Policy Arguments over Nuclear Reactor Closures and Relevant Challenges

–From Viewpoint of GHG Emission Reduction (Cases for New York and Sweden) –

Atsuhiko Suzuki[1]

Summary

In New York State, wholesale power price falls caused by natural gas price plunges became a main factor to deteriorate the profitability of nuclear power generation, triggering decisions to close some nuclear reactors. However, the state government, aggressive about greenhouse gas emission cuts and concerned on emission growth through nuclear reactor closures, considered how to prevent such closures. As a result, the state government assessed the value of nuclear power generation as a low carbon power source and created the Zero Emission Credit system to pay for the value, leading to an expectation that the nuclear reactors subjected to the closure decisions would continue operating. In Sweden, wholesale power price drops caused by growth in hydroelectric generation and the enhancement of tax on nuclear power generation deteriorated the profitability of nuclear power generation, resulting in a decision to close four nuclear reactors. Concerned on GHG emission growth like New York, five ruling and opposition parties in Sweden agreed to withdraw a nuclear phaseout policy and repeal the nuclear power generation tax. While the decision to close the four reactors has not been withdrawn, the agreement has supported the continued operation of the remaining reactors.

In both cases, policy measures to prevent nuclear reactor closures were taken on concern over GHG emission expansion, contributing to the prevention of nuclear reactors closures. While policy measures were discussed to counter market realities (deterioration of economic efficiency) from the viewpoint of setting and implementing GHG emission reduction targets, the policy measure discussions lagged behind. For Japan that is similar to New York and Sweden in that they have liberalized markets and numerous nuclear reactors and are committed to cutting GHG emissions, the two cases imply that it is important to clarify the position of nuclear reactors in reducing GHG emissions.

1. Introduction

At the end of 2016, a total of 448 commercial nuclear reactors were in operation in the world. In the decade from 2007 to 2016, 79 reactors marked their 40th anniversaries of the start of

[1] Nuclear Energy Group, Strategy Research Unit, Institute of Energy Economics, Japan

operation[2], including 44 located in the United States. Many of these old reactors have been allowed to extend their operation due to good operation records.

In the final two years of the abovementioned decade, however, many media reports came out on nuclear reactor closures[3]. Most of the reported closures were attributed to the deterioration of profitability. Profitability is the most important factor for deciding whether to continue operating nuclear reactors that generate profit through operation in a liberalized power market. Such decision is made by business operators owning relevant nuclear reactors. Given that nuclear reactor closures could seriously affect energy security and greenhouse gas emission cuts in countries or regions where reactors are located, arguments are frequently made about whether nuclear reactors should be closed or not.

In New York State and Sweden that have liberalized power markets, decisions to close nuclear reactors for the reason of deteriorated profitability came from 2015 to 2016, prompting arguments about how to deal with these decisions. As a result, the New York State government assessed the value of nuclear power generation as a low carbon power source and created the Zero Emission Credit system to pay for the value, while Sweden repealed tax on nuclear power generation. Their decisions to implement policy measures for preventing nuclear reactor closures attract our attention when we consider the position of nuclear power generation in GHG emission cuts. This paper confirms power market conditions and reasons for closing nuclear reactors in New York State and Sweden and analyzes their policy measures for preventing such closures and their backgrounds.

2. New York State

2-1. Overview

New York State is the seventh largest power generator in the United States, posting almost the same power generation as Kansai Electric Power Co. in Japan. Figure 1 shows the state's power mix trend. In 2015, natural gas accounted for the largest share of the power mix at 41%, followed by 32% for nuclear energy, 19% for hydro, 5% for renewable energy, 2% for coal and 1% for oil.

[2] See the footnote for Figure 2 for the definition of the start of operation.
[3] In this paper, a nuclear reactor closure means a permanent closure.

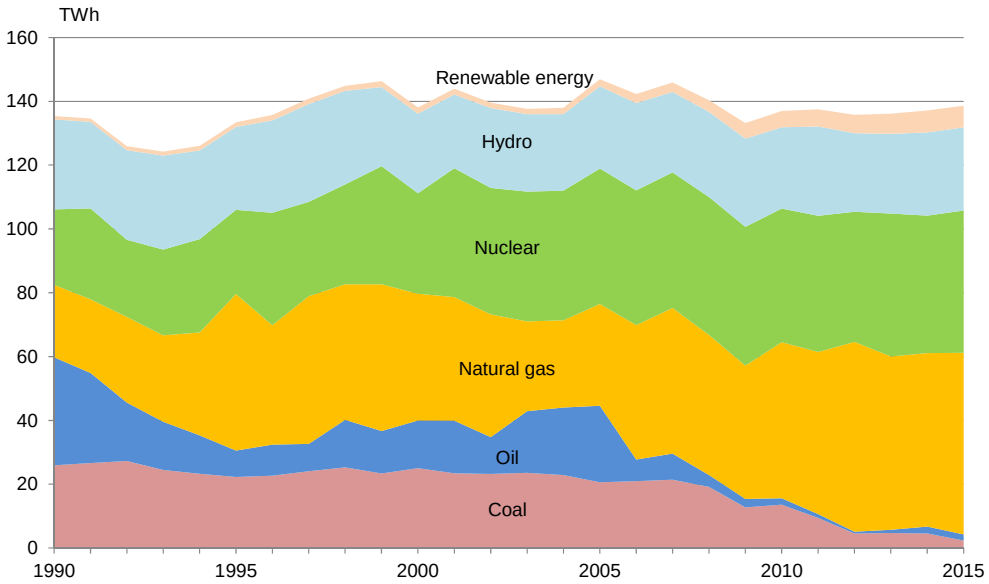

Figure 1 Power mix trend in New York State

(Source) U.S. Energy Information Administration

Figure 2 is a list of nuclear reactors in operation in New York State. Four nuclear power stations have six reactors, including five that had operated for more than 40 years by the end of 2016 and boast good operation records including an average capacity factor of more than 90% for the latest five years. Since 2015, however, their operators made decisions to close these reactors.

Reactor	Owner	Reactor type	Capacity	Year for starting operation	Average capacity factor
①Fitzpatrick	Exelon	BWR	849	1975	93%
②Ginna	Exelon	PWR	608	1969	92%
③Indian Point-2	Entergy	PWR	1,067	1973	95%
④Indian Point-3	Entergy	PWR	1,085	1976	92%
⑤Nine Mile Point-1	Exelon	BWR	642	1969	90%
⑥Nine Mile Point-2	Exelon	BWR	1,320	1987	91%

Figure 2 List of nuclear reactors in operation in New York State[4]

(Sources) NEI, IAEA Power Reactor Information System (PRIS), websites of reactor operators

[4] Circled numbers in front of reactor names match the location numbers in the map. Capacity is gross capacity in terms of megawatts. The year for the start of operation is the year for the first grid connection made available in the IAEA PRIS (Power Reactor Information System). The average capacity factor is the simple average of load factors for five years (2011-2015) on the IAEA PRIS website.

2-2. Decisions to close nuclear reactors

(a) FitzPatrick Power Plant

The FitzPatrick Power Plant, owned earlier by Entergy, saw its profitability deteriorate due to wholesale power price falls. Considering the reactor closure's impact on employment and GHG emissions, Entergy asked the New York State government to support the continuous operation of the reactor. In the absence of progress in getting support, Entergy in October 2015 announced a plan to close the FitzPatrick power station by early 2017[5]. The following are the factors that Entergy pointed out as the reason of profitability deterioration:

- Wholesale power price falls resulting from natural gas price drops
- Flawed market design failing to recognize nuclear plants as stable power generators and a carbon-free power source like renewable energy
- Growing costs for safety and other measures
- Excess power supply and slack power demand in the market for the power station

(b) Ginna Power Plant

The Ginna Power Plant had been owned by Rochester Gas and Electric (RG&E) before being purchased by Constellation Energy Nuclear Group in 2004. Then, RG&E signed a power purchase agreement to buy 90% of power output from the plant over 10 years. As the agreement was to expire at the end of June 2014, however, it was anticipated that costs for the continued operation of the plant could fail to be recovered, with all power output subjected to auction in the wholesale market after the expiration. Therefore, Exelon, which acquired Constellation Energy Nuclear Group and became the plant's owner, was reportedly planning to close the plant after the agreement's expiration.

The New York Independent System Operation (NYISO) issued a report in May 2014 on its survey on the impact of the power plant's closure[6], concluding that the retirement of the plant would reduce the reliability of the New York State power grid between 2015 and 2018. In response, the New York State Public Service Commission (NYPSC) urged RG&E and Exelon to negotiate a Reliability Support Service Agreement (RSSA) [7].

In February 2015, RG&E agreed to pay Exelon about $17.5 million per month over 42 months from April 2015 to September 2018, based on estimated costs for continuing the operation of the plant and forecast wholesale power prices. Later, the Federal Energy Regulatory Commission

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5 http://www.entergynewsroom.com/latest-news/entergy-close-jamesfitzpatrick-nuclear-power-plant-central-new-york/

6 http://www.nyiso.com/public/webdocs/markets_operations/services/planning/Planning_Studies/Reliability_Planning_Studies/Additional%20Reliability%20Studies/Exelon_ARS_Final_Report-Redacted.pdf

7 Reliability support service means that a power plant operator continues the operation of its plant to support the reliability of the power grid even if it cannot expect profit on the continuation. The RSSA covers a gap between the costs for the continuation and wholesale power prices.

(FERC) screened and revised the agreement. In the revision, the duration of the agreement was shortened to 24 months between April 2015 and March 2017, with payments integrated into a single payment worth $425 million to $510 million based on actual wholesale power prices. Finally, FERC approved the agreement in March 2016[8]. While vowing to continue the operation of the plant over the RSSA duration, Exelon said it was uncertain about operation after that.

2-3. Profitability of nuclear reactors

Next, the profitability of nuclear reactors cited as the reason for their closure is analyzed here. While each reactor's power generation costs are not available, the Nuclear Energy Institute (NEI), a nuclear industry organization covering mainly U.S. companies, has published U.S. average data (Figure 3).

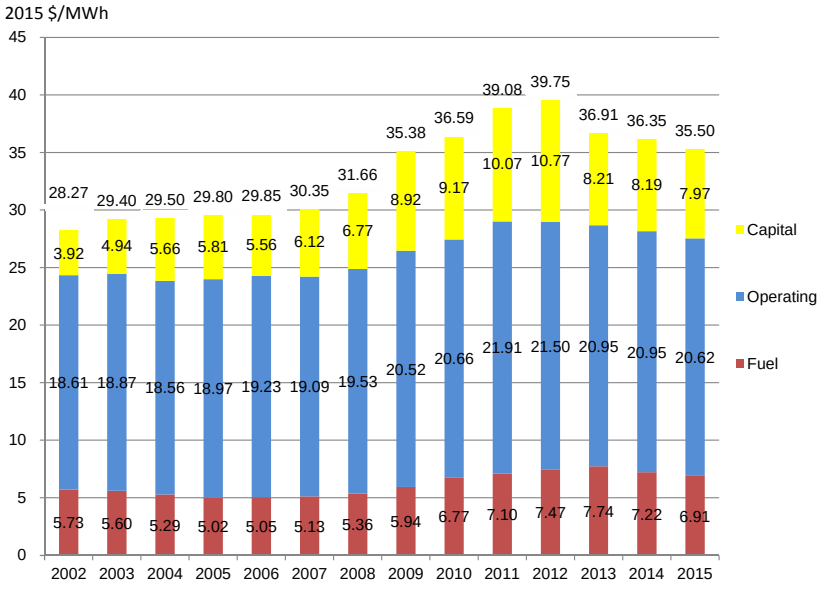

Figure 3 Average power generation costs for existing U.S. reactors

(Source) NEI

According to NEI data, the average power generation costs for existing nuclear reactors stood at $35.50/MWh in 2015[9]. The average power generation costs rose toward 2012 due mainly to a capital cost hike, affecting the profitability of nuclear reactors. This paper refrains from looking into details. The NEI has examined factors behind the power generation cost hike and set a target of cutting the costs by 30% from 2012 to $28/MWh even on the premise of maintained or improved safety for nuclear reactors[10].

On the other hand, wholesale power prices at the NYISO declined substantially from 2014

[8] https://www.ferc.gov/CalendarFiles/20160301175159-ER15-1047-000.pdf
[9] The costs are translated into 4.26 yen/kWh at the exchange rate of 120 yen to the dollar.
[10] https://www.nei.org/CorporateSite/media/filefolder/Communication-Tools/Delivering%20the%20Nuclear%20Promise/Strategic-Plan_Delivering-The-Promise_r1_rtm.pdf?ext=.pdf

to 2015 as indicated by Figure 4 (the bar graph, the left scale). Compared with the fluctuation of about $11/MWh in the average power generation costs for existing nuclear reactors as shown in Figure 3, the wholesale power price fluctuation is far wilder. According to the NYISO report, natural gas has become a marginal power source in the wholesale power market. The wholesale power price falls are attributed primarily to natural gas price drops caused by the shale revolution (the line graph, the right scale) [11].

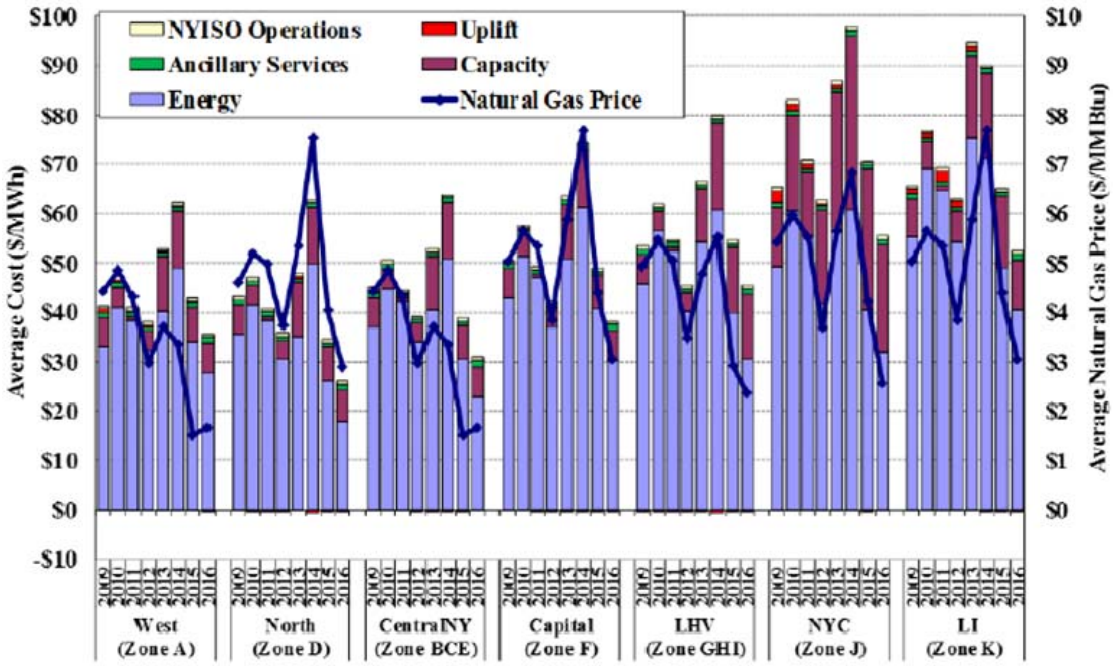

Figure 4 Average NYISO power prices by area (Average all-in price)

(Source) NYISO

In the Central NY area (the third from the left in Figure 4) where the FitzPatrick, Ginna and Nine Mile Point power plants are located, the average wholesale power price in 2016 was as low as $30/MWh including the capacity price. Particularly, the single-reactor[12] FitzPatrick and Ginna power plants with relatively small capacity might have failed to generate any profit even at high capacity factor without trouble under the severe market conditions from 2015 to 2016.

2-4. Creation of ZEC system

Then, the New York State government created the Zero Emission Credit (ZEC) system.

11 http://www.nyiso.com/public/webdocs/markets_operations/documents/Studies_and_Reports/Reports/Market_Monitoring_Unit_Reports/2016/NYISO_2016_SOM_Report_5-10-2017.pdf

12 This means that a nuclear power generation site has only one reactor. Generally, a single-reactor power station features higher unit power generation costs than a multiple-reactor power station.

The following discusses how the ZEC system was established:

New York State has traditionally been positive about GHG emission reduction initiatives. In 2014, its Governor Andrew M. Cuomo attracted attention by announcing the Reforming the Energy Vision (REV) in 2014 seeking to improve energy efficiency and expand renewable energy. In November 2015, the governor established the 2015 New York State Energy Plan, spelling out the following ambitious goals for 2030[13]:

- Reducing GHG emission by 40% from 1990 levels
- Expanding renewable energy (including hydro) to account for 50% of power generation
- Cutting energy consumption in buildings by 23% from 2012 levels

In November 2015 when the above goals were announced, the closure of nuclear power plants including the FitzPatrick and Ginna facilities was controversial, as noted in 2-2. In a letter directing the state government to establish specific systems to achieve the above goals in December 2015, Governor Cuomo stated: “Specifically, elimination of upstate nuclear facilities, operating under valid federal licenses, would eviscerate the emission reductions achieved through the State’s renewable energy programs…” He thus directed the state government to implement measures to prevent nuclear reactors[14] in northern New York State from being closed[15].

In response to the direction, the New York State government asked the consulting company Brattle Group to analyze the impact of nuclear reactor closures. In a report[16] published in December 2015, Brattle Group analyzed the effects of the continued operation of the four nuclear reactors in northern New York State as follows:

- Contributing about $3.16 billion to the state’s GDP
- Keeping 24,800 full-time jobs (direct and indirect)
- Keeping electricity prices low – without these reactors, New York consumers would pay $1.7 billion more in electricity costs in 2015 dollars annually or almost $15 billion more in the next 10 years
- Contributing $144 million in net state tax revenues annually
- Avoiding almost 16 million tons of carbon dioxide (CO_2) emissions annually

Based on the report, the New York State government published a draft Clean Energy Standard (CES) for reducing GHG emissions in January 2016, calling for renewable energy expansion measures and the creation of the ZEC system to prevent nuclear reactors from being

[13] https://energyplan.ny.gov/Plans/2015.aspx
[14] See 2-5(b) and 2-7
[15] https://www.governor.ny.gov/sites/governor.ny.gov/files/atoms/files/Renewable_Energy_Letter.pdf
[16] http://www.brattle.com/news-and-knowledge/news/report-by-brattle-economists-finds-upstate-new-york-s-nuclear-power-plants-contribute-over-3-billion-to-state-s-gdp

closed. The system positioned the nuclear reactors in northern New York State as a zero-emission power source emitting no GHG for power generation and offered some credit for their power output to prevent their closure. After detailed designing, public comments and revisions by the NYPSC, the CES including the ZEC system was established in August 2016.

Figure 5 People celebrating ZEC system establishment

(Sources) World Nuclear News (WNN) article on August 2, 2017, headlined “New York approves Clean Energy Standard”

2-5. Overview of ZEC system

(a) Period

Twelve years between April 1, 2017, and March 31, 2029, are divided into six two-year tranches. A subsidy is calculated for each tranche.

- Tranche 1: April 1, 2017- March 31, 2019
  (Four two-year tranches)
- Tranche 6: April 1, 2027-March 31, 2029

(b) Targets

- Three nuclear power stations located in northern New York State: FitzPatrick, Ginna, Nine Mile Point
- The Indian Point nuclear power station is excluded[17]

(c) ZEC price

- The ZEC is defined as a credit for electricity generated by the target power stations. The ZEC will be purchased by the New York State Energy Research and Development Authority (NYSERDA) at the price calculated with the following formula:

[17] The published reason for the exclusion is that the power station is highly profitable thanks to higher power prices in the area where it is located. As noted in 2-7, however, the New York State government’s opposition to the extension of the power station’s operation is an apparent political factor behind the exclusion.

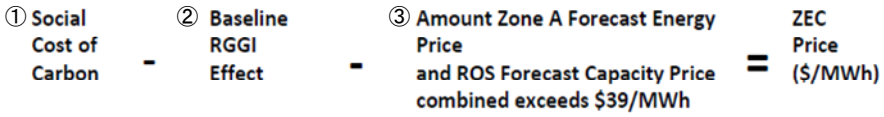

Figure 6 ZEC calculation formula

(Source) New York State government (circled numbers were added by the author)

① Social Cost of Carbon (SCC)

- The SCC is the cost forecast by an interagency working group[18] (updated in June 2015)
- The SCC is set at $42.87/short ton for the first tranche and will rise for the second and later tranches (see the table below).

Table 1 Forecast SCC

Period	SCC
Tranche 2	$46.79
Tranche 3	$50.11
Tranche 4	$54.66
Tranche 5	$59.54
Tranche 6	$64.54

(Source) New York State government

② Baseline RGGI Effect

- The forecast amount of $10.41/short ton that is receivable upon the implementation of CO_2 cap & trade and other programs under the Regional Greenhouse Gas Initiative (RGGI) created by New York and eight other states to reduce GHG emissions in the power generation sector is deducted from the ZEC.
- In contrast to ①, the Baseline RGGI Effect will be fixed at $10.41/short ton (because any rise in the second and later tranches will be reflected in ③).

③Amount Zone A Forecast Energy Price and ROS Forecast Capacity Price combined exceeds $39/MWh

- If the combination of the forecast electricity price in NYISO Zone A and forecast capacity prices in the ROS (Rest of State: Zones A-R) exceeds the standard price of $39/MWh, the excess is deducted from the ZEC. As the standard price is the forecast for the first tranche, the ③ amount for the first tranche is zero.
- In the second and later tranches, the deduction will be conducted only if the combination

[18] See 2-6 for arguments about the social cost of carbon.

exceeds $39/MWh. Even if the combination slips below the standard, the gap will not be added to the ZEC.

Based on the ①-③ amounts, the ZEC price in the first tranche comes to $32.47/short ton according to the following formula and is converted into $17.48/MWh:

$42.87－$10.41=$32.47/short ton

(d) Upper limit on purchase

- An upper limit on the purchase by the NYSERDA is set at 27,618,000 MWh for the target power stations. If one of the three power stations is closed, the upper limit will be lowered to 18,412,000 MWh. If two of them are closed, the limit will be cut to 9,206,000 MWh.
- If power generation at the target power stations in one tranche slips below 85% of the upper limit, the limit for the next tranche will be cut by 1,000,000 MWh. If power generation exceeds the limit due to the power stations' performance recovery in the next tranche, the limit for the subsequent tranche will be raised back to the original level[19].

Based on (a) to (d), payments to the three power stations in the first year (from April 1, 2017, to March 31, 2018) will total about $480 million ($17.48/MWh×27,618,000MWh).

2-6. Effects of ZEC system establishment

Excelon that owns the Ginna and Nine Mile Point power stations has indicated its intention to continue operating them as the ZEC system is expected to increase its profit. Entergy had vowed to close the FitzPatrick power station as announced earlier, branding the New York State response as too late. However, Entergy negotiated the sale of the power plant to Exelon, completing the sale at the end of March 2017[20]. The NEI has welcomed the ZEC system as clearly positioning nuclear power generation as a low-carbon power source and as attempting to prevent the closure of nuclear power plants, urging other states to introduce similar systems. Among other states, Illinois, which has many nuclear reactors subjected to retirement plans due to their lowered profitability as in the case of New York, established a similar system in December 2016. Ohio is also considering introducing a similar system.

A suit against the ZEC system has been lodged with a U.S. district court. In October 2016, Dynergy, Eastern Generation, NRG Energy and other parties filed the suit with the U.S. District Court for the Southern District of New York, urging the NYPSC to withdraw the ZEC system that they suspected as infringing on the authority of FERC that controls interstate power trade. In

[19] The upper limit rule is designed as an incentive to keep reactors' capacity factor at high levels.

[20] http://www.entergynewsroom.com/latest-news/entergy-completes-sale-jamesfitzpatrick-nuclear-power-plant-exelon/

response, the NYPSC and Exelon asked the court to turn down the suit.

The SCC, a component of the ZEC system, has been criticized by plural scholars since its inception[21]. The SCC was estimated by the Interagency Working Group on Social Cost of Carbon, organized under the Obama administration in 2009, for public comments and last updated in June 2015. Due to criticisms against the adequateness of the estimation method and the transparency of estimation procedures, the House of Representatives held a public hearing on the adequateness in 2015. In March 2017, President Donald Trump issued an executive order to dissolve the working group and ban the use of the SCC as a policy ground[22].

In protest of President Trump's announcement to withdraw from the Paris Climate Accord in June 2017, meanwhile, New York Governor Cuomo formed the United States Climate Alliance with California, Washington and other governors to further promote climate change countermeasures, indicating his strong ambition to implement climate change countermeasures. Therefore, he is unlikely to revise CES, ZEC and other relevant systems under the influence of President Trump or the federal government. However, arguments on the SCC and climate change countermeasures may exert some influences on other states' consideration of the introduction of similar systems.

2-7. Closure of Indian Point power station

Another development after the creation of the ZEC system is a decision to close the Indian Point power station. The reason for the decision is different from those for the abovementioned decisions to retire other nuclear power plants. However, the Indian Point case might have been a factor behind Entergy's decision to withdraw from nuclear power generation in New York State. The case is outlined below:

The Indian Point power station is located some 40 kilometers north of New York City, facing the Hudson River. Given that any accident at the power station close to New York City could have a great impact, movements against its operation have existed since a long time ago. New York Governor Cuomo opposed the extension of its operation when he served as the state's attorney general from 2007 to 2010.

Entergy filed an application with the Nuclear Regulatory Commission (NRC) in April 2007 for a license to extend the operation of the power station beyond 40 years to 60 years. In response, New York City and multiple organizations filed a suit asking the NRC to disapprove the extension. Then, the NRC's Atomic Safety and License Board heard opinions from the plaintiffs and sought explanations from Entergy. Separately, Entergy was in dispute with New York State over the state government's issuance of licenses regarding water quality and the Coastal Management Act.

[21] For arguments on GHG emission controls and the SCC, see "U.S. President's Enhanced Power and New Policy Means" by Ayako Sugino) (2017)

[22] https://www.whitehouse.gov/the-press-office/2017/03/28/presidential-executive-order-promoting-energy-independence-and-economi-1

Entergy said it spent $200 million on the application for the operation extension over a decade.

In January 2017, New York State finally agreed with Entergy to withdraw its suit involving the operation extension license and issue the licenses regarding water quality and the Coastal Management Act in exchange for Entergy's plan to retire the second reactor at the Indian Point power station on April 30, 2020, and the third on April 30, 2021[23].

As noted in 2-5, the Indian Point power station has been excluded from the ZEC system. Therefore, its retirement does not affect the ZEC system.

2-8. Summary for New York State

After a series of developments involving nuclear reactor closures in New York State from 2015, four of the six reactors in the state are set to remain in operation, with the other two planned to be closed by 2021. The four reactors are owned by Exelon, including one purchased from Entergy, which owns the two to be retired. The two companies thus made different decisions after growing while purchasing nuclear power plants and other power generating assets, and power generators from around 2000 when some U.S. states deregulated their power markets. Exelon has also successfully led the Illinois State government to create a system like the ZEC system, indicating its willingness to continue nuclear power generation in the two states that have deregulated their power markets. In contrast, Entergy has vowed to withdraw from power generation in any deregulated market when retiring the Indian Point nuclear power station.

As noted earlier, New York State is known for its aggressiveness on cutting GHG emissions and expanding renewable energy to that end. The state has created a system to pay the considerable costs for nuclear power generation in order to prevent an increase in GHG emissions, attracting much attention mainly from the nuclear energy industry. Meanwhile, media reports have indicated opinions doubting the adequateness of the ZEC calculation methodology and the fairness of the ZEC system that, in the end, has been used for Exelon alone.

Apart from the theme of this paper, the Trump administration's nuclear energy policy is outlined below. The nuclear energy policy has remained uncertain since the administration's inauguration. Its "America First Energy Plan," published in January 2017, made no mention of nuclear energy. The Trump administration's budget sent to Congress in May 2017 earmarks $703 million for nuclear energy measures in fiscal 2018, down 28.7% from fiscal 2016[24]. The budget includes no measure for preventing existing nuclear reactors from being retired and cut spending on supporting new nuclear reactor construction, and research and development, coming under fire from the nuclear energy industry for failing to offer sufficient spending to maintain U.S. leadership in the nuclear energy field. In his energy policy speech in June 2017, President Trump vowed to "revive

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23 http://www.entergynewsroom.com/latest-news/entergy-close-jamesfitzpatrick-nuclear-power-plant-central-new-york/

24 https://energy.gov/sites/prod/files/2017/05/f34/FY2018BudgetinBrief_2.pdf

and expand our nuclear energy sector," offering a complete review of U.S. nuclear energy policy[25]. However, details of the review have not been clarified. The revival and expansion contradict a spending cut in the budget. The Trump administration's nuclear energy policy has thus stayed unclear.

3. Sweden

3-1. Overview

Sweden generates a little more power than New York State. Figure 7 shows Sweden's power mix trend. Backed by rich hydro resources in the northern part of the country, hydroelectric generation has accounted for the largest share of the power mix. As Sweden covered power demand growth with nuclear energy instead of fossil fuels in the 1970s and 1980s, power mix shares in 2015 included 46% for hydro, 35% for nuclear and 17% for renewable energy. Fossil fuels' share was limited to around 2%, indicating that Sweden is close to zero-emission power generation.

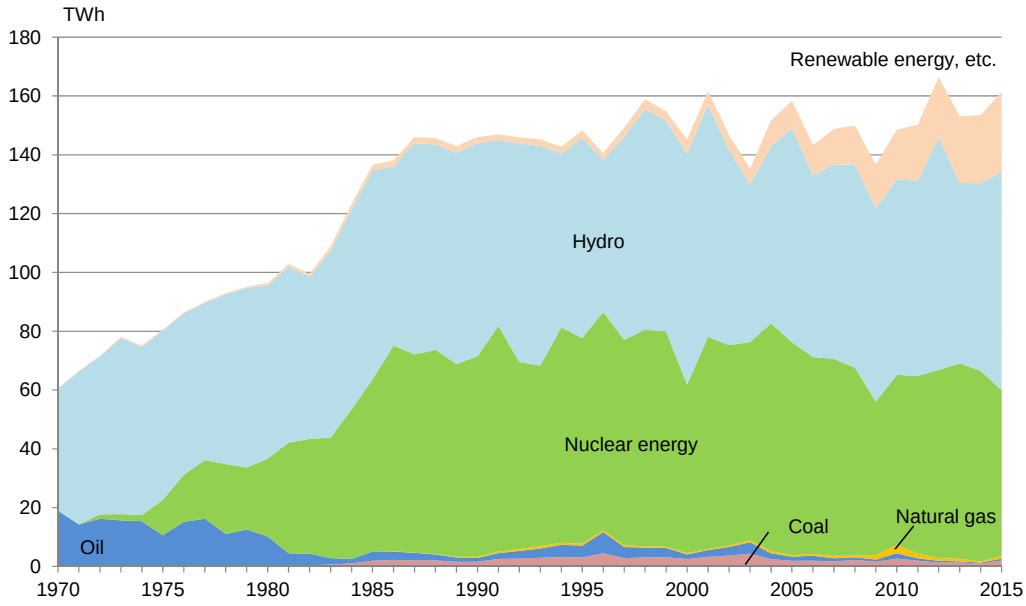

Figure 7 Power mix trend in Sweden

(Source) IEA, World Energy Balances 2016

Figure 8 shows a list of nuclear reactors in operation in Sweden. Three power stations have a total of nine nuclear reactors. The Swedish state-run power utility, Vattenfall, has majority stakes in the Forsmark and Ringhals power stations. Uniper Sweden, a Swedish subsidiary of major German power utility Uniper (former E.ON), holds a majority stake in the Oskarshamn power station. These

25 https://www.whitehouse.gov/the-press-office/2017/06/29/remarks-president-trump-unleashing-american-energy-event

reactors started operation between 1974 and 1985. By the end of 2016, their operation exceeded 40 years.

In 2015, decisions came to close the first and second reactors each at the Ringhals and Oskarshamn power stations. The following discusses details of the decisions while explaining the transition of Sweden's nuclear energy policy.

Reactor	Owner	Reactor type	Capacity	Year for starting operation	Average capacity factor
Forsmark-1	Vattenfall：66% Mellansvensk Kraftgrupp：25.5% Uniper Sweden：8.5%.	BWR	1,022	1980	85%
Forsmark-2		BWR	1,158	1981	92%
Forsmark-3		BWR	1,203	1985	81%
Oskarshamn-2	OKG (Uniper Sweden：54.5% Fortum：45.5%)	BWR	661	1974	35%
Oskarshamn-3		BWR	1,450	1985	74%
Ringhals-1	Vattenfall：70.4% Uniper Sweden：29.6%	BWR	910	1974	76%
Ringhals-2		PWR	963	1974	44%
Ringhals-3		PWR	1,117	1980	82%
Ringhals-4		PWR	1,171	1982	77%

Figure 8 List of nuclear reactors in operation in Sweden[26]

(Source) WNA, IAEA PRIS, websites of power generators

3-2. Decisions to close nuclear reactors

Sweden has repeated decisions to phase out nuclear power generation and then withdraw the nuclear phaseout. In 1980 after the 1979 U.S. Three Mile Island-2 accident, Sweden became the first nuclear power generator to implement a national referendum on a nuclear phaseout. As a result, Sweden planned to close 12 reactors in operation or under construction then after the then-assumed operation period of 25 years (to complete the nuclear phaseout by 2010). In response to the 1986 Chernobyl nuclear plant accident in the former Soviet Union, however, Sweden in 1988 decided to accelerate the nuclear phaseout completion from 2010 to 1995. Due to various problems including preparation of substitute power sources and compensation for nuclear reactors to be closed, however, Sweden closed only two reactors by 2010[27]. They were the first and second reactors of the Barseback power station. In 2010, Sweden decided to withdraw the nuclear phaseout from the viewpoint of GHG emission cuts, allowing 10 reactors in operation then to be replaced with new

[26] While the Oskarshamn-2 reactor was in operation as of June 2017 according to IAEA PRIS, it has already been closed as explained in 3-2.

[27] The two reactors' closure was based on the 1997 Nuclear Power Phaseout Act allowing the government to retire nuclear reactors for political reasons, responding to a request from Denmark that was concerned on an accident at reactors only 20 kilometers from the Danish capital of Copenhagen.

ones.

However, a coalition government formed in 2014 between the Social Democratic Party and the Green Party withdrew the allowance and reintroduced the nuclear phaseout. The coalition government set a target of boosting renewable energy's share of the power mix to 100% by 2040 and raised a tax on thermal output from nuclear power plants[28].

In April 2015, Vattenfall announced a plan to decommission the Ringhals 1 and 2 reactors by 2020. An official decision to do so came in September 2015. At an extraordinary general meeting of shareholders in October 2015, a plan was adopted to retire the first reactor in 2020 and the second one in 2019. Vettenfall cited the deterioration of the market environment and a profitability fall under the tax increase as the reason for closing the two reactors[29].

In June 2015, E.ON Sweden proposed a plan to decommission the Oskarshamn 1 and 2 reactors by 2020. The plan was approved at an extraordinary general meeting of OKG shareholders in October 2015[30]. In February 2017, OKG set the closure of the first reactor for June 2017 and decided to decommission the second without restarting the reactor that had suspended operation for renovation since June 2013. On reasons for the decommissioning, E.ON Sweden said that a record slump in electricity rates, the increased nuclear capacity tax and growing investment costs to meet additional regulatory requirements lowered the profitability of the small-capacity Oskarshamn 1 and 2 reactors.

3-3. Profitability of nuclear reactors

The profitability of nuclear reactors, cited as a reason for their retirement as is the case with New York State, is checked here. In January 2017, the Energy Committee of the Swedish parliament published a report[31] on energy market conditions and problems, analyzing power generation costs at existing power sources (Figure 9).

According to the report, costs for nuclear power generation total 31.6 öre/kWh[32] close to 30.9 öre/kWh for hydroelectric generation. The costs for nuclear power generation, though higher than for cogeneration using waste, are far lower than for wind or solar photovoltaics power generation. Cogeneration represents waste-burning power generation and heat supply and prospers in Sweden that imports waste from other European Union members. In implementing the waste import that differs from usual trade, Sweden receives costs for waste from exporters[33]. As shown by Figure

[28] The tax, created to fund the expansion of substitute power sources, was raised gradually from the initial level of 3 öre/kWh in the second half of the 2000s. In 2014, it was increased from 6 öre/kWh to 7 öre/kWh.

[29] https://corporate.vattenfall.com/press-and-media/press-releases/2015/ringhals-1-to-be-decommissioned-in-2020-and-ringhals-2-in-2019/

[30] http://www.okg.se/en/Media/Archive-2015/Decision/

[31] http://www.energikommissionen.se/app/uploads/2017/01/sou-2017_2_webb.pdf

[32] At the exchange rate of 1 öre=0.13 yen, the costs are converted into about 4.11 yen/kWh, almost equal to the abovementioned average U.S. nuclear power generation costs at 4.26 yen/kWh for existing facilities.

[33] http://eneken.ieej.or.jp/data/6384.pdf

9, therefore, cogeneration costs are relatively lower as other operation costs including the fuel cost are very low despite the relatively high capital cost.

The Swedish electricity market is not closed. The four north European countries, including Sweden, and the three Baltic countries trade power through their common Nord Pool wholesale power market. Trading volume on the market has increased year by year. In 2015, the volume totaled about 500 TWh, almost triple the domestic power generation in Sweden. Figure 10 shows the average spot price on the Nord Pool market.

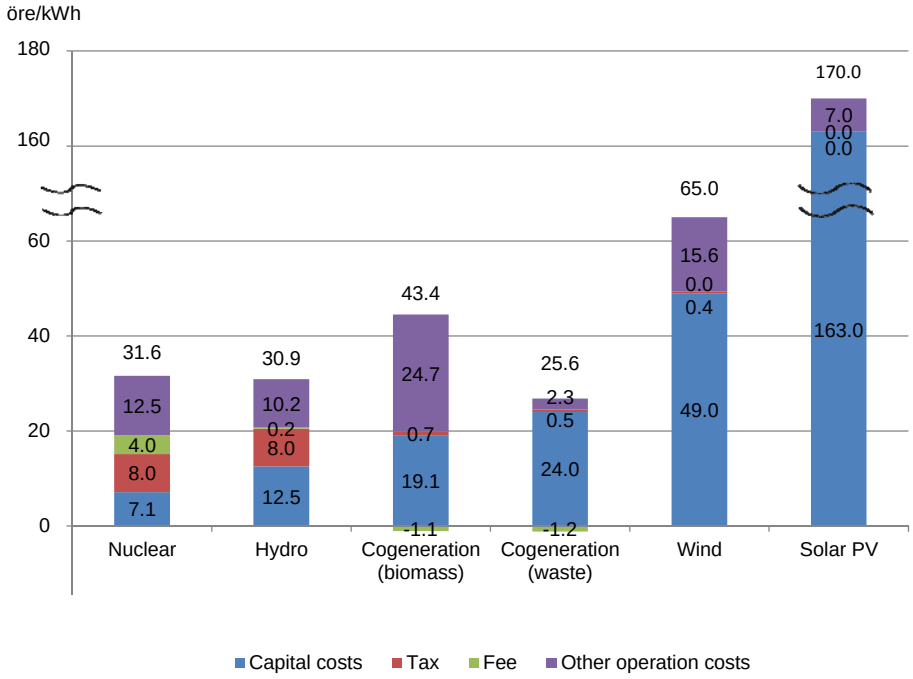

Figure 9 Power generation costs for existing facilities in Sweden[34]

(Source) Report by Energy Committee, Parliament, Sweden

[34] Fee: The fee for nuclear represents contributions to the radioactive waste fund, while that for hydro represents compensations for areas where hydroelectric plants are located. The fee for cogeneration is negative due to profit from heat sales.

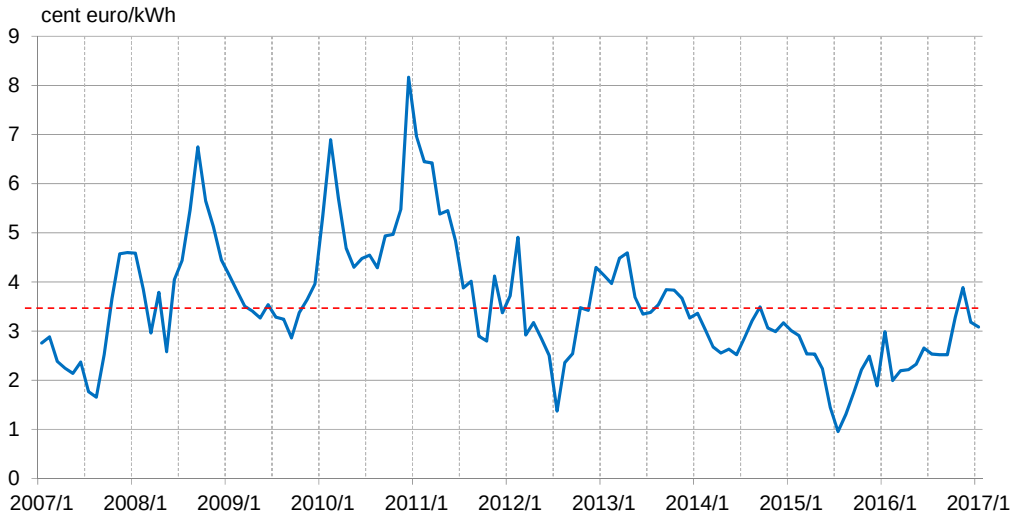

Figure 10 Average spot price on Nord Pool[35]

(Source) Nord Pool

The market features a dominant hydro power source. Trading prices fluctuate mainly in accordance with hydroelectric generation depending on precipitation. The average price rarely slipped below 3.5 cent euros/kWh (red dash line) from the beginning of 2008 to the end of 2013. From the beginning of 2014 to the end of 2016, however, the price remained below the level. The low price was attributable to hydroelectric generation growth through a precipitation increase[36]. (The average reservoir storage for the 2014-2016 period with the slack price was 6-10% more than in 2013.) The deterioration of the market environment and a record slump in electricity rates cited in the previous paragraph as reasons for closing nuclear reactors apparently represent the slack price since the beginning of 2014. In 2015, the Swedish government raised a tax on thermal output from nuclear power plants, as noted in the previous paragraph, apparently contributing to the decline in the profitability of nuclear reactors.

The Swedish Radiation Safety Authority, a nuclear regulatory agency, checked Swedish nuclear reactors after the Fukushima Daiichi nuclear power plant accident and concluded that severe accident countermeasures must be enhanced. It has urged that countermeasures for each reactor be considered and implemented by 2020[37]. In this respect, Vattenfall has decided to install an independent core-cooling system for each of the Forsmark 1 to 3 reactors. As noted above, costs for

[35] At the exchange rate of 1 öre=0.11 cent euros, the nuclear power generation costs at 31.6 öre/kWh for existing facilities in Figure 9 are converted into 3.5 cent euros/kWh. Therefore, the red dashed line is written at this level as a break-even point.

[36] http://www.nordicenergyregulators.org/wp-content/uploads/2017/01/highlights.pdf, etc.

[37] http://www.stralsakerhetsmyndigheten.se/Om-myndigheten/Aktuellt/Nyheter/Svenska-karnkraftverk-ska-bli-battre-forberedda-att-hantera-svara-haverier/

additional safety measures were cited by E.ON Sweden as a reason for closing the Oskarshamn 1 and 2 reactors.

3-4. Agreement between ruling and opposition parties

The decisions to close the four reactors in 2015, though conforming to the coalition government's nuclear phaseout policy, were controversial with concern voiced about their impact, as was the case with New York State. For example, Professors F. Wagner and E. Rachlew published a report in February 2016[38], verifying a scenario in which the reactors in operation with a total capacity of 9 GB will be replaced by renewable energy facilities. While wind and hydroelectric power generation will be expanded with considerations given to costs, gas power plants will have to be constructed to cover the intermittency of wind power because of hydroelectric power plants' failure to cover the intermittency, resulting in an increase of up to 50% in CO_2 emissions, according to the report. In addition to the report, some people voiced concern that electricity prices would increase to affect the economy.

In such situation, the parliament reconsidered the coalition government's initial policy. In July 2016, as a result, the Social Democratic Party and the Green Party from the ruling coalition side agreed with three opposition parties[39] – the Moderate Party, the Center Party and the Christian Democrats – on a basic energy policy framework[40].

The agreement between the ruling and opposition parties says that Sweden's energy policy aims to combine ecological sustainability, competitiveness and security of supply. It also says: "The target by 2040 is 100 percent renewable electricity production. This is a target, not a deadline for banning nuclear power, nor does it mean closing nuclear power plants through political decisions." The agreement also gives basic policies on individual power sources, including the following on nuclear energy:

"Swedish nuclear power needs major investment if it is to meet upcoming safety requirements. The Swedish Radiation Safety Authority has decided that these requirements must be met by 2020, otherwise reactors may no longer be operated. Decisions have already been taken to decommission four reactors by 2020. Nuclear power must cover its own costs, and the principle that nuclear power should not be subsidized remains in place. The principles contained in Government Bill 2008/09:163, En sammanhållen klimat- och energipolitik (Cohesive Climate and Energy Policy) remain in place. This means that:

[38] https://epja.epj.org/images/stories/news/2016/10.1140--epjp--i2016-16173-8.pdf
Wagner is a professor at the Max Planck Institute Germany and Rachlew is a professor at the Royal Institute of Technology in Sweden.
[39] The five parties account for about 80% of the Swedish parliament seats.
[40] http://www.government.se/49d8c1/contentassets/8239ed8e9517442580aac9bcb00197cc/ek-ok-eng.pdf

- The Nuclear Power Phaseout Act[41] has been repealed and will not be reintroduced.
- The period in which nuclear power was to be used has been extended by allowing new construction at existing sites within the framework of a maximum of 10 reactors.
- It is possible to grant permits for successively replacing current reactors as they reach the end of their economic life.
- Permits for new reactors will be examined on the basis of legislative requirements for the best technology available.
- Central government support for nuclear power, in the form of direct or indirect subsidies, cannot be assumed.

The following points also apply to nuclear power:

- The tax on thermal output will be phased out gradually over a two-year period beginning in 2017.
- The rules on investments in the Nuclear Waste Fund will be changed such that investment opportunities are expanded from the start of the next three-year period in 2018.
- Based on the new conditions for nuclear power, the Swedish Radiation Safety Authority will, in consultation with the Swedish National Debt Office, investigate the need for changes to operating lifetimes in the Nuclear Waste Fund. The principle should remain that the costs of disposal of spent nuclear fuel and nuclear waste should be covered by those who generated the waste; the State should not pay for either decommissioning or disposal.
- The level of payments to the Nuclear Waste Fund is decided by the Government, based on proposals from the Swedish Radiation Safety Authority.
- An increase in liability in the event of radiological accidents to EUR 1200 million will be made in accordance with the parliamentary decision in report 2009/10:CU29."

This paper does not go into details of the agreement but emphasizes that the agreement represents the coalition government's withdrawal of the initial nuclear phaseout to allow existing reactors to be replaced with new ones and repeals the tax on thermal output from nuclear power plants.

However, the agreement clarifies that policy support will not be given for nuclear power generation. It calls for reducing the property tax on hydropower plants and implementing renewable energy expansion policies, as well as withdrawing the nuclear phaseout. Sweden is known for its priority given to equality and rationality as well as for high-level welfare. The policy agreement indicates that the coalition government equally and rationally assessed each power source again without sticking to the initial nuclear phaseout policy.

[41] This represents the 1997 Nuclear Power Phaseout Act (see 3-2)

Based on basic policies given in the agreement, specific bills and institutions will be discussed at the Swedish parliament and put into effect in the future.

3-5. Nuclear plant owners' response and future prospects

While Uniper Sweden and Fortum made no comment on the ruling-opposition agreement, Vattenfall issued a press release on the agreement day welcoming the abolishment of the nuclear capacity tax as an important precondition for the company to be able to consider the investments needed to secure the long-term operation of nuclear reactors[42]. Five days later, Vattenfall announced a board of directors decision to invest in independent core-cooling systems to be required for the operation of the Forsmark 1-3 reactors beyond 2020. In a published interview (March 2017) [43], Torbjörn Wahlborg, senior executive vice president for generation at Vattenfall, indicated a plan to invest in continuing to operate the Ringhals 3 and 4 reactors and an ambitious target of lowering the average power generation costs for the company's existing nuclear reactors from about 30 öre/kWh in 2014 and 2015 to 19 öre/kWh by 2021 by taking advantage of the tax abolishment and other measures.

Unlike the New York State case, the withdrawal of the nuclear phaseout and the abolishment of the nuclear power plant tax under the ruling-opposition agreement in Sweden fell short of reversing the earlier decisions to close the Ringhals 1-2 and Oskarshamn 1-2 reactors. The four reactors may be retired by 2020 as planned. However, the agreement might have had at least a positive impact for the continued operation of the other five reactors in which Vattenfall is the largest shareholder.

3-6. Summary for Sweden

As noted above, Sweden has heavily depended on hydro and nuclear energy for power generation, being close to zero-emission power generation. If Sweden were to phase out nuclear energy without increasing GHG emissions, it would have no choice but to expand renewable energy. Given its heavy dependence on hydroelectric generation and competition in the Nord Pool wholesale power market featuring very low prices, however, it may not be easy for Sweden to expand renewable energy power generation that costs far more than hydroelectric generation. The Swedish case indicates how difficult it is to change a power mix in a deregulated market while holding down adverse effects. Sweden may also have to take into account direct and indirect effects that its energy policy and power mix changes would exert on other countries participating in the Nord Pool wholesale power market.

[42] https://corporate.vattenfall.com/press-and-media/press-releases/2016/vattenfall-welcomes-energy-agreement/
[43] http://www.world-nuclear-news.org/C-Vattenfall-sees-challenging-but-promising-year-ahead-0603175.html

Given these points, the agreement between the five ruling and opposition parties in 2016 to revise the policy set upon the inauguration of the ruling coalition in 2014 was a very realistic choice for Sweden. In the future, specific legislation and institutions to achieve energy policy targets will be considered and implemented, based on the report by the Energy Committee of the Swedish parliament. Attracting attention will be how Sweden would mitigate the impact of the nuclear reactor closures by 2020 and how it would expand solar PV, wind and other renewable energy sources that are now less competitive.

4. Conclusion

In many countries including Japan, the so-called 3E's – energy security, environmental friendliness and economic efficiency – are key points in energy policy consideration and implementation. In the New York State and Swedish cases, the deterioration of economic efficiency (profitability) led to decisions to close nuclear reactors. As the remaining energy security and environmental friendliness attracted attention, New York States created the ZEC system and Sweden abolished the nuclear power generation tax. Regarding environmental friendliness, particularly, countries or regions with many existing nuclear reactors, including New York State and Sweden, are required to consider the difficult question of how to balance competition in a deregulated market and the maintenance of nuclear reactors to avoid growth in GHG emissions.

Policy measures have been taken through arguments in New York State, leading to the reversal of decisions to close nuclear reactors. In Sweden, policy measures, though failing to reverse decisions to decommission nuclear reactors, have had a positive impact on the continuation of the other nuclear reactors' operation in the future. In both cases, arguments about policy measures came in response to the deterioration of economic efficiency in the market. These measures were taken as the adverse effects of nuclear reactor closures, including a possible increase in GHG emissions, became controversial after the announcement of energy policy goals. The measures thus lagged behind. To increase the predictability for nuclear power plant operators and other power market participants, any government must analyze various factors influencing GHG emissions and consult with stakeholders in setting energy policy targets including those for cutting GHG emissions. Japan has many nuclear reactors, an ambitious GHG emission reduction target and plans to further promote power market deregulation. Regarding these points, Japan is similar to New York State and Sweden. Their cases give important implications for Japan.

From the viewpoint of business operators, New York State and Swedish policy measures may be favorable for nuclear power plant operators including Exelon and Vattenfall. As noted by these nuclear plant operators, however, they must strive to lower power generation costs while maintaining good operation records as far as the market environment, including slack power prices, remains severe. Japan's nuclear industry has close relations with its U.S. and Swedish counterparts.

In one recent deal, Mitsubishi Heavy Industries, Ltd. won an order for replacing a nozzle for the pressurizer for the Ringhals 3 reactor in Sweden in February 2014 and completed the replacement in November 2016[44]. In April 2017, Japan Atomic Power Co. and Exelon formed a joint venture named JExel Nuclear[45]. Operation performance improvement, cost reduction and other initiatives by nuclear plant operators such as Exelon and Vattenfall will serve as useful practices for the Japanese nuclear industry.

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