resources, and the rising threats from climate change require the humankind to accurately identify the link between energy generation and greenhouse gas emissions, as well as to come up with effective policies to accomplish a more sustainable energy mix.

Today's rising global temperatures are largely attributable to industrialization accompanying massive fossil fuel generations in advanced nations. Together, the United States and the European Union emitted 26 percent of the world's greenhouse gas emissions due to fossil fuel generation and some industrial processes in 2011 (Boden et al., 2015). China is still the biggest single source of emissions in the world, but the U. S. and the EU are the greatest developed emitters with mature economies.

Predicting the energy landscape in these political territories is thus significant. They face different challenges and have varying energy profiles, so comparing and analyzing them can derive an important policy implication especially for developing countries like China. The U. S., in particular, is the world's largest energy consumer. About 82 percent of its primary energy use is provided by fossil fuel (EIA, 2016). Meanwhile, the EU has a chronic problem with energy security stemming from limited import routes of natural gas. Despite the great volume of literature that concerns the status and prospects of two countries' electricity generation and GHG emissions, there is no direct comparison of the two, with a specific focus on the link between varying emissions by power generation technologies.

In this study, it will be examined how these technologies, including coal, natural gas, nuclear, and renewables (wind, hydro, solar, biomass, and geothermal), are currently generating greenhouse gas emissions in the EU and the U. S., and how developments might affect China's policies in the future. To that end, today's emission 'snapshots' will be juxtaposed, and how they will evolve will be explored with increasing renewable usage. The following questions will be answered: Between the U. S. and the EU, which one is the bigger emitter in terms of electricity generation only? Which energy source(s) are responsible for this? Which technologies should be eliminated? Which technologies should be encouraged? What kind of lessons can be learned from this comparison when designing a policy? And finally, could this affect large developing economies, such as China?

II. Literature Review

The greenhouse gas inventories are publicly available both in the U. S. and the EU. Both countries provide GHG emissions by various sources and sectors, including the power generation. These records include Annual Energy Outlook by the U. S. Energy Information Agency (EIA), Inventory of U. S. Greenhouse Gas Emissions and Sink: 1990-2014 (U. S. EPA), Annual European Union Greenhouse Gas Inventory 1990-2014 and Inventory Report 2016 (European Environment Agency), the EU Energy Trends to 2030 (European Commission), and EU Reference Scenario 2016: Energy, Transport and GHG Emissions, Trends to 2050 (European Commission). As for China's GHG emissions status and policies, the Energy Foundation's 2004 report was found useful albeit somewhat outdated (Energy Foundation, 2004).

The International Energy Agency (IEA) offers in-depth country-specific reviews for energy status, projections and policies. Even though the membership to the organization is established on country-by-country basis, as decarbonization paths and energy policy choices, an in-depth country report is available for the EU since 2008. The Agency also provides a detailed report of CO2 emissions from fuel combustion, which gives the overview of energy-related GHG emissions around the globe (IEA, 2016).

While these official resources are helpful in understanding the anatomy of each country's GHG emissions, there is no study, at least to the author's knowledge, that is conducted specifically on the U. S. – EU pair as regard to the GHG emissions caused from the power generation sector. Meanwhile, Barrett et al. (2013) develops a legal discourse of the two countries, addressing how these two countries have dealt the issue of climate change under the framework of the United Nations within their respective territories. This study is unique as it focuses narrowly on electricity generation and the greenhouse gas emissions resulting from it, exploring how the two advanced nations will follow different or similar trajectories from present to several decades later.

III. Methodology

1. Categorizing the Sources of Electricity Generation

The sources for electricity generally include fossil fuels, such as coal, natural gas and petroleum, nuclear, and renewables. In the U. S., the "renewables" are defined by the EIA as following: (a) biomass (includes: wood and wood waste, municipal solid waste, landfill gas and biogas, ethanol, biodiesel), (b) hydropower, (c) geothermal, (d) wind, and (e) solar. In the EU, the definition is largely similar: (a) biomass and wastes (organic, non-fossil material of biological origin, which may be used for heat production or electricity generation; comprises wood and wood waste, biogas, municipal solid waste

and biofuels; includes the renewable part of industrial waste),
(b) hydropower, (c) geothermal energy, (d) wind energy, (e) solar energy (European Commission).

While the categorizations in the two countries are akin to one another, a major difference was found. The recent reports published by the European authorities often use a term “solids” that “include both primary products (hard coal and lignite) and derived fuels (patent fuels, coke, tar, pitch and benzole) (European Commission, 2016),” whereas their U. S. counterpart use the term “coal.” According to the U. S. EIA, “coal includes anthracite, bituminous, subbituminous, lignite, and waste coal; synthetic coal and refined coal; and beginning in 2011, coal-derived synthesis gas (IEA[1]).”

2. Linking the Emissions to Power Generation

Generally, the amount of greenhouse gas emissions resulted from certain economic activities is calculated using carbon emission factors, usually expressed in MtCO2/Mtoe. The IEA provides the emission factors both for the OECD and non-OECD member nations (WEO 2008). In addition, the International Panel on Climate Change (IPCC) specifies carbon emission factors in its 2006 guidelines as following: 15.3 tC/TJ for gas, 15.7 to 26.6 tC/TJ for oil products, 25.8 to 29.1 tC/TJ for primary coals. An online access[2] is available as well to an IPCC library of different emission factors and other parameters.

3. Utilizing the Concept of Lifecycle Emissions

“Lifecycle emissions” is a concept studied by many scholars including Pehnt (2006), Weisser (2007) and Sovacool (2008). It surfaced with the emergence of distributed and renewable energy systems, which were considered superior to conventional energy generation systems. However, there is a need for a life cycle assessment (LCA) to quantify the benefits of these newer energy systems. Such “cradle-to-grave” assessment helps identify “GHG emissions resulting from the use of a particular energy technology over all stages of the technology and its fuel-life cycle (Weisser, 2007).”

While traditional resources such as EIA statistics[3] provide GHG emission by fuel type in the electric power sector, their primary focus is on fossil fuel combustions. This paper will utilize the estimates for the technologies specified in Table 1, excerpt from Sovacool’s 2008 paper, in an attempt to make a more comparable presentation of the renewable systems as opposed to conventional ones.

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[1] https://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_1_01
[2] http://www.ipcc-nggip.iges.or.jp/EFDB/main.php
[3] http://www.eia.gov/totalenergy/

Table 1 Lifecycle estimates for electricity generation (Sovacool 2008)

Technology	Capacity/configuration/fuel	Estimate (gCo2e/kWh)
Wind	2.5 MW, offshore	9
Hydroelectric	3.1 MW, reservoir	10
Wind	1.5 MW, onshore	10
Biogas	Anaerobic digestion	11
Hydroelectric	300 kW, run-of-river	13
Solar thermal	80 MW, parabolic trough	13
Biomass	Forest wood Co-combustion with hard coal	14
Biomass	Forest wood stream turbine	22
Biomass	Short rotation forestry Co-combustion with hard coal	23
Biomass	FOREST WOOD reciprocating engine	27
Biomass	Waste wood steam turbine	31
Solar PV	Polycrystalline silicone	32
Biomass	Short rotation forestry steam turbine	35
Geothermal	80MW, hot dry rock	38
Biomass	Short rotation forestry reciprocating engine	41
Nuclear	Various reactor types	66
Natural gas	Various combined cycle turbines	443
Fuel cell	Hydrogen from gas reforming	664
Diesel	Various generator and turbine types	778
Heavy oil	Various generator and turbine types	778
Coal	Various generator types with scrubbing	960
Coal	Various generator types without scrubbing	1050

- Wind, hydroelectric, biogas, solar thermal, biomass, and geothermal estimates taken from Pehnt (2006), Diesel, heavy oil
- Coal with scrubbing, coal without scrubbing, natural gas, and fuel cell estimates taken from Gagnon et al. (2002). Solar PV estimates taken from Fthenakis et al. (2008). Nuclear is taken from this study. Estimates have been rounded to the nearest whole number.

For the purpose of this paper, the estimates in grey shadings will be used to calculate the emissions. Justification of selection of variables is described in the following paragraphs:

- Wind

  Considering the scale of onshore wind facilities compared to offshore farms, with the former's market size being almost 5-fold of the latter's, the estimate for onshore (Marketsandmarkets, 2011), 10, was selected.
- Hydroelectricity

  While the types of hydroelectricity facilities encompass reservoir, run-of-river, and pumped storage, this paper only utilizes the estimate for the reservoir type. The reason for this simplification is the unavailability of detailed profiles for the EU and the U. S., both in the present and in the future.

- Biomass
  The lifecyle emission estimates for biomass range widely from 14 to 41. As hydroelectricity, detailed information on biomass usage by generation type was unattainable. In order to ensure the minimum level of accuracy, the median number, 27, was taken.
- Solar
  Given that today's solar energy is exploited primarily in the form of photovoltaics rather than solar thermal, the estimate of 32 was chosen.
- The categories of geothermal, nuclear, and natural gas have only one estimated value.
- Petroleum
  Both diesel and heavy oil feature 778.
- Coal
  Most industrialized countries such as the U. S. and the EU have established pollution regulations, and such measures will be increasingly in place in the following years. For this reason, the estimate of 960 instead of 1050 for generators with scrubbing was selected.

There are major uncertainties regarding the lifecycle estimates, which will be discussed in the Discussion section. In particular, it is known that the estimates themselves vary largely, due to enrichment method and mining technologies, among others (Beerten et al., 2009). For verification, the emissions obtained by the lifecycle emission methodology were compared with the national inventory[4]. Whereas the respective numbers did not completely converge, the approximate orders and ratios to one another were found consistent.

IV. GHG Emissions Resulting from Electricity Generation

1. The U. S.

In 2015, the United States generated approximately 4 trillion kilowatthours of electricity. About 66% of it was from fossil fuels such as coal, natural gas and petroleum (EIA). Accordingly, the lifecycle GHG emissions generated in the U. S. electric power sector can be calculated using Table 1, as summarized in Table 2. Note that the U. S. depends 65% of electricity on coal and natural gas, but their share of GHG emissions is 96%.

[4] http://www.eia.gov/tools/faqs/faq.cfm?id=77&t=11

Table 2 Net Electricity Supply and Calculated GHG Emissions in the U. S. in 2015

Fuel type	Net generation		GHG emissions using lifecycle estimates	
	[billion kWh]	(%)	[mmt CO2]	(%)
Coal	1,340	34	1,286	67
Natural gas	1,234	31	547	29
Nuclear power	798	20	53	3
Renewable sources	493	13	8	0
Conventional hydro	247	6	2	0
Biomass	56	1	2	0
Geothermal	17	0	1	0
Solar	38	1	1	0
Wind	190	5	2	0
Petroleum	25	1	19	1
Total	3,801	100	1,839	100

Source: EIA Annual Energy Outlook 2016 (Excerpted and rearranged from Tables A8 and A16)

Note: Includes combined heat and power, but CHP using renewable resources are not included due to negligible numbers. Also excluded is distributed generation from natural gas and offshore wind, as the shares are negligible. Renewable resources include end-use sectors, including some CHP plants and electricity-only plants. The numbers are rounded, which may result in inconsistency.

2. The EU

For starters, the geographical boundary of "EU" is so-called EU-28, which comprises 28 European nations including Germany, France, and the United Kingdom[5]. Even though the EU provides energy statistics for the whole political block, the energy mix profiles vary largely in the past and today (Ortega-Izquierdo et al., 2016).

In 2015, the EU generated 3,251 TWh of electricity. TWh is equivalent to billion kWh. Unlike the U. S., the EU provides data of gross electricity generation rather than net generation. The calculated values differ from the inventory report published the European Environment Agency (EEA, 2016) due to the methodologies and errors. Table 3 summarizes the results; while the coal and natural gas accounts for 43% of total electricity generation, they are accountable for 92% of the EU's total GHG emissions from the power generation sector.

[5] This section considers the year of 2015, so Brexit is not relevant. However, it is noteworthy that the following section about 2030 projections will be probably affected by the event.

Table 3 Gross Electricity Supply and Calculated GHG Emissions in the EU in 2015

Fuel type	Gross generation		GHG emissions using lifecycle estimates	
	[billion kWh]	(%)	[mmt CO2]	(%)
Coal	847	26	813	70
Natural gas	566	17	251	22
Nuclear power	867	27	57	5
Renewable sources	936	29	15	0
Conventional hydro	362	11	4	0
Biomass	189	6	5	0
Geothermal	7	0	0	0
Solar	104	3	3	0
Wind	274	8	3	0
Petroleum	35	1	27	2
Total	3,251	100	1,163	100

Source: the EU Reference Scenario 2016 (Excerpted and rearranged from Appendix 2)

3. Comparison

Before comparing the results, it is important to note that the U. S. data features net generation, while the EU does gross generation. The gross generation is larger than the net generation, as the latter equals to the former minus operational power needed for in-house loads. While most power plants typically do not measure net MWh output directly so that it should be calculated indirectly, the difference between net and gross generation can be significant because pollution control devices tend to decrease overall plant efficiency by 2 to 6 percent.

As the ratio of net generation to gross generation can vary widely by technology, this paper will analyze the results based on the given datasets, with net electricity supply for the U. S. as opposed to gross supply for the EU. However, for a fairer comparison, the analysis will focus on percentage changes rather than absolute values.

The electricity generation profiles categorized by fuel type, along with the calculated lifecycle GHG emissions, are described in Figures 1 and 2 in the form of pie charts. While the EU shows a more diverse energy mix with a greater share of renewables and nuclear power, the lifecycle emissions profiles are largely similar with coal and natural gas being dominant.

Figure 1 Fuel Mix for Electricity Generation in U. S. and EU in 2015

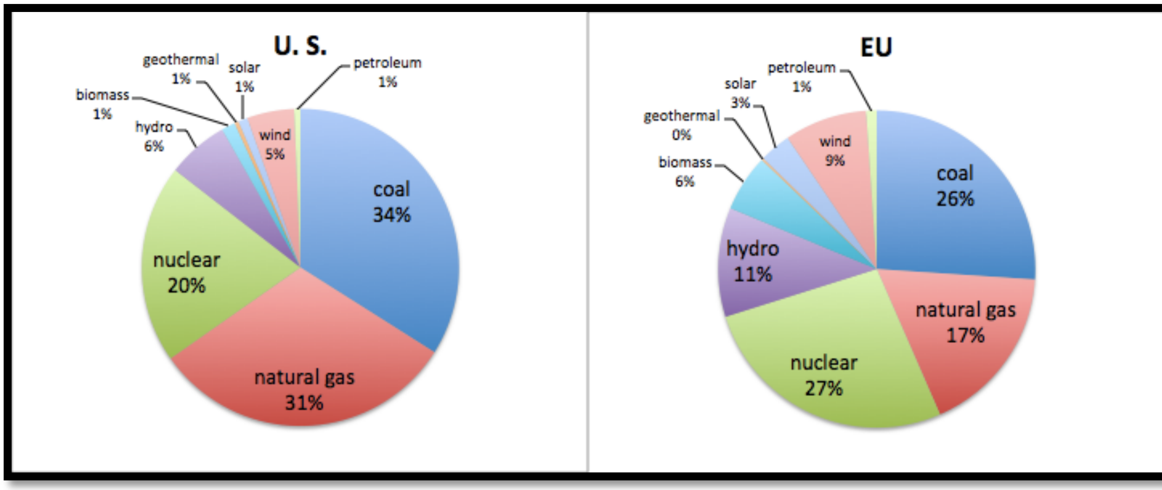
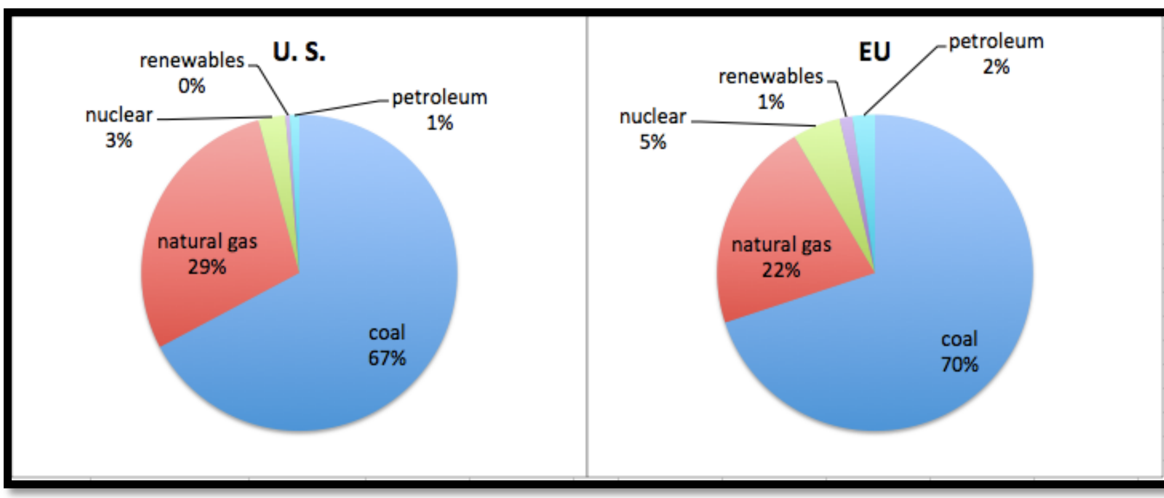


Figure 2 Lifecycle GHG Emissions by Energy Source in U. S. and EU in 2015

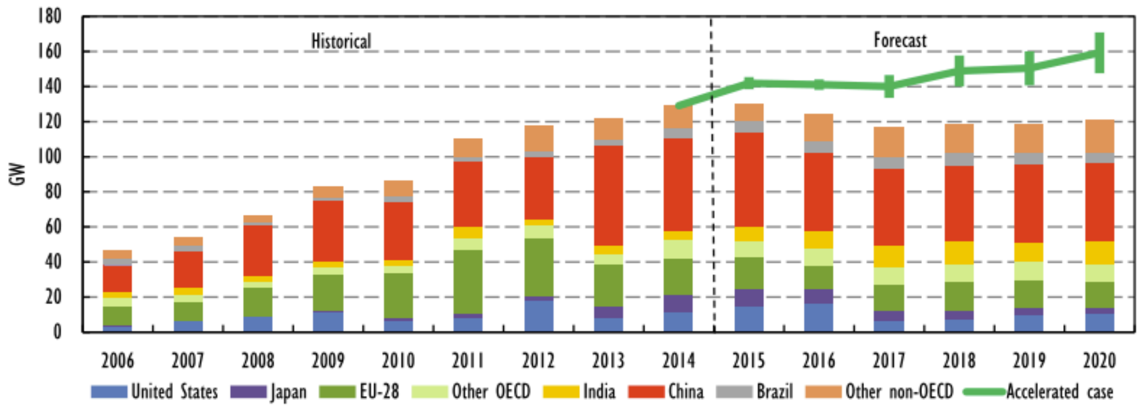


V. Projections

1. Energy Outlooks in the U. S. and the EU

In the past decades, the U. S. and the EU have established a policy framework for a cleaner energy infrastructure to curb global climate change. Partly owing to these efforts, the share of renewable sources in the energy mix is expected to continuously grow both in the U. S. and the EU. Figure 3 depicts the pace of growing renewable capacities in the countries around the world. While the U. S. and the EU show constant and considerable contribution over the past decade, China's growth rate is remarkable as well.

Figure 3 Renewable power net additions to capacity under main and accelerated cases



Source: IEA (2015)

a. The United States

The U. S. EPA's Clean Power Plan (CPP) is one of the major determinants that would shape the future emissions portfolio. According to the EIA, the CPP "requires states to reduce CO2 emissions from existing fossil fuel generators, and an extension of tax credits for wind and solar energy (EIA, Annual Energy Outlook 2016)." The EIA also expects that 92 GW of coal-fired capacity would be retired by 2030, allowing natural gas and renewable generation to surpass in 2024 and 2028, respectively. In "no-CPP" case, coal-fired generation will hardly change between the years of 2015 and 2030 (*ibid.*).

The United States has the sufficient potentials in replacing fossil fuel generation with renewables. A 2013 study estimates the vast potentials of various renewable energy sources as summarized in Table 4.

Table 4 Renewable potentials in the U. S.

Renewable type	Potential (million GWh)	Current usage (GWh)	Obstacles to growth
Wind	65.0	90,000	Distributed and intermittent nature, negative social impacts, lack of grid integration
Solar	56.0	9000	High cost, distributed and cyclic nature, lack of grid integration
Geothermal	1.8	18,000	Lack of mature EGS technology, negative environmental impact
Hydropower	0.6	315,000	Negative environmental and social impact, most promising sites already exploited
Biomass	1.4	63,000	Incentive for biofuel production discourages use for electricity

			generation

Table source: Osmani et al. (2013)

The EIA projects the net electricity supply as described in Table 5. The total electricity generated will grow to 4,406 billion kWh, by about 12% from the 2015 level, but the increment will be largely sustained by renewable sources. As a result, the GHG emissions will decrease from 1,1913 to 1,689 mmt CO2, by around 12% as well. Figures 4 and 5 demonstrate the projected changes from 2015 to 2030; note that the lifecycle emissions resulted from renewables grow in 2030 as opposed to those from coal generation. This indicates the potential growth of renewable capacity.

Table 5 Net Electricity Supply and Calculated GHG Emissions in the U. S. in 2030

Fuel type	Net generation		GHG emissions using lifecycle estimates	
	[billion kWh]	(%)	[mmt CO2]	(%)
Coal	959	22	921	54
Natural gas	1,559	35	691	41
Nuclear power	789	18	52	3
Renewable sources	1,089	25	19	0
Conventional hydro	296	7	3	0
Biomass	67	2	2	0
Geothermal	42	1	2	0
Solar	227	5	7	0
Wind	457	10	5	0
Petroleum	10	0	8	0
Total	4,406	100	1,689	100

Source: EIA Annual Energy Outlook 2016 (Excerpted and rearranged from Tables A8 and A16)

Note: Includes combined heat and power, but CHP using renewable resources are not included due to negligible numbers. Also excluded is distributed generation from natural gas and offshore wind, as the shares are negligible. Renewable resources include end-use sectors, including some CHP plants and electricity-only plants. The numbers are rounded, which may result in inconsistency.

Figure 4 Fuel Mix for Electricity Generation in 2015 and 2030 in U. S.

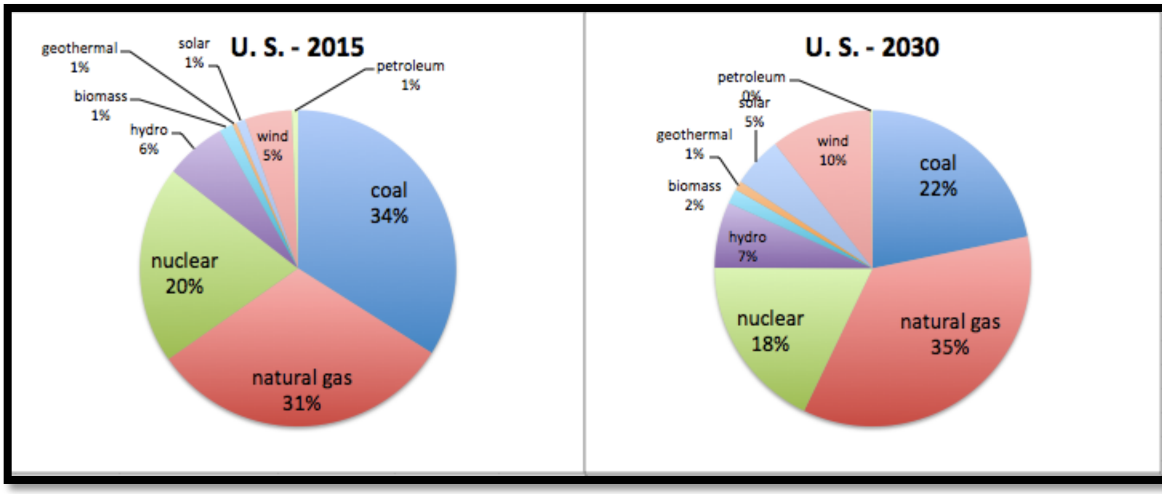
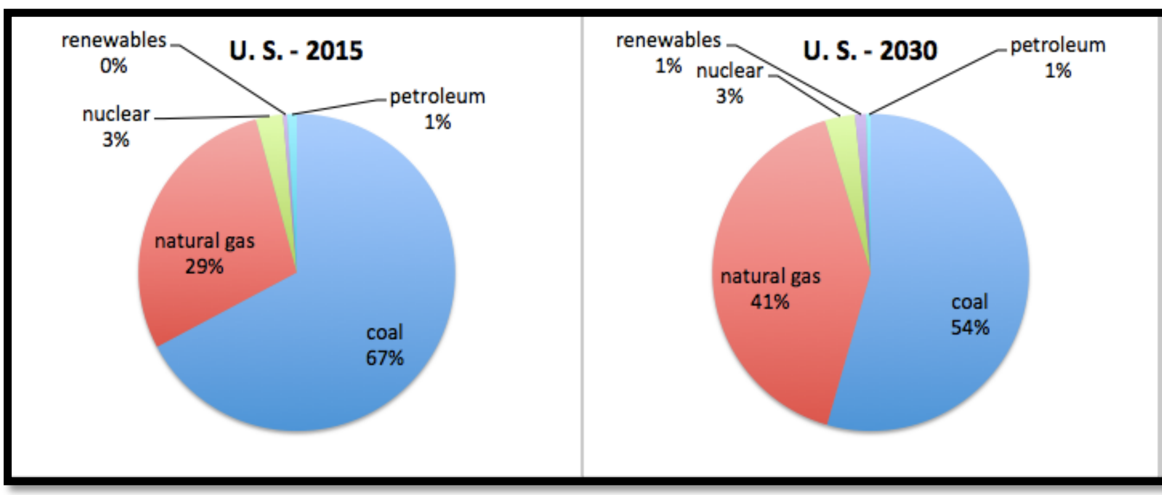


Figure 5 Lifecycle GHG Emissions by Energy Source in 2015 and 2030 in U. S.



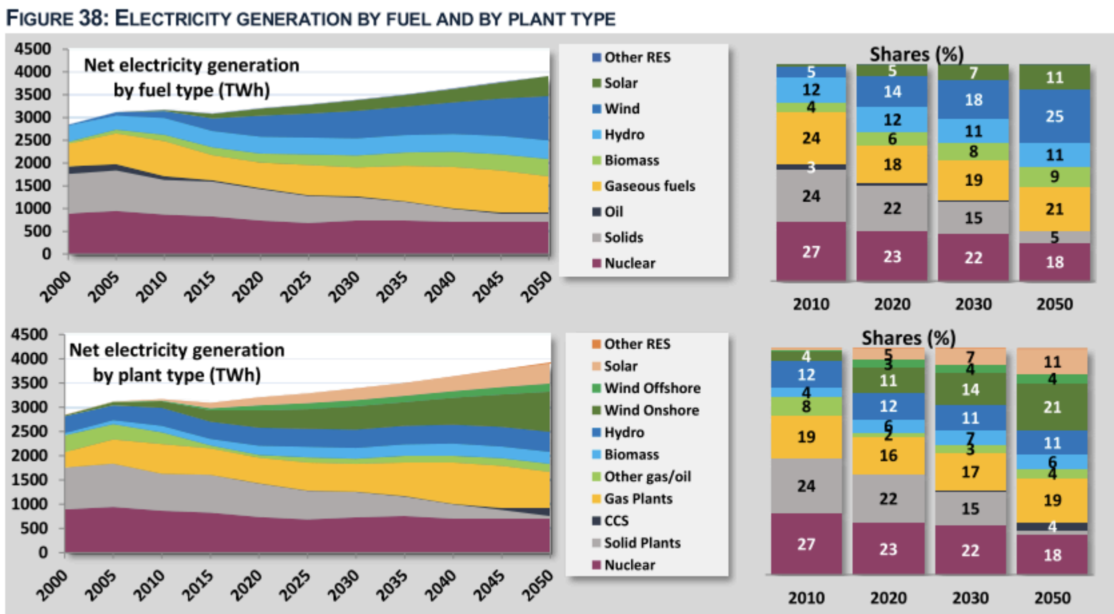
b. European Union

In the EU, renewable electricity generation grew significantly in the past decade. According to the EEA, the average annual growth rate between 2002 and 2012 was 18% (EEA[6]). A study finds that "renewable energy consumption contributes around ½ less per unit of energy consumed than fossil energy consumption in terms of GHG emissions in EU countries. A shift in energy mix towards renewable energy technologies might decrease the GHG emissions (Boluk et al., 2014)." The EU envisions a renewable contribution of at least 60% to the total power generation (EU Energy Roadmap 2050). Figure 6 and Table 7 describe the projections for gross electricity supply in the EU. Figures 7 and 8 juxtapose the

[6] http://www.eea.europa.eu/data-and-maps/indicators/overview-of-the-electricity-production-1/assessment

energy mix and lifecycle emissions in the years of 2015 and 2030, respectively. Like the U. S.'s case, the share of renewables in lifecycle emissions will increase whereas the one of coal would decrease.

Figure 6 Electricity generation by fuel and by plant type



Source: EU Reference Scenario 2016

Table 6 Net Electricity Supply and Calculated GHG Emissions in the EU in 2030

Fuel type	Gross generation		GHG emissions using lifecycle estimates	
	[billion kWh]	(%)	[mmt CO2]	(%)
Coal	563	16	540	59
Natural gas	655	19	290	31
Nuclear power	778	22	51	6
Renewable sources	1,532	43	25	3
Conventional hydro	379	11	4	0
Biomass	284	8	8	1
Geothermal	10	0	0	0
Solar	232	7	7	1
Wind	608	17	6	1
Petroleum	19	1	15	2
Total	3,528	100	922	100

Source: The 2013 EU Reference (Excerpted and rearranged from Appendix 2)

Figure 7 Fuel Mix for Electricity Generation in 2015 and 2030 in EU

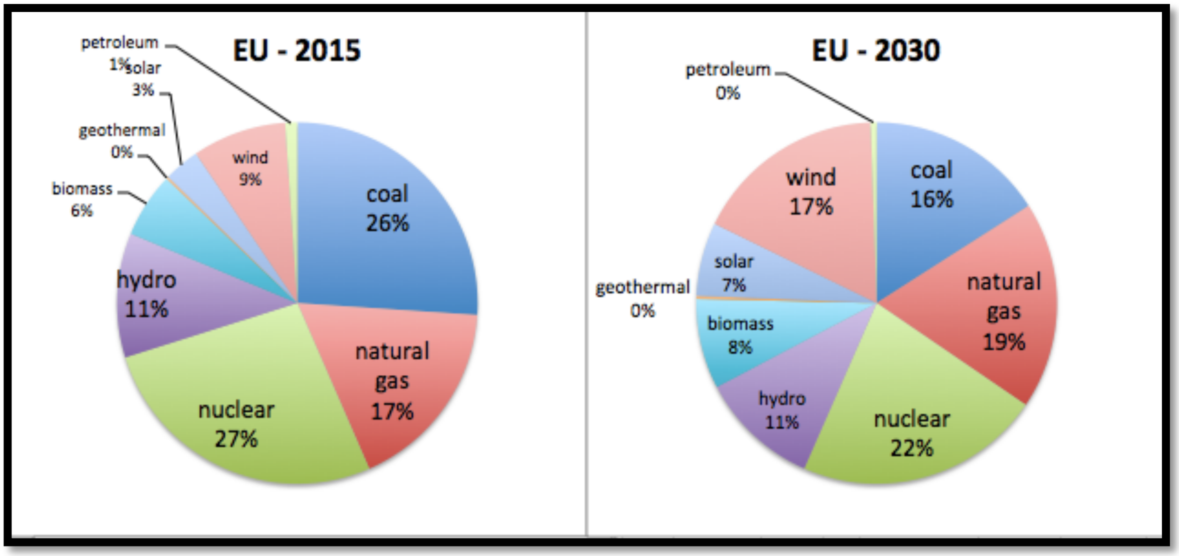
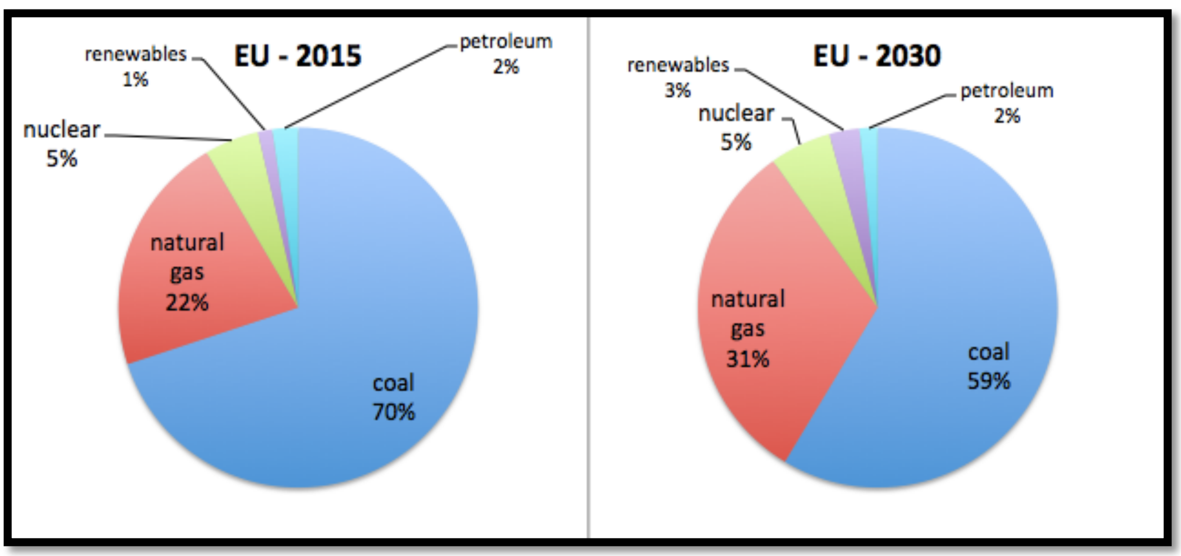


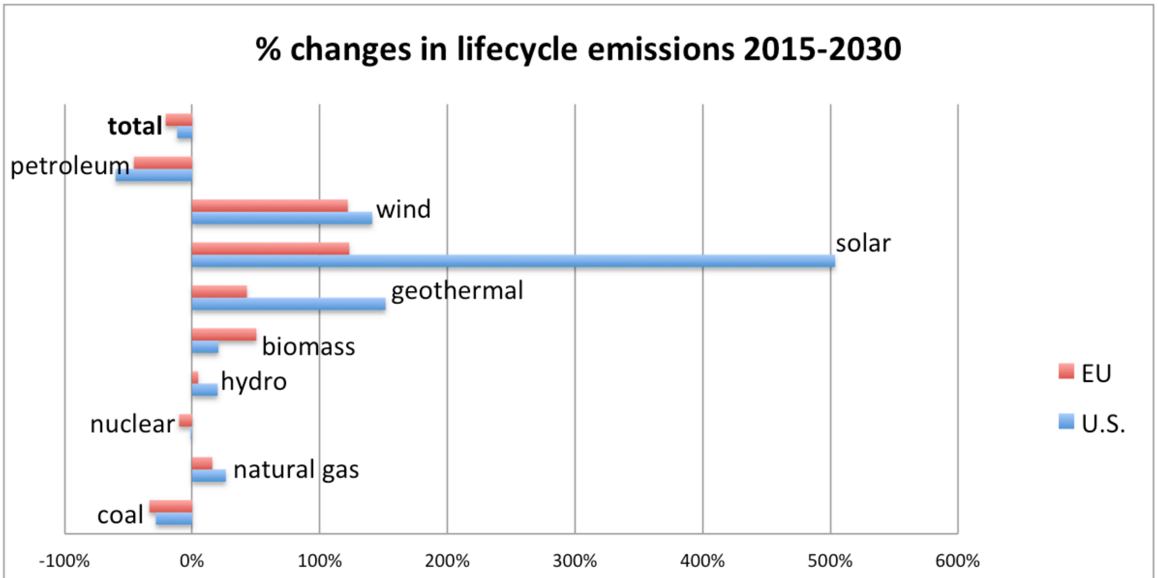
Figure 8 Lifecycle GHG Emissions by Energy Source in 2015 and 2030 in EU



2. Comparison for the Year 2030

In 2030, both the U. S. and the EU are expected to see the total lifecycle emissions decrease by 12 and 21 percent, respectively. Interestingly, despite the differences in details the overall trends are projected similarly for both; the portion of the emissions from coal, nuclear, and petroleum will decrease, whereas that of natural gas and renewable sources will rise. This is rather encouraging because it represents dramatic expansion of renewable capacity, considering how little renewable technologies contribute to the total emissions. In particular, solar power generation is expected to grow in the most rapid pace.

Figure 9 Percentage changes in lifecycle emissions in U. S. and EU: 2015-2030



	coal	natural gas	nuclear	hydro	biomass	geothermal	solar	wind	petroleum	total
EU	-34%	16%	-10%	5%	50%	43%	123%	122%	-46%	-21%
U.S.	-28%	26%	-1%	20%	21%	151%	504%	141%	-60%	-12%

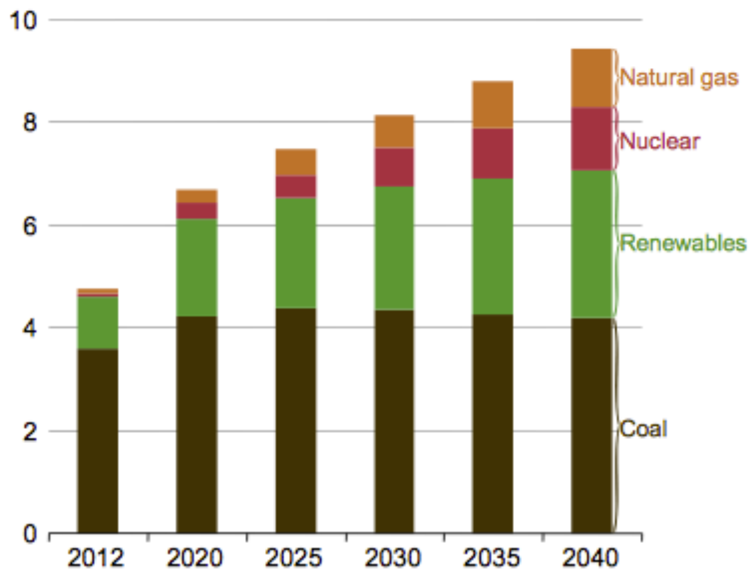
3. Influence on Developing Economies such as China

In 2012, a whopping 76 percent of China's power generation came from coal-fired power stations, according to the IEA. Even though the country is the leading producer of renewables and its investment in clean energy is constantly increasing, the sheer scale of the country's energy demand and economic growth drive China to exploit cheap coal at least for the foreseeable future. Through its INDC, in which China pledges to move forward to a cleaner energy system, the goal largely concerns energy intensity, not GHG reductions in absolute terms.

China is not the only country where an immediate scaleback of fossil fuel generation is out of the question. Many developing economies such as India and Brazil face the skyrocketing demand for electricity with poor infrastructure for renewable generation. The Paris Accord requires both developed and developing nations to cut emissions through individual national plans, and the global emissions level in the coming years will significantly affected by the policies of these developing economies as well as by those of the advanced ones.

Figure 10 depicts how China's electricity mix has been and will be changing from 2012 to 2040. While the share of renewables constantly grow and that of coal somewhat stabilizes after 2020, the amount of generation itself will continue to grow—the increment will be met by natural gas and nuclear. In terms of lifecycle emissions, the amount of additional GHGs emitted by China from natural gas and nuclear generation in 2040 by far exceeds the American and European equivalent combined in 2015. Considering the size of the Chinese economy, there will be little change in the global emissions status unless it establishes far more aggressive renewable policy.

Figure 10 China electricity generation by fuel source, 2012-2040 (trillion kWh)



Source: EIA, International Energy Outlook 2016

VI. Discussions

While the comparative analysis conducted in the previous sections shows several important implications from the policy perspective, there remains a room for further development for this paper to be more robust. In this section, a number of factors that give rise to considerable uncertainties.

1. The issue with datasets

The biggest source of uncertainties lies in the fact that the datasets used for comparison are intrinsically different between the U. S. and the EU. While the American and European statistics that were used for the analysis are both dated 2015, the EU provides "gross electricity generation" whereas the U. S. "net electricity generation." According to the EIA, "Net generation is the amount of gross electricity generation a generator produces minus the electricity used to operate the power plant. These electricity uses include fuel handling equipment, water pumps, combustion and cooling air fans, pollution control equipment, and other electricity needs (EIA[7])."

Indeed, most of the power plants have devices to control stack emissions such as precipitators, baghouses, and scrubbers, which may consume 2 to 6 percent of the plant's gross output. The values may vary depending on the system design, so it is difficult to apply a single number to the gross generation value to obtain a net

[7] https://www.eia.gov/tools/faqs/faq.cfm?id=101&t=3

generation figure. Electric power plants are often "designed and constructed with direct metering of gross electricity output, an important operating control parameter, at individual generation units," even though today's generators' face deregulation that favors unit-level measurement of net electric generation (FirstEnergy Corp., 1999.).

For this complication, this paper utilizes the datasets as they are provided, yet limits the boundary of the comparison to the percentage changes rather than absolute numbers.

2. The errors resulting from calculation methods

As energy systems are highly complex, the electricity output and emissions inventory from one source are not always consistent with others depending on the accounting methods and categorization of fuel types. In this paper as well, there are several significant discrepancies that result in errors.

First of all, the total emissions calculated from lifecycle emissions estimates that are specified in Table 1 do not match with the actual inventory data. In particular, the results for the biomass category, whose lifecycle emissions estimates vary widely from 14 to 41, are less robust. Despite its status as a renewable source, calculating the emissions from biomass is complex as the GHG emissions can vary greatly depending on different biomass fuels and production (Environment Agency, 2009). Although the EIA does provides emissions statistics for each fuel type[8], data availability is limited regarding the heat content for all the different types of woody biomass consumed in each sector, as well as the respective efficiencies at combustion facilities.

Another issue concerns categorization of electricity generation sources. As discussed in the previous section, the U. S. and EU have a largely similar system in categorizing the different sources for power generation. However, the details may vary; for example, in the case of the EU, there is a category named "other fuels," which is not found in the U. S. dataset. According to the EEA, they "include electricity produced from power plants not accounted for elsewhere, such as those fuelled by certain types of industrial wastes. It also includes the electricity generated as a result of pumping in hydro-power stations." This category was ignored when conducting the analysis, but may be a source of errors as it accounts for about 1 percent of total electricity generation.

Finally, the paper was developed based on the assumption that the lifecycle emissions factors are a given and will remain unchanged in 2030—which may lead to a serious flaw. Not only would the accuracy improve with the evolution of details and complexity, the estimates in Table 1 are likely to become outdated in the future; as Weisser mentions in his 2007 paper, "technology experience curves potentially render older LCA inappropriate for reference use today (Weisser,

[8] http://www.eia.gov/totalenergy/data/monthly/pdf/sec12.pdf

2007).” However, as this paper attempts to conduct a comparative analysis rather than pursuing absolute values, the errors due to changed estimates can be minimized.

3. Other general uncertainties

Even setting aside the two problems that were mentioned above, comparing the current and future energy status of two different political blocks bears intrinsic limitations. First, the comparison does not properly address technological progress in power generation technology (EU Reference 2016, p. 41). Renewable and fossil fuel generation are fundamentally different and thus should be treated differently (Neuhoff et al., 2016). In addition, as the EIA report mentions, it should be noted that “energy-related CO2 emissions vary widely with different assumptions about economic growth, energy prices, and policies (EIA, 2016).” Both the U. S. and the EU are witnessing a significant political change; Donald Trump was elected as the next President of the U. S., who has openly denied climate change and promised scrapping the CPP, while the U. K. decided to step out of its EU membership. These political events are a potential game-changer in the energy policy landscape.

Finally, the results should not be blindly applied to other countries like China, because every nation faces different circumstances and restraints. The U. S. and the EU both have a large and mature economy, the structure and characteristics of their respective electricity markets largely differ (Neuhoff et al., 2016). Moreover, even though the EU has shown a competitive edge over other countries in terms of renewable energy, there is a flip side; even though “the support schemes have been a crucial driver of RES-E deployment,” the support costs have increased by 144% between 2009 and 2012 (Ortega-Izquierdo, 2016).

VII. Conclusion

With increasingly more countries committing to battling climate change through various measures to curb greenhouse gas emissions from smokestacks, the policies taken by the U. S. and the EU will have a profound influence on developing countries. While the comparative analysis presented in this paper may have limitations due to incomplete datasets, calculation and assumption errors, and other uncertainties, it implies that fossil fuel dependence will decrease over the coming decades both in the U. S. and the EU. More aggressive policies will further foster cleaner energy sources while discouraging fossil fuel generation, and the change in 2030 will be significant as reflected in the more diversified energy mix profiles.

One crucial lesson that can be learned from this U. S. – EU comparison is that the fossil fuel combustion should be reduced in absolute terms to bring about real changes, regardless how large the renewable share will grow. Although China is making strides in terms of expansion of renewable generation, this can be a valuable message to the country with the daunting growth rate in electricity generation.

VIII. References

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