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Uneven Rates of Renewable Energy Deployment: Cannibalization, Stranded Assets, and Policy Iteration

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Abstract: The present study reviews the challenges associated with renewable energy (RE) project development and implementation in an era of rapid technology advancement and of progressively declining equipment prices. Dynamic policy support and institutional strength have helped high-income countries derive the benefits of the economies accruing both from product improvements and process improvements; lower-income, climate-vulnerable countries appear not to have derived such benefits. Study investigates the relationship between RE deployment and socio-economic factors such as the population size, previous fossil fuel use, and economic growth for member countries of the Climate Vulnerable Forum. While these factors have played a significant role in RE deployment in high-income countries, the present study finds that they have no significant correlation with either boosting or impeding RE deployment in the short run for climate-vulnerable countries. Therefore, there might be merit in strengthening external intervention and enhancing support for rapidly building institutional capacity within the "climate-vulnerable" countries to assess context-specific factors and for testing business models that incorporate long-run risk mitigation and management measures so as to promote expeditious RE deployment as a climate adaptation measure within climate-vulnerable countries.

Keywords: negative electricity price, cannibalization, technology and market risk, institutional strength, policy support

1. Introduction

"Disruptive innovations" are known to start within a niche and then to grow "exponentially" to disrupt an entire technological system; importantly, such innovations are also known to create stranded assets [1]. Innovators might benefit from longer use of technologies, while latecomers adopting incumbent technologies might be left with shorter time windows for asset use before the use of such assets is rendered unviable for one reason or another [2]. In keeping with these characteristics of a disruptive innovation, forecasts of renewable energy (RE) capacity addition—or more generally "cleaner energy" technologies—in response to the climate emergency and pursuant to rapid technology development, intrinsically and routinely include a prediction of an increase in fossil fuel stranded assets. The direction and speed of the energy transition away from the dominant fuel source of the era toward the next—and in the present context, relatively environmentally benign source—are therefore, among other considerations, a function of "path dependence" and attempts at delaying the "stranded asset" risk faced by the incumbents [3].

The "Green Paradox" refers to the impacts of climate legislation intended to limit future fossil fuel use including, for instance, offering incumbent investors large incentives to extract more fuels before the regulation limits such extraction. Tighter norms on fossil fuel combustion and the planned end of the "fossil fuel era" had therefore raised apprehensions relating to accelerating fossil fuel extraction and consumption in the short run, referred to as the "green paradox effect of RE" [4], or the "dwindling demand–abundant reserves" scenario [5]. Hansen [6] has observed that the fossil fuel industry had enjoyed greater profit margins than the RE industry over the preceding 10-year period and that these higher profit margins had provided incentives for the fossil fuel firms to impede climate action. Notwithstanding such short-run prospects, by mid-2023 international banks, insurance and re-insurance companies, export credit agencies, multilateral development banks, development finance institutions, pension funds, and asset managers and even central banks had developed formal policies aimed at "leaving fossil fuels underground," restricting investments in coal mining and in building and operating coal-fired thermal power plants, or both [7].

Researchers and policymakers have generally focused on the risk faced by illiquid, partially depreciated physical assets including fossil fuel reserves and the power generation assets that depend on such reserves, especially of coal. Such stranding of assets was projected to affect the largest among fossil fuel—oil, gas, and coal—companies deemed responsible for a significant proportion of human-induced global warming in recent decades. Beyond physical assets, Curtin et al. [8] observe that owners of financial assets could be exposed to risks from lower valuations of coal, oil, and gas reserves held by [relatively undiversified] corporations; however, the understanding of the ultimate impact of such risks on individual financial institutions and on the stability of the

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financial system is limited. An uncoordinated transition to a low-carbon economy and the legal claims that were projected to follow were also expected to impact workers with technology-specific skill sets and entire economies that had hitherto depended on fossil fuel exports [9]. In line with such projections, Jaffe [10] believes that stranding of oil and gas assets controlled by sovereign states—and by extension state-owned entities—could go beyond writing down of valuations and could adversely affect sovereign credit ratings as well: the incentive structures faced by policymakers are quite apparent. The pace of transition to cleaner alternatives might still represent a function of historical fossil fuel use in an economy.

2. Background

Approximately between 2008 and 2015, large numbers of companies within the solar photovoltaic (PV) module production segment, for instance—alongside companies producing trackers, inverters, parabolic troughs, engines, and allied service providers—especially in the US and in the EU area, suffered from high fixed costs and manufacturing over-capacity on the upstream end and price pressures in the international market place on the downstream side. These companies had become insolvent or were acquired at deep discounts largely for the know-how and intellectual property assets they had accumulated. Solyndra LLC, a cylindrical thin-film solar cell manufacturer, was one such company that had filed for bankruptcy in 2011 after availing of USD 535 million in US federal loan guarantees [11].

SolarReserve Inc. faced a similar predicament with its USD 1.0 billion Crescent Dunes solar project in Nevada, USA. The project was slated to be the biggest solar plant of its kind anywhere in the world. Citigroup Inc. and other investors had contributed USD 140 million in funding, while the US government had offered loan guarantees and public land for building the project. By the time the solar-thermal plant with molten salt storage was commissioned in 2015, solar PV modules had achieved far superior price-performance ratios. The Crescent Dunes plant lost its only customer, NV Energy Inc., and taxpayer resources were called to repay USD 737 million in debt[1].

Until about 2015, given the peripheral role of the newer technologies in large parts of the world, scant attention had been paid to the role of RE technology evolution and scale economies in production and the consequences imposed on the RE project assets themselves. For instance, some countries introduced generous subsidy programs for rooftop solar PV installations. With rapid improvements in product efficiency in tandem with declining prices, homeowners chose to replace their rooftop solar arrays after a few years, with several years' worth of life still left in the existing equipment. These partly depreciated pre-used solar PV modules and other system components might continue to operate at marginally lower performance levels relative to new PV modules and other system components. Yet, when the homeowners chose to re-sell the system components and the "pre-loved" solar arrays, such older and marginally less efficient equipment was not always available to buyers at deep discounts relative to newer equipment. This put perfectly functional equipment at a disadvantage in the marketplace owing to the low cost of trading up [12]. Rapidly declining prices and large-scale production are known to take perfectly functional, partially used equipment out of the market and into landfills.

Socio-economic determinants of RE deployment remain unknown. The International Renewable Energy Agency (IRENA) Renewable Energy Statistics 2025 report highlights that RE capacity growth has been unevenly distributed across countries and continents—over 70% of the capacity growth happened in Asia, while regions like Africa lagged behind[2]. Bourcet [13] has reviewed literature to list the determinants of RE deployment and has come up with a list of mechanisms that encourage or impede RE deployment. For instance, RE support policies consistent with the Kyoto Protocol have helped with RE deployment, while lobbying by incumbent energy investors has had a negative effect overall. Curiously, population size has had an overall positive effect. Li and Lee [14] have considered data relating to 20 OECD countries in Europe covering the period 1993–2018 and have confirmed the central role of economic growth and long-run causality leading to RE capacity addition.

The present research work commenced with a simple query relating to the prevalence of negative electricity prices; such pricing was promptly attributed to the limited overlap between generation and consumption and to the limited storage capacity to time-shift the surplus energy generated during times of low demand. The research effort then went on to investigate whether the declining equipment prices had encouraged the rapid deployment of RE across countries more or less uniformly. Evidently, the discovery of negative prices on the markets suggests that capacity addition had exceeded volumes that could stabilize production and supply at a near "zero" positive price. Studies from the OECD are cited and compared with investigations of the factors that might influence RE deployment within the member nations of the climate-vulnerable forum. In an era of rapid technology advancements and declining prices, with such economies-of-experience accruing from both product improvements and process improvements, some countries had not derived the benefits at all. The present study, thus, reviews the possible technical and nontechnical challenges associated with RE project development and project implementation in climate-vulnerable countries. Following this listing of the challenges, based on the author's professional experience as well as from published literature, the present study discusses the uniqueness of the present situation with the urgency in transition mandated by the climate crisis.

3. Literature Review

3.1. Buying time

Fanone et al. [15] have modeled intra-day spot electricity prices while providing for the possibility of negative prices being discovered on the European Energy Exchange covering the French and German markets. The authors observe a correlation between periods of low demand and surplus production—especially from wind farms in Germany. Mulder and Scholtens [16] had, similarly, investigated the impact of weather conditions on day-ahead prices over the time period when RE capacity was being built up in the connected markets of the Netherlands and Germany. The authors had observed that the average wind speed

[1]"A $1 Billion Solar Plant Was Obsolete Before It Ever Went Online," *Businessweek*, January 06, 2020. https://tinyurl.com/4kshsp6j, last accessed May 23, 2024.

[2]International Renewable Energy Agency (IRENA). (2025). *Renewables boom highlights growing regional divide*. https://www.irena.org/News/pressreleases/2025/Jul/Renewables-Boom-Highlights-Growing-Regional-Divide

in Germany had negatively affected Dutch electricity prices. Overall, however, Dutch electricity prices over the time window were driven by marginal costs of conventional gas-fired power plants. De Vos [17] reviews power system operations during periods of low end-use demand ("downward adequacy") and observes that negative day-ahead prices were driven by a combination of low demand and high supply expectations from installed RE capacity. The increasing proportions of lower marginal cost RE capacity and the progressively higher efficiencies at which such capacities operated have worked through the "merit order effect," frequently translated into lower wholesale prices for utilities (but not necessarily lower retail prices for end-users) [18]. Bajwa and Cavicchi[3] report similar observations from California and Texas in the USA and attribute the increase in frequency of negative electricity prices to production-based subsidies that artificially lower energy prices, thereby distorting markets and generating perverse incentives for investors. In Europe, too, there is a rising trend in the number of negative pricing hours in the electricity markets, which has already crossed over 300 h in each of 6 countries [19]. Seel et al. [20] observe that negative prices could serve as markers to indicate the incremental value of additional RE deployment at specific—wind or solar resource rich—locations and to indicate the need for additional transmission and storage build-out on the supply side and for load growth on the demand side.

In response to such observations, financial aid for RE production in Germany is reduced when negative prices are seen persisting for four consecutive hours or longer, though this regulatory measure has been criticized as punishing low-marginal cost RE for the inflexibility of centralized power plants [21]. Further, negative spot prices might be expected to provide storage operations with additional revenues but given the low frequency of such negative prices [22] and given the limits on inter-temporal arbitrage, and given that negative prices have been discovered for merely about 300 h in a year, such negative prices might not impinge significantly upon storage project design, storage technology choice, or storage project financial viability. The progressive addition of storage capacity might itself start the cannibalization process for storage capacity, given that the additional capacity might provide progressively lower marginal benefit and might be left with ever lower arbitrage opportunity to exploit. Simshauser and Akimov [23] have proposed a technology-agnostic policy prescription for dealing with intermittently stranded assets involving temporarily "parking" such excess capacity—analogous to medium-term curtailment—and issuing government–sponsored bonds to finance underlying debt, presumably to lower the overall cost of capital for the temporarily-stranded asset.

Given the evolution in market demand and in [regulated or market-determined] tariffs, the "parked" assets could be "unparked" and brought back online. Scott Cato and Fletcher [24] propose a process of gradual elimination of stranded assets beginning with the most polluting units and other such low-ranking plants and progressively moving along the pecking order to facilitate an orderly transition. This suggestion, however, does not offer a pecking order for phasing out or reviving RE-generating assets of varying vintage. In implementing a variant of this structure, ACWA Power's USD 4.40 billion Noor Energy 1 Concentrated Solar Power plant in Dubai was designed to include 15-h molten salt storage: Dubai Electricity and Water Authority had committed to paying USD 29.00 per MWh between 10:00 h and 16:00 h each day during the 7-month summer season and USD 92.00 per MWh at other times of the day and months of the year. The premium was intended to compensate for the investments made into storage and to ensure the bankability of the composite project asset [25].

[3]"Growing Evidence of Increased Frequency of Negative Electricity Prices in US Wholesale Electricity Markets," *IAEE Energy Forum*, vol. 37, https://www.iaee.org/en/publications/newsletterdl.aspx?id=444.

3.2. Inflexible incumbents and cannibalization

The spot price might continue to guide short-term dispatch decisions as the proportion of variable RE capacity ("non-dispatchable RE") increases within a given energy mix serving a defined market, till such time that storage capacity does not ensure "dispatchability" as a matter of course [26]. Mays [27] argues that spot energy prices might *not be* "volatile enough" to support a theoretically ideal level of efficiency and flexibility in dispatch. In other words, more granular matching of supply and demand should help discover equilibrium prices that truly reflect the value of RE generation. In keeping with the fallacy of composition, Peña et al. [28] conclude that the increase in RE deployment in Spain between 2014 and 2020 had undermined market remuneration for all technologies, with such impacts being stronger and nonlinear as wind energy capacity exceeded 43% of the energy mix. Such volatility in remuneration might impose a self-limiting condition on RE capacity addition and deter further investments ("cannibalization").

However, capital investment decisions might be guided by long-term and stable price levels that might be compatible with ensuring the bankability of such investments. Newbery [29] has argued that in single electricity markets, the *marginal* curtailment of RE generation could be significantly higher than the average curtailment, especially in the absence of system-wide flexibility. The present study reviews the cannibalization among RE assets and offers recommendations to keep RE assets of varying vintage operating in the energy mix. Further, Foster et al. [30] observe that competitiveness of RE generation was dependent on endogenous technological learning (operating and maintenance costs of an onshore wind turbine constituted about 26% the levelized cost of energy), while the cost of fossil fuel generation was determined largely by the price of the fuel itself (operating and maintenance costs of a combined cycle gas turbine plant constituted about 74% of the levelized cost of energy). Large-scale deployment of RE therefore was likely to displace the demand for fossil fuel generation, impacting the price of fossil fuels, which in turn was likely to have a measurable impact on the competitiveness and further deployment of RE options.

3.3. Carbon pricing tools

Brown and Reichenberg [31] observe the likelihood of diminished market values for RE owing to highly correlated generation, the consequent cannibalization of revenues, and the resulting imposition of limits on capacity addition. RE capacity addition beyond such limits might be increasingly attractive for the utilities and the consumers but might be unappealing for potential investors, given that revenues might be below cost-recovery levels at high levels of RE penetration. Brown and Reichenberg propose the use of carbon dioxide (CO_2) taxes to compensate for declining market values for RE with progressively higher levels of taxes to compensate for higher levels of RE penetration, curtailment, and cannibalization. Following the simulation of the energy mix, the authors conclude that if the CO_2 prices were high enough to cover generators' costs, market values of RE generation could remain stable even at penetrations approaching 100%, given sufficient flexibility from transmission and storage capacity within the system. The basis for the computation of the "carbon price," however, is not explicitly mentioned, and the baseline for such assessment is not defined. The observation in itself might be axiomatic, given that RE with adequate storage and transmission is rendered "dispatchable" and the end-use consumers are expected to bear the average system-level costs.

Biggar [32] lists seven issues in energy network regulation including among them the need for "a clearer understanding of the basis for certain financial incentive mechanisms in the regulatory process." In keeping with the theme of internalizing the environmental externality, Liebensteiner and Naumann [33] believe that given the cannibalization effect of RE capacity addition and given the relative unattractiveness of RE investments in the medium term, carbon pricing could drive the wedge between the short-term marginal cost pricing (which at times of surplus supply even turns negative) for consumers and the long-term risk-adjusted returns for investors. The authors model the impacts of cannibalization and confirm that carbon pricing elevated market values of RE. The authors believe that carbon pricing could represent a pathway for RE capacity addition after subsidy and tariff support were phased out in various markets. Given the foregoing, there might also be merit in investigating whether digitalization of the economy may spur RE growth [34, 35], particularly in contexts where institutional research capacity is weak but digital tools can enable newer business models and wider adoption.

4. Methodology and Analysis

Founded in 2009, the Climate Vulnerable Forum (CVF) is a partnership of countries believed to be vulnerable to climate change: as of the end of 2024, the 70 countries that were home to a total of 1.70 billion people were responsible for a mere 5% of global greenhouse gas emissions (https://cvfv20.org/membership/). The present study has examined patterns in RE deployment to assess if RE capacity addition had suffered cannibalization among the CVF member countries. Examination of data patterns published by the IRENA revealed stagnation of capacity addition at low levels in some of the member countries, implying that RE deployment in these countries might not have reached self-limiting levels. The study then assessed if income levels—measured by GDP per capita published by the World Bank—had been correlated with RE deployment in the short run.

Of the sample of 70 countries, a time-series dataset was assembled for a set of 19 countries covering the period 2006–2023, approximately overlapping with the "implantation phase," the "sprouting phase," and the commencement of the "maturity phase" [36]: the 2023 population of these 19 countries ranged from about 5 million in Costa Rica to 247 million in Pakistan. Table 1 presents the results of statistical tests conducted to estimate the post hoc correlation relationship between fossil fuel generation and the change in renewable energy capacity.

1) The statistically significant relationships between income and [non-large-hydro] RE deployment were observed for countries within the 20–50 million population range (year 2023).
2) The study observed a positive *post hoc* correlation between the marginal GDP per capita and the RE [non-large-hydro] capacity addition in Sri Lanka for the same year, though the explanatory power of the variability was just about 23%.
3) The study observed a negative *post hoc* correlation between the marginal GDP and the RE [non-large-hydro] capacity addition in Burkina Faso with a two-year lag, with an explanatory power of the variability at about 31%.
4) The study observed a positive *post hoc* correlation between the marginal GDP and the RE [non-large-hydro] capacity addition in Tunisia with a two-year lag, with an explanatory power of the variability at about 21%.
5) The correlation between the marginal GDP and RE [non-large-hydro] capacity addition in the remaining 16 countries in the sample was not statistically significant.

In studying the short-run impact of previous fossil fuel use published by the US Energy Information Administration on RE deployment, Nepal was dropped from the sample, leaving a net of 18 countries. Table 2 presents the results of statistical tests conducted to estimate the post hoc correlation between fossil fuel generation and marginal GDP.

1) The statistically significant relationships between income and [non-large-hydro] RE deployment were observed for countries within the 10–40 million population range (year 2023).
2) The study observed a negative *post hoc* correlation between marginal fossil fuel use and RE [non-large-hydro] capacity addition in the Dominican Republic with a two-year lag, though the explanatory power of the variability was just about 24%.
3) The study observed a positive *post hoc* correlation between marginal fossil fuel use and RE [non-large-hydro] capacity addition in Sri Lanka with a one-year lag, though the explanatory power of the variability was just about 20%.
4) The study observed a negative *post hoc* correlation between marginal fossil fuel use and RE [non-large-hydro] capacity addition in Morocco in the same year, though the explanatory power of the variability was just about 23%.
5) Marginal fossil fuel use did not appear to be correlated with [non-large-hydro] RE capacity addition in the remaining 15 countries in the sample.

5. Discussion

The benefits of new technology development accrue to society beyond the confines of the narrowly defined boundaries of an innovating company. The price decline accruing from economies of scale and experience, however, is contingent on early-stage, high-priced production and field testing. Having the manufacturing wherewithal and the organizational know-how in place offers producers the option to derive such economies-of-experience at later stages. In some of the high-income countries, such basic research might be undertaken within state-sponsored educational institutions or specially constituted research institutions that are funded directly by taxpayer resources [37]. The benefits from such knowledge accretion might be available to society at large ("technology diffusion"). In lower-income countries, however, where protection for intellectual property might be weak and where universities and research institutions might not be equipped to undertake and implement industry-leading research, such work might have to be funded by and undertaken within industry itself: the knowledge so accumulated by for-profit entities might not be available in the public domain, thereby limiting the prospects for downstream innovation and other spill-over effects. Such research might relate to customizing technology packages and testing market mechanisms or business models and might not necessarily include fundamental research or technology development.

At the time of this research effort, it is apparent that OECD and other markets leading RE deployment had reached such self-limiting conditions of deployment, given the more frequent discovery of negative prices. Subsequent deployment

Table 1
***Post hoc* correlation relationship between fossil fuel generation and the change in renewable energy capacity**

Country	Regression (Coeff, t-stat)	R^2	Regression Lag 1 (Coeff, t-stat)	R^2	Regression Lag 2 (Coeff, t-stat)	R^2
Costa Rica	–0.015 (–0.845)	0.045	0.020 (1.034)	0.067	–0.010 (–0.545)	0.019
Nicaragua	–0.008 (–0.041)	0.000	0.114 (0.624)	0.025	–0.026 (–0.134)	0.001
Honduras	0.288 (0.426)	0.012	0.322 (0.476)	0.015	–0.111 (–0.165)	0.002
Dominican Republic	1.422 (0.944)	0.056	1.364 (0.863)	0.047	–2.942 (–2.150)*	0.236
Cambodia	0.354 (1.347)	0.108	0.231 (0.727)	0.034	–0.365 (–1.169)	0.084
Guatemala	0.064 (0.620)	0.025	0.087 (0.769)	0.038	–0.033 (–0.217)	0.003
Sri Lanka	–0.275 (–0.796)	0.041	0.610 (1.954)*	0.203	–0.573 (–1.807)	0.179
Burkina Faso	0.309 (0.350)	0.008	–1.102 (–1.308)	0.102	0.098 (0.110)	0.001
Morocco	–2.242 (–2.117)*	0.230	–0.694 (–0.567)	0.021	2.012 (1.890)	0.192
Uganda	–0.026 (–0.789)	0.040	–0.011 (–0.325)	0.007	0.025 (0.893)	0.050
Tunisia	3.693 (1.305)	0.102	–0.874 (–0.274)	0.005	1.076 (0.307)	0.006
Colombia	–0.407 (–0.999)	0.062	0.519 (1.247)	0.094	–0.212 (–0.487)	0.016
Kenya	0.074 (0.674)	0.029	0.072 (0.661)	0.028	–0.123 (–1.156)	0.082
Tanzania	0.221 (1.432)	0.120	0.122 (0.733)	0.035	–0.007 (–0.098)	0.001
Vietnam	1.540 (1.324)	0.105	1.837 (1.616)	0.148	–0.951 (–0.827)	0.044
Philippines	0.031 (0.034)	0.000	0.135 (0.163)	0.002	–0.269 (–0.326)	0.007
Bangladesh	–0.643 (–0.424)	0.012	0.374 (0.242)	0.004	1.590 (1.060)	0.070
Pakistan	–1.756 (–0.848)	0.046	0.548 (0.259)	0.005	3.308 (1.705)	0.162

Note: * Significant at 95%.

Table 2
***Post hoc* correlation between fossil fuel generation and marginal GDP**

Country	Regression (Coeff, t-stat)	R^2	Regression Lag 1 (Coeff, t-stat)	R^2	Regression Lag 2 (Coeff, t-stat)	R^2
Costa Rica	–0.368 (–1.381)	0.113	0.274 (0.856)	0.047	0.079 (0.241)	0.004
Nicaragua	–0.211 (–0.385)	0.010	0.595 (1.058)	0.069	0.360 (0.617)	0.025
Honduras	0.771 (0.559)	0.020	–0.108 (–0.078)	0.000	–1.453 (–1.078)	0.072
Dominican Republic	–0.154 (–0.112)	0.001	0.400 (0.291)	0.006	–0.970 (–1.241)	0.093
Cambodia	–1.053 (–0.727)	0.034	1.070 (0.762)	0.037	–0.719 (–0.533)	0.019
Guatemala	–0.295 (–0.440)	0.013	0.930 (1.488)	0.129	0.382 (0.591)	0.023
Sri Lanka	1.450 (2.134)*	0.233	–0.188 (–0.243)	0.004	1.504 (1.867)	0.188
Burkina Faso	1.969 (1.183)	0.085	0.394 (0.227)	0.003	–3.936 (–2.610)*	0.312
Nepal	1.137 (1.221)	0.090	0.656 (0.680)	0.030	0.233 (0.219)	0.003
Morocco	1.137 (1.221)	0.090	0.656 (0.680)	0.030	0.233 (0.219)	0.003
Uganda	0.140 (0.397)	0.010	–0.264 (–0.757)	0.037	–0.385 (–1.135)	0.079
Tunisia	–1.099 (–0.832)	0.044	1.765 (1.357)	0.109	2.510 (1.982)*	0.208
Colombia	1.383 (1.620)	0.149	0.092 (0.100)	0.001	–0.065 (–0.073)	0.000
Kenya	0.501 (0.736)	0.035	–0.203 (–0.348)	0.008	0.444 (0.761)	0.037
Tanzania	–0.089 (–0.255)	0.004	0.003 (0.010)	0.000	0.425 (1.321)	0.104
Vietnam	–1.743 (–0.818)	0.043	–0.348 (–0.189)	0.002	–0.773 (–0.415)	0.011
Philippines	0.170 (0.218)	0.003	–0.154 (–0.211)	0.003	–0.293 (–0.401)	0.011
Bangladesh	–0.912 (–1.336)	0.106	–0.744 (–0.908)	0.052	–0.860 (–1.081)	0.072
Pakistan	0.069 (0.047)	0.000	2.762 (1.891)	0.193	0.332 (0.205)	0.003

Note: * Significant at 95%.

of RE capacity, without the simultaneous addition of storage capacity to time-shift the surplus generation, was likely to progressively reduce the viability of the entire RE fleet. Further, while published literature has listed lobbying by incumbent investors and technical path-dependence of fossil fuels as impeding factors, it was not apparent if previous fossil fuel use had significantly slowed or boosted RE deployment in hitherto fossil-fuel-heavy developing countries. The long-run causality running from economic growth—measured by variability in per-capita GDP—to RE deployment might suggest that the historical consumption of fossil fuels might actually lead to higher incomes, which might eventually lead to RE deployment in the long run. Such linkages have, however, not borne out in the short run either for high-income countries or for the climate-vulnerable countries forming part of the present study.

In Sri Lanka, for instance, the rise in fossil fuel use appears to stimulate [non-large-hydro] RE capacity addition as well, with a lag of one year, while the results are barely of "borderline" significance. In Morocco (same year) and in the Dominican Republic (with a two-year lag), a decrease in fossil fuel use appears to be correlated with an increase in RE deployment. Curiously, the present study has not observed a short-run *post hoc* correlation between incremental fossil fuel consumption and [non-large-hydro] RE capacity addition for the remaining 15 countries in the sample.

Similarly, the present study has also not observed a short-run *post hoc* correlation between incremental GDP per capita and [non-large-hydro] RE capacity addition for 16 countries in the sample. Among the countries where patterns were indeed observed, for instance, in Sri Lanka, the rise in per capita GDP appears to stimulate [non-large-hydro] RE capacity addition in the same year, and in Tunisia, the rise in per capita GDP appears to stimulate [non-large-hydro] RE capacity addition with a two-year lag. However, in Burkina Faso, a decline in per capita GDP appears to be correlated with [non-large-hydro] RE capacity addition, albeit with a two-year lag. The explanatory power of the equation is quite limited, implying that other factors besides income and fossil fuel use might play a major role in RE capacity addition.

Several member countries of the CVF, being developing island nations, are most likely to be endowed with solar and wind resources that might be sufficient to meet demand on individual islands; inland nations in general might also be in a position to deploy RE even if such capacity were to operate at lower levels of efficiency. The group of countries might need to deploy RE technologies expeditiously—particularly solar PV systems and wind energy generators—to adapt quickly to emerging climate patterns, to ensure energy security, and to reduce dependence on imported fossil fuels. However, the factors that boost or impede growth in high-income countries (Li and Lee [14] and Bourcet [13] cited above) do not appear to play similar roles in this group of countries.

6. Conclusions and Recommendations

The prospect of progressively declining market prices for RE equipment—which might consequently motivate end-use consumers to delay their purchases—requires funding schemes within early-adopter countries to be designed to operate project assets of different vintages at levels of indifference to the end-use consumers. In other words, the rebates or buydowns offered to projects at early stages of development would have to continue to keep such plants operating, notwithstanding the prospect of lower prices offered by plants commissioned in subsequent years. Regulators are tempted to design subsidies that decrease over time [38], with higher allocations at early stages to try and stimulate more rapid declines in prices. Later-stage, lower-priced, market-driven deployment is clearly contingent upon the early-stage high-risk funding for research and market penetration during the "implantation phase" [36]. Therefore, the progressively lower subsidies might apply to newer projects, while the older projects continue to run at lower levels of efficiency and at higher costs. Unfortunately, this also represents long-term and potentially sizable payments for early-stage projects that several governments might not be disposed to sustaining, especially in the light of newer projects that might appear more efficient and might require less or no state support.

In developing countries in particular, including CVF member countries like Pakistan, as larger numbers of captive RE plants are built, high energy prices offered by the utilities—and frequent disruptions in supply—provide incentives for consumers to disconnect entirely from the grid. When such defection materializes, fewer consumers are left bearing the burden of paying for the legacy generating plant and, more importantly, paying the costs of building and maintaining the utility grid networks. Curiously, the limited energy storage capacity made available with decentralized RE plant, combined with the economies of scale in installation and maintenance of centralized RE plant, may mean that a large part of the self-generated power might actually be wasted, while the fixed costs of running grid networks might drive a significant wedge between the marginal costs of production and the price paid by end-use consumers leaving everybody worse off[4]. In other words, the consumers utilizing the utility grid network as a "backup" option to the captive generators do not pay the full cost of having access to such a backup, thereby imposing the costs on the marginal consumers not hosting and using captive generators.

In all, the present study has observed negligible correlation between the factors that might have contributed to large-scale RE deployment in high-income countries on the one side and the progressive and largely inertial deployment of RE capacity within the member countries of the CVF. In the near future, research work continuing in this direction could possibly uncover the specific factors that might have impeded the deployment of RE capacity within these countries. Given the limitations in institutional capacity [39], the inability of the state to fund research into business models, and the private sector investors' reluctance to absorb long-term market risks, RE deployment appears to have stalled in the very set of countries known to need aggressive RE deployment to adapt to emerging climate patterns. There might be merit in more intense external intervention and in enhancing support to building institutional capacity within the climate-vulnerable economies and to testing business models that incorporate long-run risk mitigation and management measures. The experience from the OECD member countries suggests that such capacity addition may continue through the decline, till such time that the investors are able to achieve expected returns on investments. This volume serves as a threshold beyond which growth in generation capacity has to be matched by the addition of requisite storage capacity for wholesale prices to begin to rise again.

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Ethical Statement

This study does not contain any studies with human or animal subjects performed by the author.

Conflicts of Interest

The author declares that he has no conflicts of interest to this work.

Data Availability Statement

The data that support the findings of this study are openly available in IRENA at https://www.irena.org/Publications/2025/Jul/Renewable-energy-statistics-2025.

Author Contribution Statement

Sunderasan Srinivasan: Conceptualization, Methodology, Validation, Formal analysis, Data curation, Writing – original draft, Writing – review & editing, Visualization, Project administration.

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