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Carbon Exchanges and Nuclear Power: A Solution to the Financing Problem?

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Reforming existing carbon exchanges to enable nuclear power plants to earn carbon credits against the greenhouse gas emission they displace could be a simple but powerful mechanism for expanding the provision of low-carbon energy generation. This document describes a simple method to quantify the greenhouse gas emissions nuclear power plants prevent, and to calculate the income earned if regulatory frameworks included their participation in existing carbon exchanges.

Carbon exchanges aim to fund decarbonization projects that capture or avoid greenhouse gas emissions. Many of these projects or activities are not profitable on their own and would not be performed in the absence of economic incentives. However, carbon credit markets can be designed to internalize negative climate externalities, ensuring that polluters help fund decarbonization efforts. By the same token, they allow producers of clean energy to internalize their positive climate externalities, ensuring the contribution they make in the fight against climate change is reflected in their bottom line.

Credits are now commonly used to fund renewable energy projects, such as solar, wind, biomass and hydroelectric generation projects, as well as energy efficiency projects and those aiming to capture and sequester carbon. Although nuclear power plants are the largest contributors to grid decarbonization, no nuclear project currently participates in a carbon exchange. Uniquely among zero-carbon power sources, nuclear power plants are arbitrarily barred from being credited for the positive externalities they generate.

A simple desk reform would reverse this absurdity and mobilize substantial financial resources for deployment of nuclear power around the world. Our analysis shows at least 28% of the value of the electricity a plant generates and up to 180%, in some scenarios. Accruing such credits to support nuclear decarbonization may allow developing countries to leapfrog highly polluting fossil fuel-based energy grids, in a way analogous to how they moved directly to cellphones and skipped landlines.

Methodology

To quantify the carbon emissions prevented by a given Nuclear Power Plant, we begin by establishing the theoretical maximum electricity production of a nuclear power plant, that is, its nameplate capacity.

In a nuclear power plant with multiple reactors each reactor has a *net capacity*, or design maximum output. To obtain the nameplate capacity of the plant, we add the net capacity of every reactor in the plant.

For instance, the Diablo Canyon Power Plant, in California, has two reactors, one with a net capacity of 1,138 MW and another with a net capacity of 1,118 MW. Together, DCPP has a nameplate capacity of 2256 MW.

To arrive at the maximum yearly electricity generation for the plant, we multiply these 2,256 MW by 24 hours in a day, and by 365 days, this is 8760 hours. This yields a theoretical maximum yearly generation of 19,762,560 MWh, or 19.76 TWh. Since the plants power down occasionally for maintenance and unforeseen contingencies, actual generation is always below this number.

For Diablo Canyon, the actual electricity generation in 2022 was 17.63 TWh. Dividing actual generation by the maximum theoretical generation gives us the plant's capacity factor (CF): the ratio of actual to theoretically possible electricity output. This gives us a CF of 0.89 for Diablo Canyon.

To calculate generation from not-yet finished plants, we assume a CF of 0.8. (This is a conservative estimate, unlikely to overestimate actual generation.)

The equation that describes the total electricity generation for a nuclear power plant is:

$$E_g = N_p \cdot 8760 \cdot C_f \qquad \text{Eq 1}$$

Where E_g is Electricity Generated, N_p is Nameplate Capacity and C_f is Capacity Factor. The total electricity generated is equal to the nameplate capacity multiplied by 8760 (24 times 365) multiplied by the capacity factor.

For plants currently in operation, we focus on actual yearly generation. We assume that the generation by the plant replaces an equivalent generation by either coal or natural gas when the yearly generation of a specific fossil fuel is larger than what would be generated by a nuclear plant, since a nuclear power plant generates electricity 24/7 and cannot be compared to electricity generation that is not available on demand, like that from solar or wind, or even hydro depending on seasonal weather patterns.

For grids with more diverse sources of generation (e.g., oil, peat, and biomass) we can also evaluate scenarios where the generation from the nuclear plants replaces a mix of other fossil dispatchable electricity sources. This excludes hydro, since it does not emit significant amounts of carbon. In cases where a plant is already connected to the grid and there is data about electricity generation, instead of these calculations we can directly calculate the decrease in use of fossil fuels after the plant is brought online.

Once we establish the sources of electricity the nuclear plant will replace, we multiply the value of the replaced electricity by their *emissions coefficient*. This is a measure of the mass of CO_{2eq} emitted to generate a unit of electricity.

For instance, to generate one TWh of electricity by burning coal, a coal power plant emits, on average, 924,000 tonnes of CO_{2eq}. The emissions coefficient of a coal plant is therefore 924 gr CO_{2eq}/KWh.

For its part, producing one TWh with a combined cycle natural gas plant emits 521,000 tonnes of CO_{2eq}. The emissions coefficient of a gas plant is therefore 521 gr CO_{2eq}/KWh.

Multiplying these emission factors by the replaced generation for each fuel, and by the fraction of the total electricity generation they are displaced by, adding the resulting tonnes and then subtracting the emissions generated by nuclear generation (12 gr CO_{2eq}/KWh according to the IPCC) gives us the amount of averted emissions by the nuclear power plant.

$$T_a = \sum_{i=1}^{n} E_g \cdot F_{di} \cdot Em_{fi} - 12 \cdot E_g \qquad \text{Eq 2}$$

Where T_a are the total avoided tons of coal, E_g is Electricity generated, obtained from the previous equation, F_d is the fraction of the displaced fuel by nuclear generation and Em_f is the emissions factor of the fuel. For a country with an abundance of coal F_d would be 1 or close to 1 for coal, while for a country with natural gas F_d would be 1 for it. In a case where there are multiple fuels, like Finland, each fuel would have its specific F_d and be multiplied by it.

Finally, we multiply the avoided tonnes of GHG by the price of a carbon credit.
The equation describing this is:

$$R = P_c \cdot T_a \qquad \text{Eq 3}$$

Where R is the total yearly revenue from carbon credits, P_c is the price of the ton of carbon, and T_a the avoided tons obtained from Eq. 2

This price fluctuates, and varies widely between carbon exchanges. For instance, in the European Carbon exchange, the price of the carbon ton in early February of 2025 was above $80, while in the South Korean exchange the price of the ton is about $7. Carbon credit prices depend crucially on the institutional design of the exchanges where they trade.

Case Studies

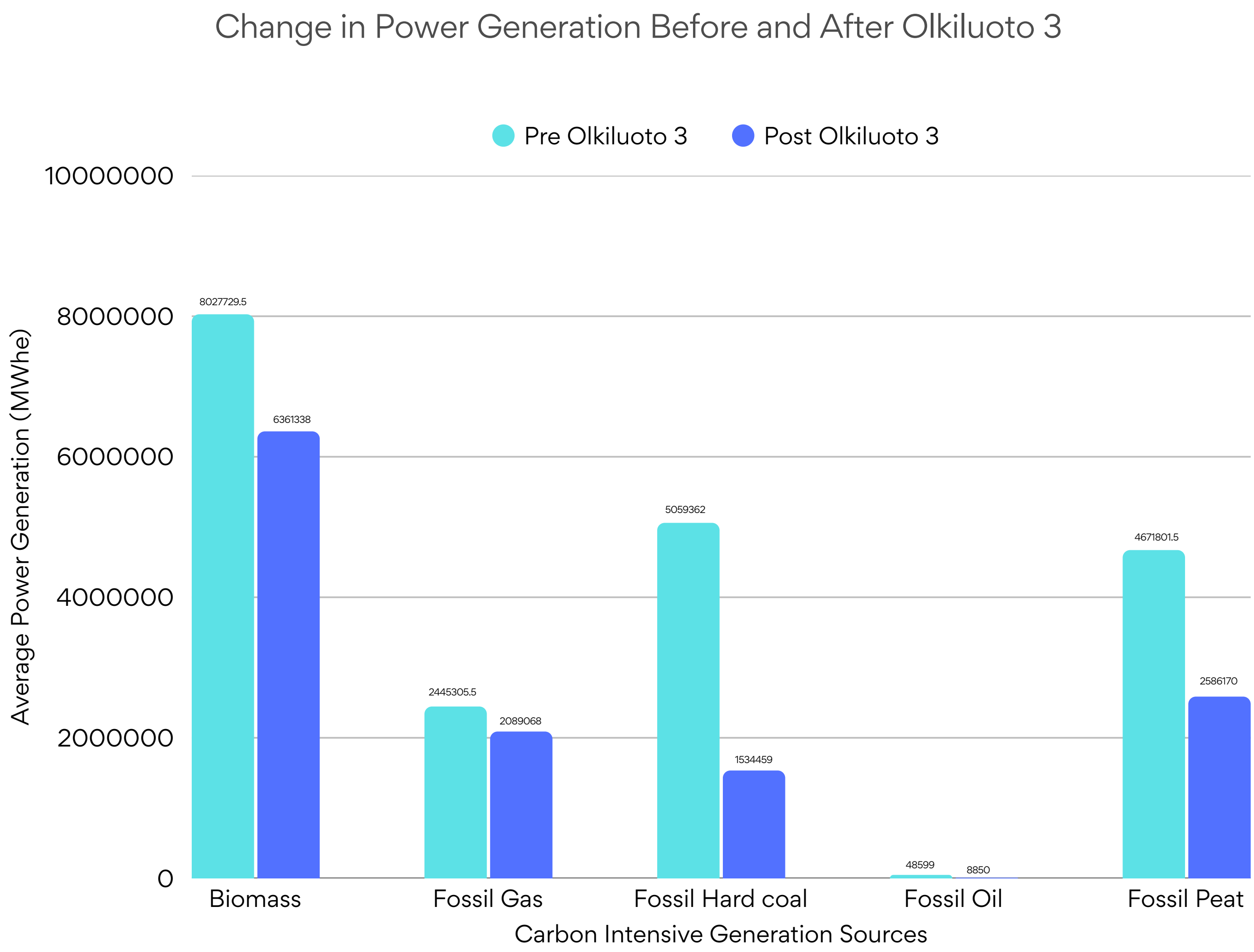
Finland, Olkiluoto-3

Olkiluoto 3 is a Third Generation pressurized water reactor with a nameplate capacity of 1,600 MW added to Finland's generation park when it came online in spring 2023. Together with Olkiluoto 1 and 2, boiling water reactors with a nameplate capacity of 890 MW each, they comprise the Olkiluoto Nuclear Power Plant complex.

Since we have access to the electricity generation data from Finland, we can directly observe the decrease in emissions from fossil fuels in the period immediately before and after Olkiluoto-3 is connected to the grid. In Finland, carbon-intensive generation comes in the form of coal (4%), biomass, peat, fuel oil and natural gas (combined around 15%).

Looking at average hourly power generation before and after Olkiluoto 3 coming online we can clearly see its effects on the generation from fossil fuels:

	Generation Pre O3 (Mwhe)	Generation Post O3 (Mwhe)	Percentage change (%)
Biomass	710.38	562.77	-20.78
Fossil Gas	216.36	184.83	-14.57
Fossil Hard Coal	447.67	135.76	-69.67
Fossil Oil	4.30	0.78	-81.79
Fossil Peat	413.38	228.81	-44.65



We calculated the reduction in emissions between May 1st and Dec 31st 2023, as 4.08 million tonnes. Had these emissions been priced at $30 per ton, the avoided emissions would have generated revenue of **$122.4 million**, nearly 60% of the value of the electricity the plant produced, at the Finnish wholesale price of $43.94/MWh. Calculated instead at the current European carbon exchange price ($86.4), the avoided emissions would have earned **$345.1 million**, around 1.7 times the value of the electricity produced.

Case Studies

Bangladesh, Rooppur

This nuclear plant is still under construction, but using its specs we estimate the GHG emissions Rooppur will avoid, and subsequently the revenue it would generate if it had access to carbon exchanges.

Rooppur has two generators, each one with 1080 MW of net capacity, for a total nameplate capacity of 2160 MW. Assuming a capacity factor of 0.8, the power plant can be expected to generate 15.14 TWh/year.

Bangladesh has a grid mostly based on fossil fuels: according to IEA data, the Bangladeshi energy mix is composed of natural gas (68%), oil (25%) and coal (6%).

If Rooppur's electricity generation decreases generation from coal in an equivalent amount, the avoided carbon from a year's worth of operations should entitle Rooppur to somewhere between **$400 million** (at $30 per ton of CO2 avoided) and more than **$1.2 billion**, calculated at the current European price. The lower estimate is 32% of the value of the electricity produced at Bangladesh's wholesale price of $83/MWh, the higher estimate 96% of the value. Internalizing the carbon benefits of this plant could, in other words, nearly double its gross revenue.

Japan, Kashiwazaki-Kariwa

This plant was shut down after the Fukushima-Daiichi accident and went through security upgrades afterwards. In 2017 it received an authorization to load fuel into the reactors, but it has not been restarted yet. As of 2024, Tepco was in the process of getting authorization from local authorities to restart reactors 6 and 7, but the authorization has not been granted.

The nameplate capacity of these reactors is 2,630 MW, which would yield 18.43 TWh/year at a capacity factor of 0.8. If this electricity replaces coal, which accounts for nearly a third of the electricity generation in Japan (32% according to the EIA, alongside 28.5% of coal, with nuclear, hydroelectric, solar and biofuels contributing the remainder), the value of the avoided emissions from Kashiwazaki-Kariwa is between **$510 million** per year, at a price of $30/ton of carbon and **$1.47 billion**, at the current European price of carbon. This is equivalent to 28% of the wholesale value of electricity that would be produced, at the lower estimate, and 80% at the higher estimate.

Case Studies

Bataan, The Philippines

Bataan is a nuclear power plant that, although finished in 1986, was never started. The combination of post-Chernobyl caution and the association of the plant to an unpopular government kept Bataan off-line. Its single reactor has a net capacity of 621 MW. With a capacity factor of 0.8 would yield 4.35 TWh/year. Since coal is an important part of the electricity mix in the Philippines (around 60% of electricity generation, natural gas 16% and geothermal and hydro contributing the remainder), all the generation from Bataan could replace coal and deliver carbon credits worth between **$350 million and $120 million** per year.

United Arab Emirates, Barakh

Barakh is a complex composed of 4 reactors, each one of 1350 MW, which would generate 37.7 TWh/year at a capacity factor of 0.8. Since the grid of UAE relies mostly on natural gas (composing 81% of the UAE electricity mix, followed by nuclear at 13% and solar photovoltaic at 5%), fewer CO2 emissions are avoided than if the plant had replaced coal generation. Nonetheless, the potential yearly revenue of the carbon credits generated through avoided emissions is still significant, between **$600 million and $1.7 billion** per year.

Case Studies

This table summarizes the potential income from carbon credits for selected plants around the world, showing scenarios for different carbon prices and displaced fuels, it also contextualizes the extra revenue compared to revenue from electricity generation:

Plant	Olkiluoto-3	Rooppur	Kashiwazaki-Kariwa	Bataan	Barakh
Nameplate	1,600	2,160	2,630	621	5380
CF	0.80	0.80	0.80	0.80	0.80
Yearly Production in MWh	11,212,800	15,137,280	18,431,040	4,351,968	37,703,040
Wholesale Price MWh	$43.94	$82.72	$100	$187.60	$80.00
Yearly Value of Electricity	$492,690,432	$1,252,155,802	$1,843,104,000	$816,429,197	$3,016,243,200
Displaced Fuels	Coal, gas, peat, biomass	Coal	Coal	Coal	Gas
Low estimate Carbon Cred	$293,760,000	$400,000,000	$510,000,000	$69,330,000	$600,000,000
High estimate Carbon Cred	$828,240,000	$1,200,000,000	$1,470,000,000	$347,190,000	$1,045,000,000
Low CC/Value of Electricity	59.6%	31.9%	27.7%	8.5%	19.9%
High CC/Value of Electricity	168.1%	95.8%	79.8%	42.5%	34.6%

Obstacles to implementation

There are no technical or scientific obstacles to implement policies that allow operators to earn credits from the emissions their plants avert. The impediment is political: nuclear power has not been traditionally considered a source of clean power and has been arbitrarily excluded by regulations establishing carbon markets.

Recasting regulations to focus specifically on the volume of emissions avoidance would open space to reward nuclear power plants for their substantial contributions to decarbonization, internalizing some of the positive externalities they create. The exclusion of nuclear power as a means to achieve emission reductions can be tracked to COP 7 in 2001, however, with the positive shift in public perception of nuclear power, in the US and globally, this proposal is politically and socially more acceptable than even a few years ago. In addition, the IPCC's scenarios showing the need to triple nuclear capacity to meet climate goals, th green taxonomy of the EU labeling nuclear as clean energy, and the recent announcement from the World Bank to consider lifting its funding ban on nuclear projects add momentum at the institutional level.

An elegant mechanism to internalize positive climate externalities

Enabling nuclear power plants to issue carbon credits on the basis of the CO2 emissions they avoid is an elegant solution to the problem of ensuring electricity markets are properly incentivized to decarbonize. A simple regulatory "desk reform" could generate income that in some cases is worth more than a billion dollars per year. Such reform would transform the economics of nuclear power, and make it accessible even to low income countries currently shut out due to the financing difficulties associated with projects with decades-long amortization schedules.

Inclusion of nuclear as a clean energy source would substantially decrease the expected emissions from developing countries, as most future growth in population, energy consumption and emissions will occur in Africa and Southeast Asia. Countries with a strong industrial base and supply chains will also benefit by making reactors more affordable in the long term.

Revenue earned from nuclear generated carbon credits offers a market-based option for the least developed countries to continue their urbanization and industrialization without significantly increasing their carbon emissions. Even if the income generated through the exchange of carbon credits is not reinvested in further clean energy projects, these resources can be employed in other areas of the economy for further economic diversification, development and growth, like healthcare, infrastructure and education and help industrialize the economy, offering higher value jobs and a swifter path to development.

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Annex

Influence on Capital Cost

Influence on Capital Cost

In this model, we assume a nuclear power plant costing 15 billion dollars, of two reactors, with a total nameplate capacity of 2400 MW, in a grid where it can replace 100% of the generation by coal plants. 50% of the possible income from carbon credits goes to service the debt at a 5% interest rate.In absence of income from carbon credits income, after 30 years, a debt of $8 billion is still remaining. With carbon credits, the debt has been paid in 15 years, paying $4.7 billion, vs $14.9 billion, thus saving 68% in capital cost.

Without carbon credits, after 30 years interest payment on the debt financing of the project would end up being nearly equal to the original investment of 15 billion USD, leading to snowballing that threatens the viability of the entire project.

Parameters	
Nameplate Capacity (Mw)	2400
Capacity Factor	90%
Yearly Electricity Generation (GWh)	18921.6
Total Investment (Millions USD)	$15,000
Debt (Millions USD)	$10,500
Equity (Millions USD)	$4,500
expected debt payment	30
Interest rate	5%
Price of Electricity $/Mwh	$ 40
Emissions Factor	$ 924.00
Unit Cost $/Mwh	$ 25.00
Avoided Emissions (Yearly)	17.48
Price of ton of CO2	$ 50
Income fraction used for debt	50%

Hourly Income
(Millions USD)
$ 0.09

Daily Income
(Millions USD)
$2.07

Total operational Costs
(Millions USD)
$ 197.10

Year 1 (Millions USD)		
	No Carbon Credits Income	**With Carbon Credits Income**
Income from electricity	756.86	756.86
Income from carbon credits	0	437.09
Total Income	756.86	1,193.95
Earning before Interest, Taxes, Amortization	559.76	996.85

Amortization Table (No Carbon Credits) (Millions USD)

Year	Start Balance	Income	Interest	Amortization	End Balance
0	$10,500	$560	$525	$35	$10,465
1	$10,465	$560	$523	$37	$10,429
2	$10,429	$560	$521	$38	$10,390
3	$10,390	$560	$520	$40	$10,350
4	$10,350	$560	$518	$42	$10,308
5	$10,308	$560	$515	$44	$10,264
6	$10,264	$560	$513	$47	$10,217
7	$10,217	$560	$511	$49	$10,168
8	$10,168	$560	$508	$51	$10,117
9	$10,117	$560	$506	$54	$10,063
10	$10,063	$560	$503	$57	$10,006
11	$10,006	$560	$500	$59	$9,947
12	$9,947	$560	$497	$62	$9,884
13	$9,884	$560	$494	$66	$9,819
14	$9,819	$560	$491	$69	$9,750
15	$9,750	$560	$487	$72	$9,678
16	$9,678	$560	$484	$76	$9,602
17	$9,602	$560	$480	$80	$9,522
18	$9,522	$560	$476	$84	$9,438
19	$9,438	$560	$472	$88	$9,350
20	$9,350	$560	$468	$92	$9,258

Amortization Table (No Carbon Credits) (Millions USD)

Year	Start Balance	Income	Interest	Amortization	End Balance
21	$9,258	$560	$463	$97	$9,161
22	$9,161	$560	$458	$102	$9,060
23	$9,060	$560	$453	$107	$8,953
24	$8,953	$560	$448	$112	$8,841
25	$8,841	$560	$442	$118	$8,723
26	$8,723	$560	$436	$124	$8,599
27	$8,599	$560	$430	$130	$8,470
28	$8,470	$560	$423	$136	$8,333
29	$8,333	$560	$417	$143	$8,190
30	$8,190	$560	$410	$150	$8,040

Total Interest Paid
(Millions USD)
$14,893

Amortization Table (With Carbon Credits) (Millions USD)

Year	Start Balance	Income	Interest	Amortization	End Balance
0	$10,500	$997	$525	$472	$10,028
1	$10,028	$997	$501	$495	$9,533
2	$9,533	$997	$477	$520	$9,012
3	$9,012	$997	$451	$546	$8,466
4	$8,466	$997	$423	$574	$7,893
5	$7,893	$997	$395	$602	$7,290
6	$7,290	$997	$365	$632	$6,658
7	$6,658	$997	$333	$664	$5,994
8	$5,994	$997	$300	$697	$5,297
9	$5,297	$997	$265	$732	$4,565
10	$4,565	$997	$228	$769	$3,796
11	$3,796	$997	$190	$807	$2,989
12	$2,989	$997	$149	$847	$2,142
13	$2,142	$997	$107	$890	$1,252
14	$1,252	$997	$63	$934	$318
15	$318	$997	$16	$981	$0

Total Interest Paid
(Millions USD)
$4,786.79

Amortization Table Total Interest Paid (Millions USD)

	Amortization Table (No Carbon Credits)	Amortization Table (With Carbon Credits)
Total Interest Paid (Millions USD)	$14,893	$4,786.79

% Of total interest paid with Carbon Credits

32.14

% Of savings in interest with Carbon Credits

67.86

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