Alternative renewable energy scenarios for New York

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ABSTRACT

This case study compares the cost of maintaining a proposed subsidy for New York's three upstate nuclear power plants (Fitzpatrick, Nine Mile Point Unit 1, and Ginna) with the cost of replacing the plants with renewable technologies over the time period from 2016 to 2050. Three alternative renewable scenarios are compared with two nuclear scenarios in terms of overall system costs, which comprise all capital and operating expenditures (CAPEX, OPEX[1]) as well as Zero Emission Credit (ZEC) subsidies for nuclear power plants[2].

The results show that the two nuclear scenarios (Scenario 1, keeping nuclear operating with subsidy until 2050 and Scenario 2, keeping nuclear operating with subsidy until 2028, then replacing it with wind and solar) are the most expensive scenarios, resulting in overall system costs of $32.4 billion and $31.0 billion, respectively, in $2014[3]. The least expensive option, on the other hand, is to shut down the nuclear plants today and replace them with onshore wind capacities, saving $7.9 billion compared with Scenario 1. Substituting nuclear with a combination of wind and utility-scale photovoltaics (Scenario 5) would save $6.6 billion compared with Scenario 1. A mix of wind, utility-scale and rooftop Photovoltaics save $0.8 billion (Scenario 4). If we assumes a lower average capacity factor of nuclear generation from 2016 to 2050 (0.85 instead of 0.91) due to higher maintenance requirements over time and compensate the lower power generation with a mix of wind and PV, the system costs are slightly more expensive than in Scenario 1.

The four renewable scenarios lead to 20.1 to 27.4 Mt CO_2 greater emission reductions between 2016 and 2050 than with the two nuclear scenarios. In addition, re-investing the cost savings of the renewable scenarios into additional wind capacities increase CO_2 savings up to 32.5 Mt.

In sum, in all cases examined, subsidizing the three upstate nuclear reactors to stay open increases both CO_2 and costs relative to the renewable scenarios.

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[1] CAPEX include the annuities over an economic lifetime of 20 years of the capacity specific overnight investment costs. OPEX on the other hand comprise fuel costs as well as fixed and variable operation and maintenance costs.
[2] Although nuclear power emits lower CO_2, than fossil fuels during operation during the mining and refining of uranium, ZEC include social costs of carbon due to their externalities.
[3] All costs are given in US $ 2014.

1. Introduction

The installed capacity of the nuclear power plants Fitzpatrick, Nine Mile Point Unit 1, and Ginna is 2.1 GW [2], providing 16,330 GWh electricity per year (which equals approximately 11% of New York's overall electricity demand). Replacing these plants with 100% renewable systems would require either (a) 7.5 GW of onshore wind capacity, (b) 3.7 GW of onshore wind capacity and 4.4 GW of utility-scale PV capacity, or (c) a combination of 3.7 GW onshore wind, 2.2 GW of utility-scale PV, and 2.7 GW of rooftop PV. The decommissioning of nuclear power plants and replacement through renewable energies has been analyzed for other cases as well. In PG&E Joint Proposal Testimony for the retirement of the Diablo Canyon power plant [1], the estimated costs for an alternative, 55% renewable scenario were found to be lower than all of the nuclear scenarios.

The current generation portfolio in New York State (as of 2015) is shown in Figure 1. The most significant capacity is provided by gas fired system (natural gas, landfill gas) and nuclear power plants, followed by hydropower (conventional + pumped) and petroleum liquids.

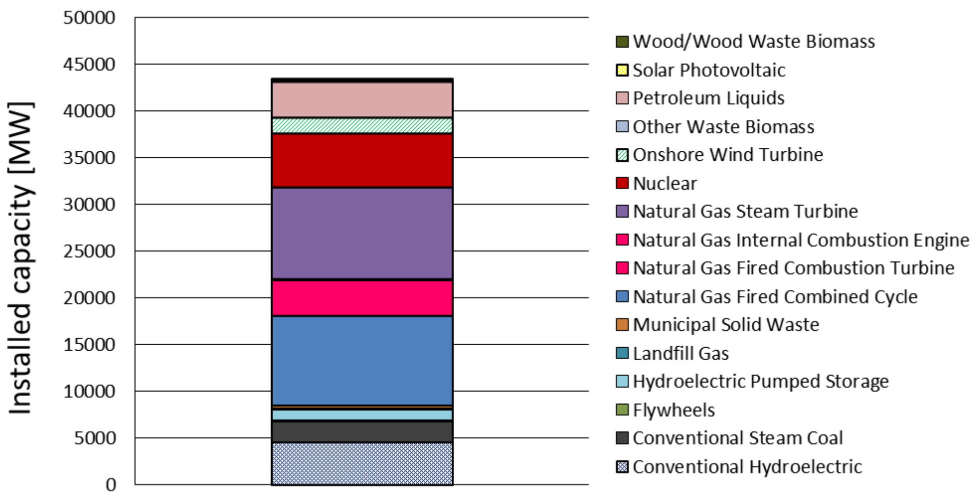

Figure 1: Technology specific installed capacity in New York [2].

2. Scenarios

Scenario 1 ("BAU"): The nuclear power plants Fitzpatrick, Nine Mile Point Unit 1, and Ginna are assumed to stay open from 2016 until 2050. Their annual electricity generation of 16,330 GWh is assumed to stay constant during that period. It is assumed that any alternative scenario[4] (except Scenario 6) has to provide the same electric energy annually. The proposed nuclear subsidy, which runs out in 2028, is assumed to continue at the rate of the last year of the subsidy.

Scenario 2 ("Nuc until 2028"): Nuclear is assumed to stays open until the end of 2028, when the current proposed subsidy runs out, and is then replaced by onshore wind. The installed capacity of wind turbines needed to provide 16,330 GWh/yr with a capacity factor[5] (CF) in New York of 25% (average CF 2013 [7]) is 7.5 GW. The investment for the wind turbines already occurs in 2025 as the construction and planning time has to be considered.

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[4] Except in Scenario 6 where a decrease of the capacity factor of nuclear implies a change in annual electric energy generation.

[5] The capacity factor describes the utilization of a generation technology. It is defined as the potential amount of energy of a generation if operated at nominal capacity for every hour of the year.

Scenario 3 (“Wind”): Nuclear closes as soon as possible (end of 2020) and is replaced by onshore wind. It is assumed that electricity generation from wind power starts in 2021, with the delay due to construction and planning time, while the investment begins to take place in 2017. In that case, the nuclear subsidy continues until the end of 2020.

Scenario 4 (“Wind/PV”): Nuclear closes as soon as possible (end of 2020) and is replaced by wind, utility scale PV and residential rooftop PV (investment starts in 2017, first operating year is 2021). Capacity factors of utility scale PV and rooftop PV are 21% and 17% and based on the 2015 mean values of the lower and upper CF range NREL’s ATB Cost and Performance Summary [9]. 50% of the overall electricity generation (16,330 GWh/yr) is provided by onshore wind (8,165 GWh/yr at 3.7 GW), while utility scale PV and rooftop PV provide 25% each, resulting in a required installed capacity of 2.2 GW and 2.7 GW.

Scenario 5 (“Wind/PV utility”): Nuclear is replaced by a combination of wind onshore (8,170 GWh/yr at 3.7 GW) and utility scale PV (8,170 GWh/yr at 4.4 GW). Wind and PV generation start in 2021. The nuclear subsidy ends at the end of 2020, as with the other cases.

Scenario 6 (“Nuc moderate CF”): This scenario assumes that the 2015 capacity factor (CF) of the three nuclear power plants averaged between 2016 and 2050 (0.91) decreases to 0.85. The rationales behind this assumption is that older nuclear plants require greater maintenance and higher penetration levels of renewable systems imply less utilization of nuclear power. As a consequence, the electric power generation from nuclear declines from 16,330 GWh/yr to 15,316 GWh/yr. In order obtain the comparability to the other scenarios (i.e. same annual electricity generation of 16,330 GWh/yr) the difference (1,013 GWh/yr) is generated by a mix of onshore wind, utility-scale PV, and rooftop PV (231 MW, 138 MW, 170 MW).

Throughout the scenarios a discount rate of 4.5% and an economic life time of 20 years are assumed. Sensitivity tests are run to test the effects of 3% and 6% discount rates.

The following specific life cycle CO_2 emissions are assumed (based on [3,4] and updated values from [5]); nuclear: 66 g-CO_2/kWh_{el}, wind: 10 g-CO_2/kWh_{el}, PV (no differentiation between utility-scale and rooftop): 30 g-CO_2/kWh_{el}.

The temporal sequence of investments and power generation until 2050 is summarized in Figure 2.

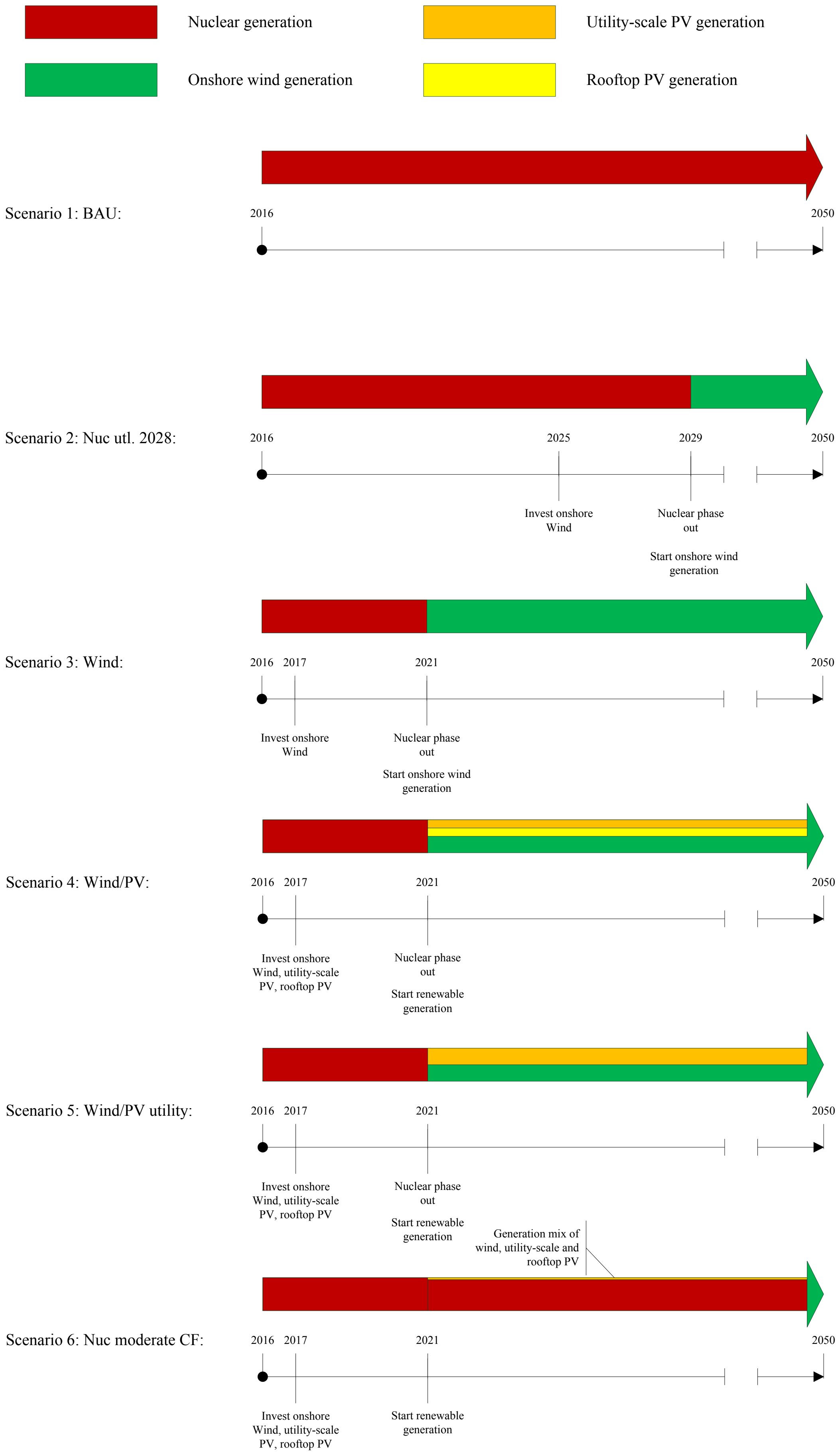

Figure 2: Timeline of investments and power generation of the main scenario.

3. Results

3.1. Cost savings

Figure 3 shows the overall system costs and life cycle CO_2 emissions for each scenario, disaggregated into CAPEX, OPEX, and subsidies for nuclear power. In Section 3.2 a comparison of CO_2 emissions is provided for the case where the costs depicted in Figure 3 are instead invested in additional wind capacity.

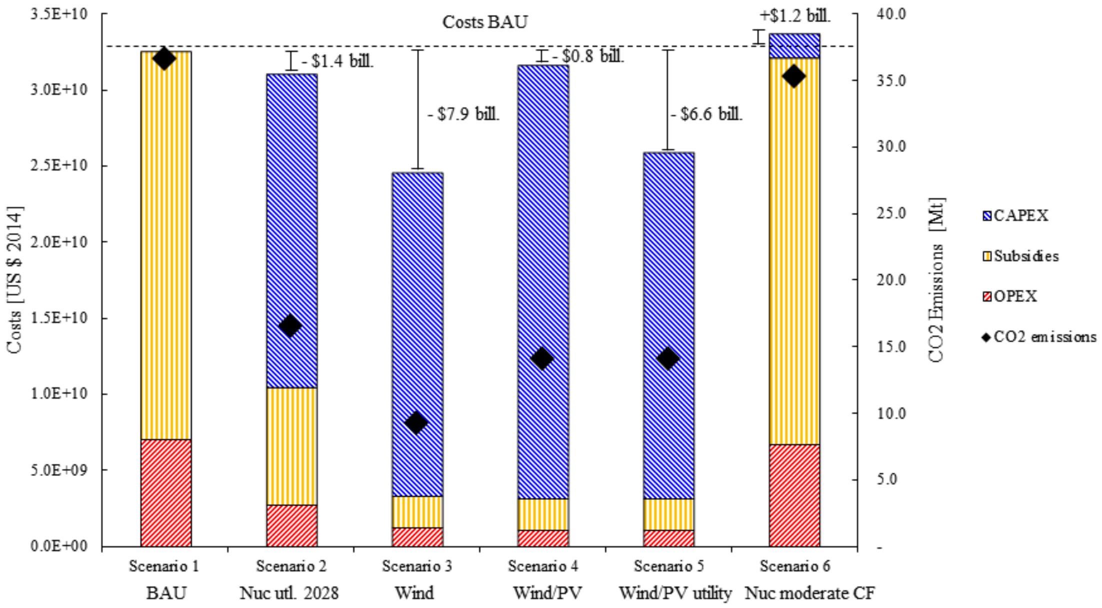

Figure 3: Comparison of all costs (primary ordinate) and CO_2 emissions (secondary ordinate) for each scenario. Operating costs (OPEX) include fuel costs as well as fixed and variable operation and maintenance costs. Subsidies refer to Zero Emission Credits (ZEC) for nuclear power plants. All exact values can be found in Table A.2. in the Appendix.

Scenario 1 ("BAU"): The overall costs are \$32.4 billion (in \$2014), mainly consisting of subsidies for nuclear power. For the first 12 years, nuclear will receive a cumulative subsidy of \$7.6 billion, with increasing yearly amounts, capping at \$805 million/yr in 2028. In this scenario, we assume that, the subsidy continues at \$805 million/yr for the remaining 22 years past 2028 until 2050, totaling an additional \$17.7 billion from 2028 to 2050 or \$25.3 billion (\$7.6 + 17.7 billion) over the entire 34 years from 2016 to 2050. Operating costs, mainly fuel costs, are around \$7.0 billion (22% of the total costs) during this period. The total life cycle CO_2 emissions are the highest among all scenarios, resulting in 37 Mt CO_2 until 2050.

Scenario 2 ("Nuc until 2028"): The overall costs are \$31 billion. Around 66% (\$20.6 billion) are CAPEX of the newly installed wind turbines, while 25% of the cost (\$7.7 billion) is subsidy to the nuclear power plants, which operate until 2028. OPEX account for only 9% (\$2.7 billion). Although the costs do not differ substantial from the BAU costs, this scenario saves 20 Mt of CO_2 emissions until 2050 compared with BAU.

Scenario 3 ("Wind"): This scenario has the lowest overall system cost (\$24.5 billion) and CO_2 emissions (9 Mt CO_2). Most of the cost reduction is achieved by avoiding the subsidy for nuclear power. Some subsidies (\$2.1 billion), however continue during the period between planning and initial investment (2017) and operation (beginning of 2021) of the wind farms. The biggest cost component is CAPEX for the new onshore wind capacities. OPEX are insignificant and consist of fixed operating and maintenance costs (variable operating costs for renewable systems are assumed to be zero).

Scenario 4 ("Wind/PV"): This scenario is only slightly less expensive than BAU, resulting in system costs of \$31.6 billion, saving around \$0.8 billion. The additional cost, compared with scenario 3 ("Wind"), arises due to the lower capacity factor and higher cost of PV (utility + rooftop) versus onshore wind in New York. Yet again, the scenario mitigates CO_2 emissions by 23 Mt (compared with BAU). As for scenario 3, the initial years after the investment into renewable capacities, nuclear power plants still need to be kept online for the duration of the construction time.

Scenario 5 ("Wind/PV utility"): The second least-costly scenario results in system costs of \$25.8 billion, reducing costs by \$6.6 billion and CO_2 emissions by 23 Mt compared with BAU. When compared with scenario 4 ("Wind/PV"), where 25% of the electricity is provided by rooftop PV, the lower CAPEX and higher CF of utility-scale PV leads to lower overall system costs. The total CO_2 emissions are identical, as the same lifecycle emissions per kWh for utility-scale and rooftop PV were assumed (see Section 2).

Scenario 6: Assuming a lower CF of nuclear power plants, while renewable technologies compensate the difference in power generation is slightly more expensive the Scenario 1 (+ \$1.2 billion). However, due to renewable generation, around 1.4 Mt of CO_2 can be mitigated compared to Scenario 1.

3.2. CO_2 savings

It was shown that all renewable scenarios lead to system costs savings. Subsequently, it is analyzed how CO_2 emissions are affected if these savings are invested into additional wind power capacities after 2050. It is assumed that these additional capacities substitute grid electricity with a specific CO_2 factor of 535 g-CO_2/kWh_{el} [6]. Figure 4 illustrates the CO_2 savings of all scenarios compared with BAU with and without re-invest into wind capacities. CO_2 emissions w/o re-invest equal the numbers shown in Figure 3.

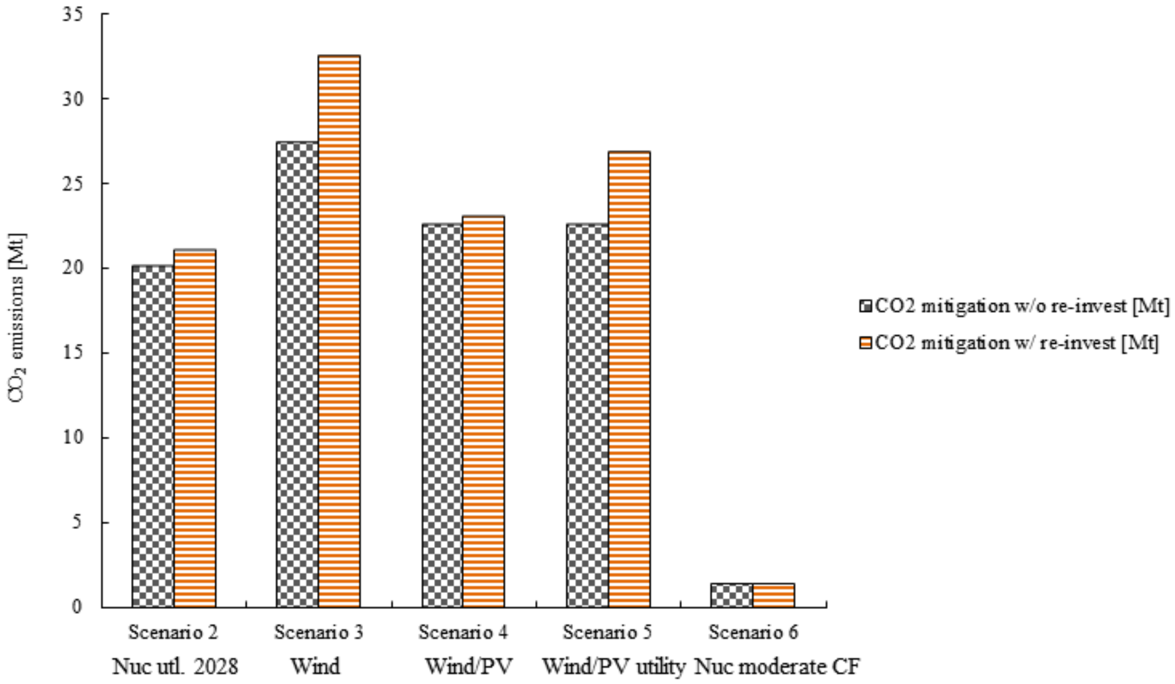

Figure 4: Comparison of CO_2 emission mitigation compared to BAU for each scenario with and without re-invest of the cost savings into additional wind capacities.

The figure shows that re-investing the cost savings into onshore wind can save up to 5.1 Mt of additional CO_2 emissions (compared with the scenarios w/o re-investments). There are no differences in CO_2 mitigation in Scenario 6 since the scenario does not result in any cost saving which could have been re-invested.

Table 1. Assumptions and results with respect to CO_2 emissions if cost savings are re-invested into further wind capacities.

Scenario	Savings [$ billion]	Add. wind cap. [GW][a]	Generation of add. caps [GWh/yr][b]	CO_2 mitig. w/ re-invest [Mt]	CO_2 mitig. w/o re-invest [Mt]	Add.CO_2 mitig.[Mt]
BAU	-	-	-	-	-	-
Nuc until 2028	1.4	0.8	1,776	20.1	19.2	0.9
Wind	7.9	4.4	9,710	27.4	22.3	5.1
Wind/PV	0.8	0.5	1,036	22.5	22.0	0.5
Wind/PV utility	6.6	3.7	8,105	22.5	18.3	4.3
Nuc moderate CF	-	-	-	1.4	1.4	-

[a] Assuming an onshore wind CF of 0.25 in 2050.
[b] Assuming a CAPEX for onshore wind of $1,787/kW based on [9].

4. Sensitivity analysis

The robustness of the results is tested against variations in the assumed discount rates and different capacity factors (CFs) for each of the five main scenarios. Variations in the CF for wind and PV foster a change in the required installed capacities of these technologies (as we require that PV and wind must always provide the same annual electric energy as nuclear, i.e. 16,330 GWh/yr). The assumptions are shown in Table 2.

Table 2. Overview of the sensitivity cases and their main assumptions.

Sub-scenario	Discount rate [%]		Capacity factor [-]		
Reference	4.5	[8], scenario HCLB	Wind:	0.25	Average CF 2013 [7]
			Utility PV:	0.21	Mean 2015 of CF Range [9]
			Rooftop PV:	0.17	Mean 2015 of CF Range [9]
CF low[a]	4.5	[8], scenario HCLB	Wind:	0.22	Scenario LCHB [8]
			Utility PV:	0.18	Scenario LCHB [8]
			Rooftop PV:	0.14	Scenario LCHB [8]
CF high[b]	4.5	[8], scenario HCLB	Wind:	0.33	Mean 2015 of CF Range [9]
			Utility PV:	0.21	Mean 2015 of CF Range [9]
			Rooftop PV:	0.18	Own assumption
Discount low	3.0	Own assumption	Wind:	0.25	Average CF 2013 [7]
			Utility PV:	0.21	Mean 2015 of CF Range [9]
			Rooftop PV:	0.17	Mean 2015 of CF Range [9]
Discount high	6.0	Own assumption	Wind:	0.25	Average CF 2013 [7]
			Utility PV:	0.21	Mean 2015 of CF Range [9]
			Rooftop PV:	0.17	Mean 2015 of CF Range [9]

[a] Due to the lower CF, the following changes in the required capacity occur (assuming 16,330 GWh/yr); wind: 8.4 GW, PV utility: 10.4 GW, PV rooftop: 13.3 GW.
[b] Due to the higher CF, the following changes in the required capacity occur (assuming 16,330 GWh/yr); wind: 5.6 GW, PV utility: 8.9 GW, PV rooftop: 10.4 GW.

The influence of the different CF assumptions on the overall costs is illustrated in Figure 5.

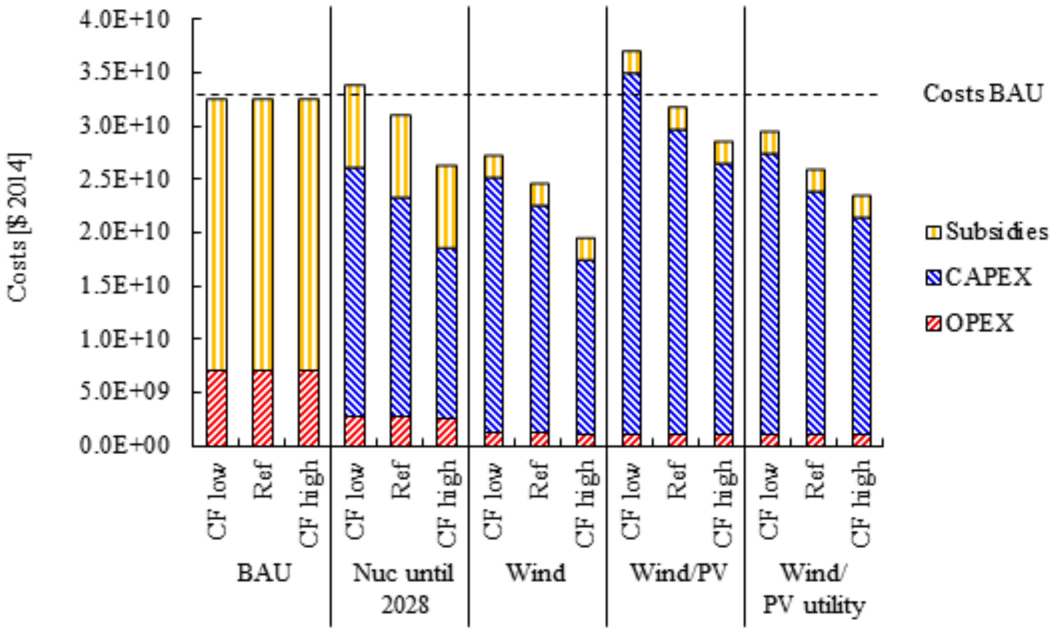

Figure 5: Comparison of the system costs of the four main scenarios with different capacity factors (CF) for wind and PV systems.

Figure 6 depicts the influence of the different discount rate assumptions on the overall costs.

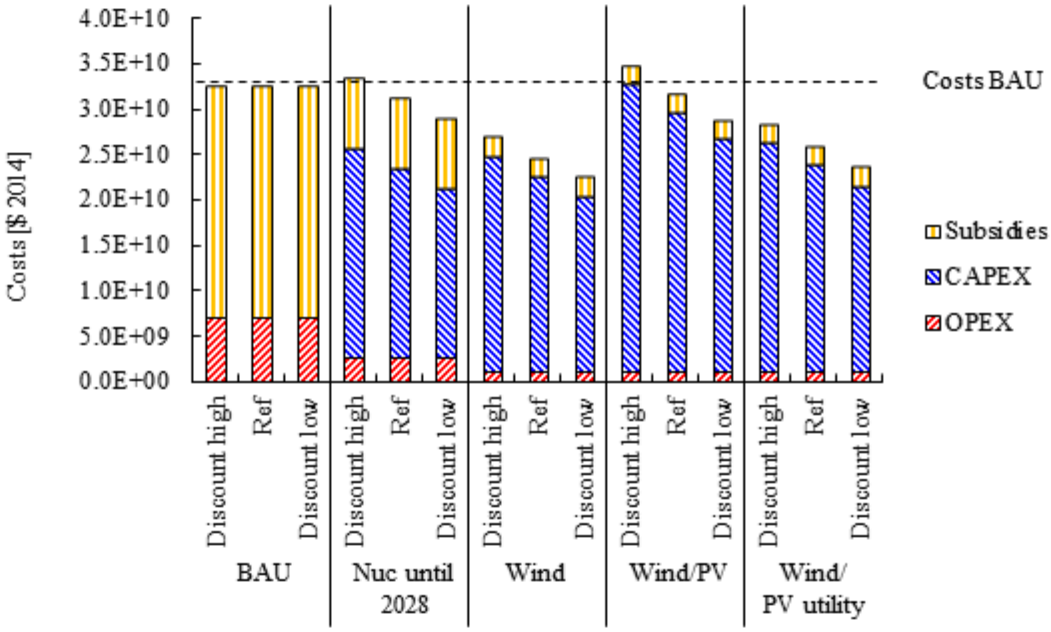

Figure 6: Comparison of the system costs of the four main scenarios with different discount rates for wind and PV systems.

Figure 5 and Figure 6 support that the key result that most of the renewable scenarios are cheaper than BAU. Only if assuming very low CFs or high discount rates, the scenarios 2 ("Nuc until 2028") and 4 ("Wind/PV") will be slightly more expensive than BAU. Yet, scenario 3 ("Wind") and 5 ("Wind/PV utility") will always be less expensive than BAU. It has to be emphasized that all renewable scenarios might be more cost beneficial than depicted in this analysis for the following reasons:

- It is assumed here that the investments of nuclear power plants are fully depreciated.
- We use rather high CFs for nuclear power (0.91 and 0.85 in Scenario 6). However, it is likely that the CF of nuclear will decrease even more with increasing penetration of renewable generation.
- All three nuclear power plants are rather old (Nine Mile: 1969, Fitzpatrick: 1976, Ginna: 1970) and require maintenance, replacement, or retrofit at some point. These costs are not included in the analysis at hand.

Appendix

1. Further assumptions

Projected fuel costs (see Figure A.1.) for uranium are based on [8]. $ 2012 are converted to $ 2014 via a price deflator ratio for electricity costs of 1.031. To conclude from $/MMBtu to $/MWh a heat rate of 10.48 MMBtu/MWh is assumed.

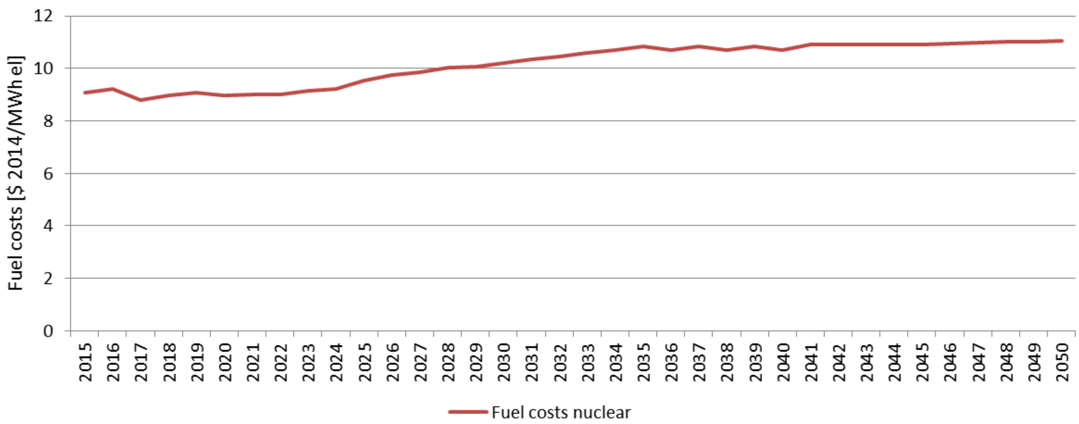

Figure A.1. Fuel cost projections for nuclear power plants.

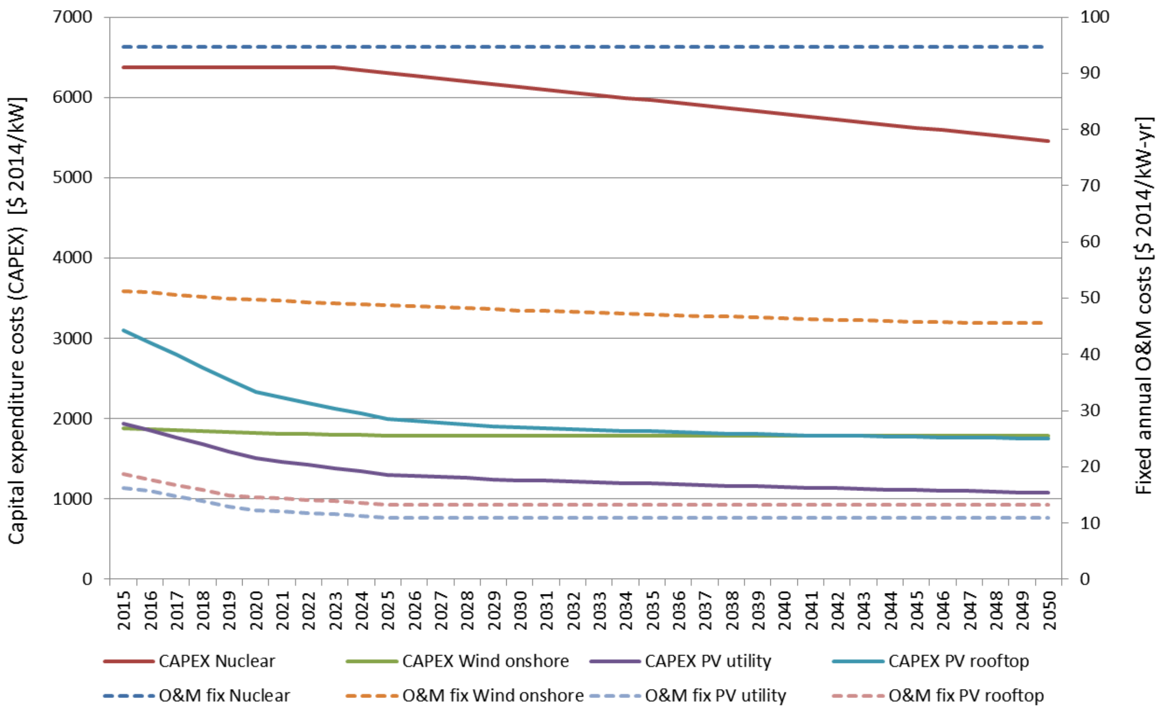

Figure A.2. Cost projections of capital expenditure costs (CAPEX) on the primary ordinate and of the fixed annual operation and maintenance costs (O&M) on the secondary ordinate. Values are based on [9].

Variable operation and maintenance costs for renewable systems (wind onshore, PV utility-scale, PV rooftop) are assumed to be zero; for nuclear power plants $2/MWh were used [9]. The projected fuel costs for nuclear power plants are based on [9].

Table A.1. Cost assumptions of subsidies for nuclear power.

Dates	Upper limit of ZEC [MWh/yr]	Adjusted social costs of carbon (SCC) [$/MWh]	Annual costs	Total costs
04/17 - 03/19	27,618,000	17.70	$488,838,600	$977,677,200
04/19 - 03/21	27,618,000	19.81	$547,112,580	$1,094,225,160
04/21 - 03/23	27,618,000	21.60	$596,548,800	$1,193,097,600
04/23 - 03/25	27,618,000	24.05	$664,212,900	$1,328,425,800
04/25 - 03/27	27,618,000	26.67	$736,572,060	$1,473,144,120
04/27 - 03/29	27,618,000	29.37	$811,140,660	$1,622,281,320
04/29 – 12/50	-[a]	-	$805,000,000	$17,710,000,000

[a] After 03/29 subsides must continue at a minimum rate of $805 million/yr until 2050

2. Detailed results

Table A. 1: Cumulated costs in $ 2014 from 2016 to 2050 of each of the main scenarios disaggregating into the different technology options and cost components.

	Invest. costs [$]	Fuel costs [$]	O&M$_{var}$ costs [$]	O&M$_{fix}$ costs [$]	Subsidies [$]
Scenario 1	-	$5,800,742,600	$1,240,263,500	$189,426,844	$25,887,689,800
Nuclear	-	$5,800,742,600	$1,240,263,500	$189,426,844	$25,887,689,800
Scenario 2	$13,369,721,461	$1,954,374,400	$460,669,300	$528,268,319	$8,177,689,800
Nuclear	-	$1,954,374,400	$460,669,300	$180,921,966	$8,177,689,800
Wind	$13,369,721,461	-	-	$347,346,353	-
Scenario 3	$13,809,662,100	$737,626,100	$177,180,500	$514,261,211	$2,560,740,960
Nuclear	-	$737,626,100	$177,180,500	$162,365,867	$2,560,740,960
Wind	$13,809,662,100	-	-	$351,895,344	-
Scenario 4	$18,487,396,793	$737,626,100	$177,180,500	$399,710,432	$2,560,740,960
Nuclear	-	$737,626,100	$177,180,500	$162,365,867	$2,560,740,960
PV rooftop	$7,656,743,554	-	-	$36,787,825	-
PV utility	$3,925,822,190	-	-	$24,609,069	-
Wind	$6,904,831,050	-	-	$175,947,672	-
Scenario 5	$14,756,475,429	$737,626,100	$177,180,500	$366,831,950	$2,560,740,960
Nuclear	-	$737,626,100	$177,180,500	$162,365,867	$2,560,740,960
PV utility	$7,851,644,379	-	-	$49,218,137	-
Wind	$6,904,831,050	-	-	$155,247,946	-
Scenario 6	$998,801,435	$5,486,482,741	$1,174,279,572	$202,425,326	$25,887,689,800
Nuclear	-	$5,486,482,741	$1,174,279,572	$189,426,844	$25,887,689,800
PV rooftop	$315,126,655	-	-	$2,014,733	-
PV utility	$255,102,530	-	-	$1,347,747	-
Wind	$428,572,250	-	-	$9,636,001	-

Table A.2. Detailed costs (in $ 2014) and CO_2 emissions for each main and sub-scenario. The CO_2 emissions for each sensitivity case do not differentiate, since technology specific, annual electricity generation is identical.

Scenario	Sub-scenario	OPEX [$]	CAPEX [$]	Subsidies [$]	CO_2 emissions [Mt]
Scenario 1	Reference	$7,041,308,249	-	$25,398,851,200	37
Scenario 2	Reference	$2,745,682,445	$20,556,252,732	$7,688,851,200	17
Scenario 3	Reference	$1,212,882,137	$21,232,671,534	$2,071,902,360	9
Scenario 4	Reference	$1,098,331,358	$28,424,795,681	$2,071,902,360	14
Scenario 5	Reference	$1,065,452,876	$22,688,418,697	$2,071,902,360	14
Scenario 6	Reference	$6,674,062,944	$1,535,680,065	$25,398,851,200	35
Scenario 1	CF low	$7,053,485,584	-	$25,398,851,200	37
Scenario 2	CF low	$2,800,417,890	$23,141,494,039	$7,688,851,200	17
Scenario 3	CF low	$1,265,733,750	$23,902,982,130	$2,071,902,360	9
Scenario 4	CF low	$1,142,205,958	$33,636,046,688	$2,071,902,360	14
Scenario 5	CF low	$1,103,524,617	$26,204,920,322	$2,071,902,360	14
Scenario 1	CF high	$7041,308,249	-	$25,398,851,200	37
Scenario 2	CF high	$2,665,525,594	$15,812,502,102	$7,688,851,200	17
Scenario 3	CF high	$1,131,675,519	$16,332,824,257	$2,071,902,360	9
Scenario 4	CF high	$1,055,684,281	$25,320,848,796	$2,071,902,360	14
Scenario 5	CF high	$1,030,349,315	$20,238,495,058	$2,071,902,360	14
Scenario 1	Discount low	$7,041,308,249	-	$25,398,851,200	37
Scenario 2	Discount low	$2,745,682,445	$18,489,735,161	$7,688,851,200	17
Scenario 3	Discount low	$1,212,882,137	$19,098,153,663	$2,071,902,360	9
Scenario 4	Discount low	$1,098,331,358	$25,567,254,450	$2,071,902,360	14
Scenario 5	Discount low	$1,066,392,630	$20,407,554,741	$2,071,902,360	14
Scenario 1	Discount high	$7,041,308,249	-	$25,398,851,200	37
Scenario 2	Discount high	$2,745,682,445	$22,761,382,426	$7,688,851,200	17
Scenario 3	Discount high	$1,212,882,137	$23,510,362,662	$2,071,902,360	9
Scenario 4	Discount high	$1,098,331,358	$31,474,007,122	$2,071,902,360	14
Scenario 5	Discount high	$1,066,392,630	$25,122,272,105	$2,071,902,360	14

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