Are electricity markets fit for purpose?

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Summary:
Are electricity markets fit for the purpose of acting as a catalyst to accelerate the clean energy transition? Are they sending the right signals for the massive investments necessary in the energy sector to rapidly scale up renewable energy deployment across the world? The stakes couldn't be higher - urgent and large-scale electrification of all energy use supported by a deep decarbonisation of the electricity sector is essential to mitigate climate change. In this article, we dive deep into the economics of the electricity sector in an attempt to find answers to above questions. We highlight the challenges renewable energy projects face and the role that electricity markets can and must play to facilitate rapid, large-scale decarbonisation of energy systems. Without going too much into technical details, we discuss some policy interventions and market adaptations in broad strokes to overcome these limitations.

Note: *This is a non-peer-reviewed opinion article, i.e., this work has not gone through a scientific review and editorial process. A previous version of this article was published in five parts in author's public blog: Clean Energy For Billions.*
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1 Designed for the past

In July 2024, I stumbled upon an opinion piece by FT's chief economics commentator and eminent financial journalist Martin Wolf, headlined, *Market forces are not enough to halt climate change* (Wolf, 2024). Drawing insights from the latest policy briefs and data showing the recent global slowdown in renewable energy projects, Martin argues that, left to itself, "the energy market alone" will not fix the global failure to incentivise pro-climate growth.

I was intrigued by the argument. Not because I disagreed with it (*and not due to a lack of trying!*), but because it ended on a somewhat hopeless note. Martin concludes that today's geo-political fragmentation at the global stage and domestic populism within countries implies that we (*read*, humanity) lack the courage and conviction necessary to fix the tragic market failure behind the slowdown in clean energy transition. After having spent a large part of my PhD studies thinking about and proposing new market designs and pricing mechanisms in the electricity markets, *specifically to accommodate the challenges that renewables bring*, I couldn't stop myself from reflecting deeply on his remarks.

There has to be a market-based fix to this global challenge, I wondered. A free market is, after all, the best coordination mechanism we have discovered so far to *steer rational and self-interested actors towards building social utility.* That competitive markets, guided by the proverbial invisible hand, are highly effective at organising economic activities such that truthful disclosure of preferences and costs, is not just evidence-backed but even mathematically provable.

When it comes to electricity, the competitive wholesale markets that we know today (mature markets in Europe and North America, for example, and emerging ones such as in India and South America) have followed a series of liberalisation and deregulation reforms of the sector, starting in the early 1990s. The story behind evolution has been well-documented, e.g., see Kirschen et al. (2018). Another example is Green (2008) which provides a succinct account of this historical development anchored in a comparison between the European and North American electricity market design philosophies and how they can be expected to fare in the future context of low-carbon electricity systems.

Our ongoing efforts to achieve the transition of energy systems towards renewable energy sources rely heavily on these market-based activities. However, it is now painfully clear that this transition is not occurring at the scale and pace necessary to reach our climate change mitigation targets (IRENA, 2024b; Ratha, 2025a).

1.1 Cold response to a warming planet

Globally, commercial activities around investments in renewable energy projects are not showing encouraging signs.

For instance, in Denmark, the undisputed global pioneer of wind energy, no bids at all were received for an auction of rights to develop 3 GW of offshore wind in adjoining North Sea (Energistyrelsen, 2024b). This was the first in a series of two auctions of 3 GW each, with a potential for developers to overplant (i.e., exceed the installation goal) up to 10 GW.

This auction series was deemed historic by the auction organiser, Danish Energy Agency (Energistyrelsen, 2024a) for two reasons. First, due to the fact that the total planned installed capacity exceeded the current average electricity demand of the entire country by a long shot. Second, it was intended to open up avenues for electrification of hard-to-abate sectors via Power-to-X, thus significantly boosting the green hydrogen economy in Europe. While the fate met by this auction call was not surprising to many of us who are active in the Danish energy landscape, it undoubtedly (*and thankfully!*) drew attention to a few fundamental questions on the viability of our current approaches to stimulate investment in clean energy which must be addressed urgently (Energistyrelsen, 2025).

Beyond Denmark, recent geopolitical developments have brewed a perfect maelstrom, caused by the pressure in global supply chains and growing uncertainty perceived by the global financial systems, which hinders renewable energy projects from seeing the light of the day. In April 2025, the US Department of Interior issued an immediate stop order to Equinor to halt work on an already-approved, under-construction 810 MW offshore wind project — a project in which Equinor has already spent $2bn and was expecting to start producing power as early as 2027 (Chu, 2025)! Thankfully, the stop work order was lifted later in May 2025 (Equinor, 2025) after extensive dialogue. But not without sending damaging ripples of uncertainty and anxiety across the energy supply chain!

Such a cold (*and short-sighted*) response to a rapidly warming planet brings me to this article, which above all, is an attempt to reconcile the dilemma brewing in my head over the last several months.

It is clear to me that while we have conquered the technological barriers to clean, zero-carbon energy for all, we are losing the battle against economics and geo-politics of the energy transition. And this is a battle we cannot afford to lose — because *electricity generation is by far the easiest and most mature decarbonisation tool we have at our disposal to reduce our carbon emissions as a society.* Deeper electrification of all energy usage coupled with rapid decarbonisation of the electricity system is crucial to ensure the continued prosperity of our future generations!

While I strongly believe that efficient market-based activities are critical to delivery of clean energy to consumers, the more I reflect on the current state of energy markets and on the long-run investment signals generated by them, I conclude that our energy markets are clearly not fit for purpose. The purpose of being a catalyst in enabling the rapid and urgent large-scale transition to cleaner sources of electricity.

And this is not surprising.

> *Designed for a former era of fossil fuels when fuel costs governed energy prices, cracks in the foundational structures of the market design start showing up in the new paradigm dominated by zero fuel cost (and zero opportunity cost) weather-dependent, renewable energy, such as wind and solar photovoltaics (PV).*
>
> *So, what can and must be done about them?*

1.2 Is the price wrong?

One of the works Martin cites in his article is Brett Christophers' recently-published book, *The Price is wrong: Why capitalism won't save the planet* (Christophers, 2024). The book meticulously crafts a rather provocative narrative of how the market-based approach has not and will not lead to reaching climate change mitigation targets, given the technological, regulatory, and financial milieu the electricity system operates in.

Brett's thesis is a demonstration, via a rather sophisticated yet solid, chain of arguments that - *without financial support from governments, renewables have not and will not get built at scale.* In fact, he goes as far as saying that only the state has the financial and logistical capabilities to deliver the trillions of dollars of investment annually needed in wind and solar projects to prevent a catastrophic climate outcome for the planet.

Notwithstanding the clear leftist inclination of the work, I wholeheartedly recommend the book to anyone seeking to understand the nitty-gritty of the geopolitics stifling the global clean energy transition. Personally, the book left a lasting impression on me. In particular, due to the breadth of sources Brett relies upon to drive across the point that current electricity markets are hindering the clean energy transition.

> *What emerges from the narrative is that the failure of markets is so stark and shocking that the very mechanisms we have devised to competitively and efficiently enable the transaction of large volumes of energy are becoming the irrelevant middle person in the transaction between producers and consumers.*

And this is clearly evident from the increasing share of long-term, fixed-price backed Power Purchase Agreements (PPAs) becoming the cornerstone of successful renewable energy projects. Without the revenue stability guarantee provided by such PPAs, investors and banks, having well-meaning intentions to provide the needed financial backing for these large-scale capital-intensive projects, develop cold feet.

To understand why this happens, one needs to dive into the economics of such renewable energy projects. After all, it is the outcome of economic assessments made by investors and banks that ultimately decides whether a project gets built successfully and starts producing clean energy.

This is where we will start in this article. Sections 2 and 3 review the expenses and revenues side of renewable energy projects, respectively. Specific emphasis will be put on the *perceived profitability* of such projects and how that is endangered by the prevalent electricity market designs.

Section 4 explores the microeconomic theory behind electricity markets in an attempt to seek possible answers to why these markets are acting as detractors rather than drivers for such projects while underscoring the crucial role of regulation and policymaking in the clean energy transition.

Section 5 discusses the purpose that energy markets must fulfill to promote investments in renewable energy and outlines a few potential adaptations to the current electricity markets to achieve this objective.

Section 6 concludes the article by highlighting why the discourse around how we trade electricity is of urgent importance and more crucially, why it must migrate beyond the academic and practitioners' circles towards the general public.

2 The incompleteness of LCOE

To explore the expenses side of the investment analysis for renewable energy projects, one starts with Levelized Cost of Electricity (LCOE). Often regarded as a key indicator of the success story of clean energy transition, LCOE has been the metric of choice when it comes to comparing various electricity generation technologies for decades.

Stated simply, it is the *cost (including the cost of capital) in \$/MWh of producing one unit of energy (MWh) from a generator, averaged over its operational lifetime.* Figure 1 shows the evolution of LCOE for various technologies in the US over the last years. This cost evolution follows a similar trajectory in other countries around the world.

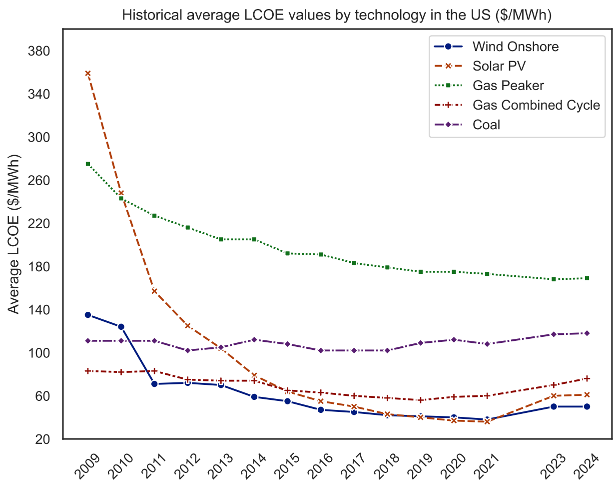

Figure 1. Historical evolution of Levelized Cost of Energy (LCOE) for various energy generation sources, built at utility scale in the US. Data source: Lazard (2024)

As can be seen, LCOE for renewables, onshore wind and solar PV in particular, has fallen drastically over the years and been below the fossil-fuel alternatives such as coal and gas around the world for nearly a decade now[1].

It is therefore established that, from a cost perspective, renewables are already the preferred choice (and will increasingly become so as we start internalising the cost of carbon emissions) for new electricity production projects.

"All else being equal", this cost dynamic should bring a massive impetus for investors and banks to fund new renewable energy projects, right? Why then, one wonders, is that renewable energy projects face challenges?

The answer lies in what LCOE is and what it isn't. And that all else is NOT equal — far from it, actually!

> *While LCOE is a great metric to compare technologies and to track their technological maturity over the years, it is also incomplete and to put it bluntly, misleading, when it comes to investment decision-making.*

2.1 Bountiful, but far, far away

First, LCOE does not include geographical aspects of the costs, i.e., the cost of transporting electricity from the site of generation to consumption.

This is not an issue for fossil fuel-based generators as they (i) typically have a smaller geographical footprint and (ii) are located optimally w.r.t. transportation networks, e.g., road-, rail-, and water-ways to transport the fuel. This layout often coincides with human settlements and demand centres, meaning that fossil fuel-based generators enjoy synergies with the consumption from a geographical standpoint. This is besides the fact that the energy produced is largely controllable and dispatch-able (i.e., can be scheduled ahead of time and adapted to meet demand fluctuations) by adjusting the fuel input.

Renewables, on the other hand, have a much larger geographical footprint and do not enjoy such synergies with existing infrastructure. To make matters worse, sites with high renewable production potential and large swathes of land (cheaply) available are often remote and located far away from the demand centres. In fact, one of the biggest roadblocks (and source of delays) for renewable projects is the development process. This refers to one of the steps before the power plant gets built, primarily concerned with identifying and securing the rights to the land (or seabed for offshore wind) and the necessary permits.

Once that is in place, projects often require a massive build-up of expensive (and unpopular) power transmission lines and upgrades to the existing infrastructure to accommodate the changes in electricity flows across entire countries (or even continents, in extreme cases) to integrate large renewable energy projects to the electricity grid. In some cases (e.g., isolated small grids with weak connections to other grids), the additional infrastructure necessary to integrate renewables may be prohibitively expensive and stall the project after an initial feasibility study.

> *Even for large-scale, interconnected, strong grids, such as, those serving continental Europe and North America, such costs are not insignificant by any means.*
>
> *Critically, they increase as the grid becomes cleaner.*

While a smaller share of weather-dependent renewables in the total generation mix may incur little to no

[1] *And this is no small feat!* Behind the lines in Figure 1, lies the incredible success story of how relatively new technologies transitioned quickly from laboratories to large-scale installations around the world, supported by a mature global supply chain of skills and components.

grid integration costs (since other dispatch-able fossil-fuel based generators can provide the flexibility needed), an electricity grid dominated by such renewables faces high costs to maintain the supply-demand balance necessary for secure grid operation.

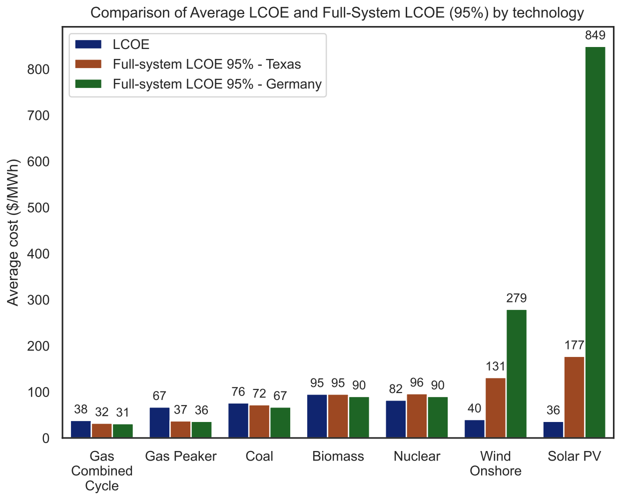

Figure 2. Full-system LCOE for various energy generation technologies compared between Texas and Germany, if 95% of the demand were fulfilled by the technology, with the remaining 5% fulfilled by an extremely cheap, fully-flexible generator. Data source: Idel, 2022.

Figure 2, based on results from Idel (2022), clearly illustrates such hidden costs underlying the LCOE values. *Full-system* LCOE refers to the LCOE value supplemented by the cost of balancing the grid (via the use of storage technologies, for instance) to meet the supply obligation mandated by the demand in the area and therefore, is an attempt to complete the picture painted by LCOE. The number 95% comes from the fact that 95% of the total system demand is assumed to be fulfilled by the technology in question whereas the remaining 5% is fulfilled by the cheapest producer in the system. It shows that considering the overall costs of enabling the consumption of a MWh of energy, given the current paradigm that a consumer may demand that MWh at any time in that geographical region, wind and solar PV no longer emerge as clear winners.

Lastly, the study (Idel, 2022) underscores that even with a 90% drop in the cost of storage, from a full-system LCOE perspective, wind and solar PV remain expensive compared to alternatives.

2.2 Cheap money or expensive money?

The second issue with LCOE, which is perhaps even more relevant from an investment decision point of view, is that it does not capture the *temporal* aspects of the costs.

While the share of capital expenditure (aka CAPEX) in renewable energy projects is roughly 90–95% of the total project cost, it is only 60–70% in the case of fossil-fuel generators. In the case of renewables, most of the large sum of money must be spent on fixed costs, e.g., land, equipment, and labour before even a single MWh of sellable electricity can be produced by the generator. This is not the case for fossil fuel-based generators where operational expenditure (OPEX) forms a larger share of the total project cost, thereby spreading the cost component out over the lifetime of the project.

Now this may not sound like a big deal, but recall that cost of capital is a key component of LCOE.

In simple terms, *cost of capital is defined as the expected rate of return that project developers require to attract funds to a particular project.* It is, therefore, natural that a higher cost of capital would make a project more expensive.

Furthermore, the cost of capital is quite specific to the context of a project. Besides the prevailing macroeconomic factors such as interest rates, other factors such as the technology underlying the project, geopolitical and regulatory environment, energy off-take agreements, etc. play a key role in determining it. Therefore, it varies dramatically across projects and is highly non-standardised. A recent report by International Renewable Energy Agency (IRENA), focusing on renewable energy financing, highlights that even for given a specific geography and a specific technology, cost of capital may vary significantly across projects (IRENA, 2024a). This stems partly from the fact that financial institutions often battle an expertise gap when assessing the risks associated with such non-standardised investments, and therefore, associate varied levels of risk premiums with them.

Revisiting our sombre theme of *"all else NOT being equal"*, renewables face serious roadblocks when it comes to an increase in cost of capital specifically because of the timing of the costs incurred.

Given that the high upfront costs are compensated over a long uncertain duration by the lower (almost zero) operating expenses and the expertise gap faced by financial institutions, renewable projects are qualified as much riskier investments compared to alternatives, as noted in the 2023 commentary (IEA, 2023b) published by the International Energy Agency (IEA). Therefore, investors look for additional risk premiums while injecting funds into projects with renewables. The fact that the time for previously-discussed steps of permitting and grid connection often takes years (IEA, 2023a), adds more uncertainty to such renewable energy projects, thereby further increasing the cost of capital.

This makes the LCOE numbers, such as those shown in Figure 1, particularly misleading since they assume a common discount rate (as a proxy for cost of capital) across all technologies.

2.3 Fake it till you make it?

With such inadequacies inherent to the LCOE numbers, it is quite unfortunate that policy makers and their economic advisors alike, have regularly used (and still use) the downwards trending and seemingly favourable LCOE of renewables to justify the withdrawal of state support for renewables.

While it is a sign of confidence on the technological progress we have made and economies of scale we have reached for renewables, it overlooks the crucial aspects of grid integration costs and the risk perception associated with the costs of such projects. Therefore, recent academic works, such as Emblemsvåg (2025), are calling for a critical rethinking of this misunderstood metric to focus on the full-system costs. Similarly, leveraging an extensive survey study and analysis of the cost of capital across various geographies, Steffen (2020) highlights the importance of understanding the disparities across geographies and involving financing costs as a key policy intervention measure for decarbonisation.

> *This is relevant because, unfortunately for the planet, while policy makers tend to measure the success of their clean energy policies by LCOE, banks and financial institutions do not care much about LCOE (nor for a rapidly warming planet, for that matter).*
>
> *They care about profitability: the expected returns and the risk underlying it.*

3 An elephant called Risk

Besides project costs and the delays in project execution potentially exacerbating those, a key determinant of whether an investment decision regarding a project is successful is how stable the earnings are expected to be.

To illustrate, let's do some role-playing.

3.1 So...tell me, how do you plan to make money?

Imagine yourself walking into a bank seeking a loan.

YOU: "I would like to borrow a million euros for my favourite project."

BANK: "How wonderful! We are here for you, exactly for that. We would love to lend you the money. But first, may we know how you intend to pay us back?"

YOU: "That's great to hear, thank you. So…about paying back, I know that I *"should be"* able to earn money for the hours I work.
But which hours I can work, in reality, depends on the weather; therefore, that is beyond my control. All I can tell you is that for any given hour in a year, there is a one-third probability that I would be able to focus on working."

BANK: "I see. So you will be able to earn money for 33% of the hours in a year?"

YOU: "Ah, I wish that were so…but not really. If the conditions are really great for me to work, then, unfortunately I get paid much less for each hour that I work.
Sometimes, I might even have to pay to work under such conditions. So it might be worthwhile in those periods to not work at all, so I can rest well to work in other periods."

BANK: [*Gasps in surprise*] What!!!

While the above interaction may sound oversimplified, unreal, and downright comical to many, it is unfortunately the meta-conversation in reality when renewable project developers approach financial institutions to raise capital.

To understand why, let's break the conversation down.

First, naturally being weather-dependent, renewable energy sources, such as solar PV and wind, produce energy only when the sun shines or the wind blows. This is measured by a generic, unit-less metric called *capacity factor* of a power plant which is *the ratio of the actual electrical energy (MWh) generated to the total possible generation (MWh), given the size of the power plant in a given year.* Typical values of capacity factors for renewable energy sources depend on site-specific conditions (e.g., how many hours of sunshine it receives, what is average wind speed, etc.) as well as the free transmission line capacity available to off-take the energy generated to sites of consumption. The number 33% mentioned above is just an example, but is not far-fetched for many sites.

Second, in a given market, as the share of renewable energy grows, there's an effect called *price cannibalisation* that comes into play (Ratha, 2025b). This implies that as more renewables enter the market, the average price they receive in the market per unit of energy (MWh) produced by them reduces, i.e., *renewable projects eat into their own profits.* This is because renewables participate in energy markets offering their forecasted energy production at a zero price, since there are no fuel costs associated with actually producing that energy and there is no opportunity cost with not being asked to produce (i.e., when their bid gets rejected by the market).

Lastly, not just the depression of average prices which reduces the expected revenues generated by renewable projects, it's the variability of those prices (and consequently, the revenue) that especially troubles financial institutions.

3.2 A rollercoaster ride into uncertainty

Figure 3, sourced from Nielsen (2023), shows the trends in hourly day-ahead electricity prices in one of the energy market regions in Denmark (DK2), which is surrounded by market zones typically having high share of renewable energy in the electricity mix. It's hard to miss the recent intense increase in volatility of day-ahead prices in electricity markets. This can be explained by Russian invasion of Ukraine in the beginning of 2022 which led to sudden disruption of natural gas supply chain in Europe and consequently, price increases that shook Europe.

While some level of price stabilisation has been achieved since then as the supply chains have adjusted in response to the shock, price volatility still remains quite high, as observed in a recent report on the electricity and gas market developments in Europe produced by the EU Agency for the Cooperation of Energy Regulators, ACER (ACER, 2025).

Figure 4, sourced from the same report highlights the seriousness of this development by showing the share of

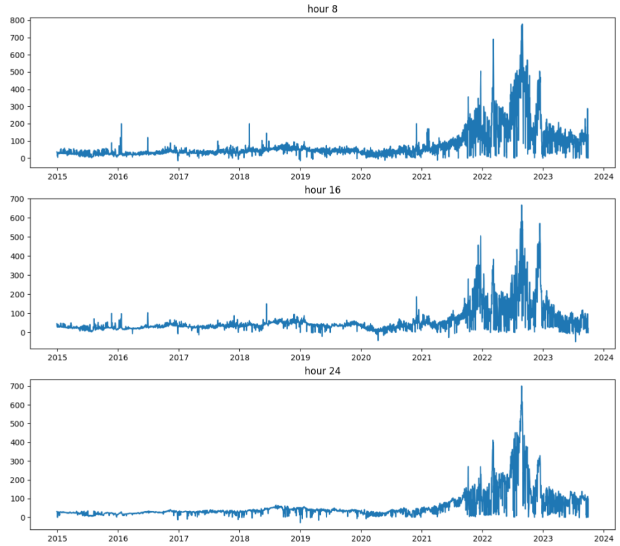

Figure 3. Day-ahead electricity prices in DK2 region in Denmark in hours 8, 16, and 24 from Jan 2015 to Sep 2023. Figure credit: Nielsen (2023). (Re-used with author's permission)

days in the recent years when the day-ahead electricity prices in the hours of the day varied larger than 50 EUR/MWh.

To put this number into perspective, consider that the average wholesale electricity price itself was less than 50 EUR/MWh up until early 2021 in most European energy exchanges (AleaSoft, 2021).

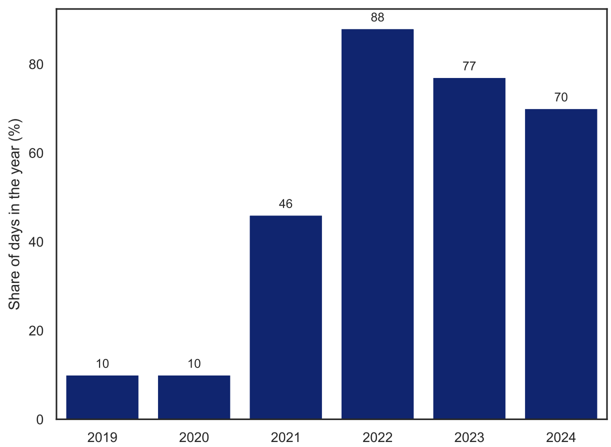

Figure 4. Share of days in a year when prices in day-ahead electricity markets in EU swung more than 50 EUR/MWh within a single day. Figure credit: ACER (2025).

Volatility in electricity market prices is expected to increase as more renewables become a part of the generation mix. In fact, it will be *structural* and *fundamental* to the electricity markets in the near-term. This can be partly explained by extending the example discussed in the context of price cannibalisation effect in Ratha (2025b), as illustrated in the following.

In the hours when sun shines and the wind blows, prices will be very low — in fact, hours with negative prices are growing year-on-year particularly during sunny midday hours as supply massively overshoots demand. Whereas in hours with reduced availability of these resources, prices shoot up as fossil-fuel based generators (mostly gas-fired power plants) with high fuel costs have to ramp up their production to meet the demand. Moreover, as the grid becomes "cleaner", the capacity factor for these generators reduces, which coupled with increasing gas prices, implies that they must bid at very high prices to maintain the same level of returns on investment promised to the asset owner(s).

Other factors contributing to volatility are the increasing coupling among the markets, the lagging growth of flexibility providers in the system compared to the growing share of renewables, etc.

As a result, electricity prices often swing wildly between very low and very high and become highly correlated with weather — which is notoriously difficult to predict accurately. Not to mention the extended periods of windless, cloudy days and nights — so-called periods of *"Dunkelflaute"* in German, which loosely translates to *"dark-lull"* — when reliance on expensive sources of energy becomes critical, given the current absence of long-term electricity storage options.

Due to such price dynamics, the risk associated with uncertain revenues — termed as *merchant market risk*, looms large over renewable projects.

Even typical PPAs written by electricity retailers (utility companies, for instance) to off-take the electricity from such projects are often a lagging indicator of this risk, i.e., they are *marked-to-market.* This implies that there is always some an exposure to wholesale electricity market prices of various degrees associated with such contracts.

Moreover, the underlying contract duration is trending towards the shorter end over the years to reflect the fast-changing trends in average prices — no utility wants to be locked-in for 10 years at a price of 60 $/MWh when forecasts put at least some probability mass on average market prices lingering around 42 $/MWh in 3 years time.

Current geopolitical conflicts around the world further exacerbate the risk woes of renewable projects. Financial support from states and political stability among countries appears shaky as the priority and focus of governments shifts from long-term climate change mitigation to short-term adaptations to the changing world order.

> *Do all of the above imply that buying and selling electricity will always be "risky business" going forward? How does one reconcile this with the fact that electricity demand is projected to (and most likely will) increase significantly in all countries around the world?*
>
> *If this were any other commodity, long-term contracts should ideally be the mechanism by which resellers should be looking to lock-in favourable prices at a time when global (and local) demand to hedge the long-term price risk. Why is it not the same for energy?*

> *Is there something more fundamental at play here?*

4 Is the commodity wrong?

In Sections 2 and 3, we looked at the cost and revenue side of renewable energy projects in detail, highlighting the market developments that create roadblocks for successful renewable energy projects. We covered how energy markets are posing more risk than reassurance to project developers, thus acting as detractors rather than drivers for renewable projects.

In this Section, we will explore the microeconomic theory behind electricity markets in an attempt to seek answers. We will question the very fundamental pillar that upholds energy markets and discuss possible solutions to mitigate their deficiencies.

4.1 Is electricity even "trade-able"?

Given the inadequacies current energy markets exhibit in fulfilling their role in the clean energy transition, Brett Chistophers concludes his book, *The Price is Wrong* (Christophers, 2024) with a radical claim. Brett claims that, in fact, *electricity* as a commodity is *wrong*. He refers to (and extends) Karl Polanyi's argument around fictitious commodities introduced in *The Great Transformation* (Kindleberger, 1974).

The argument is that *electricity*, in addition to *land*, *labour*, and *money* as identified by Polanyi, is a *fictitious commodity*. This argument is based on the fact that electricity traded (in its current form of MWh of energy) has been forcefully commoditised to fit the liberalisation and marketisation agenda in the late '80s and early '90s. The main propeller behind this agenda being the capitalist, neoliberal reforms pushed for by economists in financial institutions such as World Bank and International Monetary Fund.

Whereas, electricity, in fact, exhibits properties of a *necessity good* - one which must be delivered to the public, irrespective of the cost involved, and is therefore, naturally suited to be delivered by tightly-regulated, vertically-integrated suppliers owned by governments. Therefore, Brett concludes that deep and ongoing financial involvement by governments in the energy sector around the world is the only way to decarbonise it at the scale and pace necessary to mitigate climate change.

The way I read this conclusion is that it leaves two viable options on the table: either (i) ramping up of the subsidies and other support mechanisms for renewables (i.e., deliberately and continually overriding the free market dynamics), or (ii) a complete overthrow of the current liberalised energy markets by nationalised, vertically-integrated utilities.

Interestingly, there are some merits to both these options. For the first option, if not for any reason other than the fact that the classical competitors of renewables, i.e., fossil-fuels, have typically enjoyed (*and still do!*) decades of direct and indirect state subsidies around the world. So why shouldn't the same courtesy be extended to renewables?

To justify the second option, one need only consider the reality of how electricity markets truly work in practice. To trade electricity effectively, we must have an intricate and complex structure of regulations governing a multi-layered market structure (involving a combination of futures, spot, balancing, and capacity markets) in place. Looking at such complexity, it would be naive to not question whether all this orchestration reflects our futile attempts to tame an untameable beast.

Ensuring a safe and reliable supply in a complex, interconnected physical system, which does not obey any human-enforced laws for fulfilment of transactions and where physical laws govern the instantaneous flow of the commodity (electricity), raises credible questions of whether we are asking too much of the electricity markets.

That is, irrespective of any shape or form of the market orchestration itself, is it the commodity that is indeed wrong?

> *One must ask, where does that lead us?*
>
> *Is re-nationalisation of our energy system and perennial government subsidies the only way forward to save the warming planet?*
>
> *On the other hand, the industry has expended (and is still expending) massive amounts of resources since the 1990s to prop up a mostly-functional system to organise market-based energy transactions.*
>
> *Is it time to pull the plug on it?*

Not necessarily, at least, in my opinion.

There is a middle ground where free-market capitalism and calls for more regulation can and, I argue, *must* coexist (and cooperate) to make energy markets fit for the purpose of accelerating clean energy transition.

4.2 From cost reduction towards value certainty

First, there must be a fundamental rethinking about what does it take for renewable energy projects to take off the ground in a market-based environment. With that comes the need to assess and communicate the true-cost of a *failed* renewable energy project.

Let me clarify.

Hopefully by now you are convinced that profit (and the perceived certainty of it) governs the growth of renewable energy projects, not the low costs of renewables.

From an individual project perspective, therefore, we must get rid of the prevalent thought process around "*cost of energy production*". While analysing financial feasibility of projects, LCOE should be replaced by a metric representing the "*value of energy delivered*".

We need to leave behind the zealous excitement over the cost-competitiveness at point of generation to adopt a more pragmatic and self-reflective view that focuses on

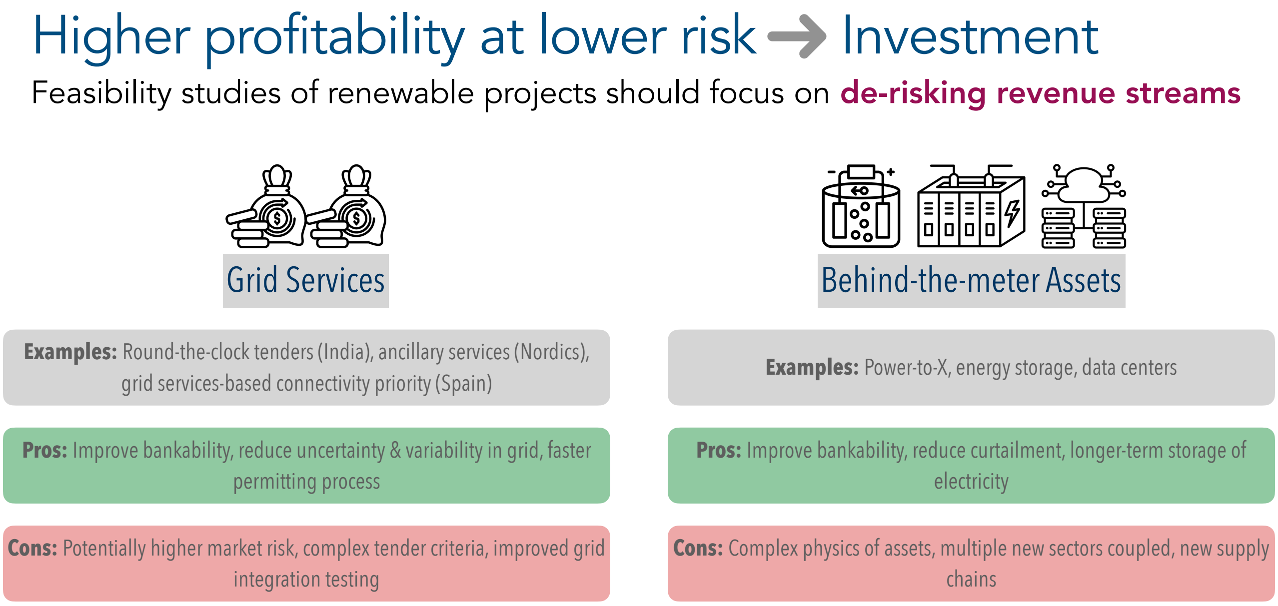

Figure 5. Example of two de-risking pathways available to renewable energy projects, each with their pros and cons. Source: Ratha, 2024

ensuring value-competitiveness at the point of consumption instead.

This implies looking beyond the sheer number of MWh produced, rather focusing on the value that each MWh produced brings at a low risk. This could, for instance, be achieved by extending the conventional revenue streams available to renewable projects (i.e., participation in volatile energy markets or low PPA price lock-in) to provide grid services and adding behind-the-meter assets. This strengthens the revenue prospects significantly, as renewable energy projects are no longer passive, non-dispatchable actors in the market. Rather, they earn additional revenues as active, flexible market participants that actively contribute towards strengthening the electricity grid.

Figure 5 illustrates examples and lists the pros and cons of such value-based de-risking pathways for the development (augmentation) of new (existing) renewable energy projects. As evident from this list, achieving a successful value competitiveness of renewables is a multi-faceted challenge which needs a similar response to address it.

Another critical pathway to increase value competitiveness of renewable energy projects is through energy trading. Energy trading is expected to play a key role, given the headwinds faced by renewable energy projects due to the various geopolitical and regulatory bottlenecks hightlighted in Section 1 and a shift away from long-term PPAs, discussed in Section 3.

Short-term energy trading, both asset-oriented energy balancing and profit-oriented proprietary kinds, can become effective mechanisms to maximise and stabilise operational revenue from energy assets and provide confidence to potential investors on the value of supporting new and operational renewable energy projects.

This could be achieved by, e.g., revenue stacking across markets and products, adopting risk-adaptive trading strategies built upon a foundational understanding of energy markets, and making robust data-driven decisions considering uncertainty and risk. Short-term trading is expected to eventually achieve its full potential in de-risking renewable energy projects, beyond price arbitrage and liquidity provision, to support the clean energy transition.

4.3 What is the cost of energy system transition, really?

Zooming out from individual projects and adopting a systemic perspective, it is crucial that energy academicians and practitioners weave a public narrative that acknowledges and publicly admits the challenges that a renewable-based energy system entails.

Some of these challenges have been discussed in this article, e.g., ensuring adequacy of available energy, controllability of generation for a continuous supply-demand balance, and above all, the requirement of a massive, expensive build-up/upgrade of grid infrastructure, supported by short- and long-term energy storage, to deliver clean energy to consumers all year round. A recent IEA report further highlights these challenges, dividing them into 6 phases of integration of weather-dependent renewables (IEA, 2024).

However uphill a task it may seem, we need to hold constructive dialogues to convince decision-makers and more importantly, the general public to whom they're answerable, that these are existential challenges that we must overcome by *making massive meticulous strategic investments in R&D, public infrastructure projects, and targeted financial support aimed at climate change mitigation.*

Because, contrary to popular belief, doing so makes economic sense right now. And the cost is not just about the cost of renewables, rather the cost of not investing.

Not in the short- or long-term, but in the now!

And it is less relevant a question what form this targeted and country-specific investment (and the regulatory framework underlying it) takes.

Indeed, it matters whether this support takes the form of direct or indirect capital subsidies (e.g., in the US and the UK), an extension of feed-in tariffs (e.g., in China and Germany), double-sided contract for differences (CfDs) to hedge market price risk (e.g., in the UK and soon in DK), socialisation of grid costs (e.g., in the Nordic countries), preferential treatment while integrating renewables to grid (e.g., in Spain), favourable land leases for large-scale renewable projects (e.g., in India and China), research grants to academia and industry for CleanTech breakthroughs, and so on.

The investment mechanisms must be designed to fit the specific needs of individual countries and regions.

But the fact that we need this investment must no longer be debated. Above all, it provides the confidence to all market participants involved that their long-term interests are protected, thus, enabling them to make the "riskier" bets necessary for climate change mitigation!

As a concrete example, one model could be to design incentives for large electricity consumers, e.g., metal and steel industries, data centers, etc. to procure their energy demand from renewable energy projects through (long-term) corporate PPAs, discussed in Section 3. Such a policy framework when implemented with a requirement for *"additionality"*; i.e., demand must be met with new (greenfield) energy projects, will give a massive impetus to de-risking renewable energy projects. This has recently been the case, when massive industrial off-takers with long-term PPAs have repeatedly saved the day for renewable projects. For instance, in case of the Nordlicht wind farm project in Germany, the recent agreement with the chemical giant BASF on a long-term PPA was crucial for the final investment decision to be reached (Vattenfall, 2025) .

Now, this may not work everywhere and at all times. Luckily, we have access to so many investment models that have worked already to support renewables, and we must keep iterating on them to make them even better.

4.4 Regulation: Voice of the future generation

In their recent article titled, *Climate change and growth* (Stern et al., 2023), eminent economists and thinkers Nicholas Stern and Joseph Stiglitz argue that at this juncture, the opportunity costs of taking strong climate actions are especially low whereas the benefits are incredibly high. In other words, it makes macroeconomic sense to invest heavily in climate change mitigation now and that conventional metric of achieving economic growth is in complete alignment with these investment costs.

This is where regulation must step up in its role as a steward of the future generations. Whereas corporate boardrooms see a horizon of a few years, at best, for return on capital deployed, regulators and governments must work relentlessly and ruthlessly to force a longer view on both public and private investments.

> *Once we've rid the air of the grandiosity of renewables and acknowledge that they come with their flaws that we must address by public and private investments, how do we adapt current energy markets to transform them to become drivers of the clean energy transition rather than detractors?*

5 Towards future-ready markets

Given that policymaking must ensure that the necessary investments are made, this Section explores how policy and market design could work together more closely to generate the necessary *"long-run market signals"* to promote those investments.

5.1 Market signals

Market signals commonly refer to the events or trends resulting from market-clearing activities that trigger (by *incentivising* or *disincentivising*) market participants to take any action in the market, e.g., *to buy or to sell and by how much and where to offer or bid*, etc.

Here's a simple example in the electricity context. A *short-run* market signal is the occurrence of high prices of electricity, let's say due to an unplanned outage of a nuclear power plant. This deficit in supply immediately triggers more participants to offer to sell in the next market iteration— which in turn, has the effect of bringing the price down and a stable market equilibrium is reached. Therefore, short-run market signals provide generators and loads incentives to change their decisions today or in the coming week (e.g., when responding to weather conditions, planned grid outages or maintenance, etc.).

In contrast, *long-run* market signals refer to those which guide investment decisions, e.g., *when and where to build new power plants or loads such as data centers or storage units, how to dimension such investments, which technology to prefer*, and so on.

A similar example of a long-run signal is the frequent congestion in the grid connecting, say, two countries, which leads to higher prices in one of them. This incentivises investors to, over time, build new power plants in the country with higher prices. This leads to: (a) increase in social welfare in the long term as consumers in the country pay lower prices, and (b) alleviation of congestion in the grid, thereby deferring the investment costs of upgrading it.

A market signal, both short-run and long-run, is *"correct"* when it aligns the social welfare goals with the rational, utility-maximising goals of individual market participants. Therefore, a correct market signal incentivises participants to act towards improving the efficiency of the market while taking actions towards improving their own profits.

Hence, long-run market signals are extremely relevant when it comes to bringing changes in markets in the long term. Pertinent to our discussion, long-run market signals in electricity markets must incentivise rapid and large-scale capacity growth in renewables.

Referring to long-run market signals in the current energy market paradigm, Conejo et al. (2018) discuss the role of long-term forward (or *futures*) electricity markets in generating them. Purely financial products, i.e., those without any associated expected physical delivery of energy, are traded in such forward market which are settled by financial transactions instead of energy flows.

The primary goal is to enable market participants to hedge against adverse realizations and volatility in the short-term (day-ahead, intra-day and real-time) physical energy markets. A secondary goal is to facilitate long-term capacity planning and investment, by shielding investors from energy price volatility in short-term markets, discussed in Section 3. Large volumes of energy (and energy-based derivatives) are traded in such forward markets, typically with delivery periods up to a few years ahead and through bilateral contracts between buyers and sellers.

However, they suffer from several drawbacks which implies that the above goals are attained to a limited extent. First, such forward markets have traditionally been energy-only and do not have an explicit focus on facilitating new capacity build-up. Furthermore, given the nature of products traded and the primary goal, i.e., hedging against short-term prices, they suffer from liquidity issues as the contract horizons increase. A recent policy paper from ACER (2023) highlights the challenges for new investments in energy, owing to the lack of liquidity in energy-only forward markets beyond 3 years-ahead[2].

In the following, we do not focus on the long-term forward markets. This is reasonable because prices in *energy-only* forward markets are anchored to and move according to the underlying energy prices in short-term markets. Therefore, if prices are *"incorrect"* in those markets, long-term markets cannot be expected to fulfill their objectives fully.

In other words, the above approach implies that policy interventions and market adaptations proposed in the following operate under the paradigm that marginal prices arising from clearing of short-term electricity markets are responsible to generate the long-run signals, such as discussed in the congestion example above.

5.2 Uncertainty and risk mitigation at the core

Given the market deficiencies we've discussed so far, several academic and non-academic voices have recently raised the topic of a possible redesign of energy markets necessary for a renewable future. Such works have been covered by Pinson (2023), which addresses the question of how future electricity markets may look like, from a well-rounded socio-techno-economic perspective and provides several interesting recommendations.

Of particular relevance to our topic here, is the recommendation that *electricity markets should go from the current deterministic market-clearing practices towards a more stochastic approach.*

What does that mean?

It implies that uncertainty and variability, inherent to the power produced by weather-dependent renewables, is accommodated in the market not via ad hoc patch-fixes as is the current norm, but should instead form a structural element of the price formation process itself.

The risk arising from the uncertainty and variability is, therefore, priced into the market-clearing process. For instance, Ratha et al., 2023 proposes a multi-commodity and multi-period day-ahead electricity market that not only clears quantities of energy (MWh) to be traded, but also flexibility products, e.g., *"contracts"* that flexible producers and consumers can enter into to provide response to forecast errors during real-time operation next day. These additional commodities (flexibility products) are priced according to a competitive, spatial price equilibrium framework, i.e., at periods and locations where less flexibility is available, the price of these flexibility products is higher (thereby, sending the correct long-run market signals for investment in flexible resources e.g., energy storage) and vice-versa.

The fact that flexibility products must play a crucial role in the grids with high shares of renewable energy is highlighted the recent report (Energinet, 2024) published by the Danish Transmission System Operator (TSO), Energinet.

5.3 Bidding of firmed supply: A hedging tool?

Additionally and perhaps more fundamentally, one must pose the question whether pricing electricity based on marginal (fuel) costs is compatible with a future where the energy system is dominated by renewables which not only have no fuel costs but also no opportunity costs.

> *What is the marginal cost of power production from a wind farm or a solar PV park?*
>
> *Without the fuel used up to produce that unit of energy, could it be a combination of the "cost of capital" and the "cost of supply firming"?*

Here *supply firming* refers to the operation of flexibility provider, e.g., energy storage unit or demand response aggregator, that is on standby to step in to produce/consume depending on whether the renewable power producer under-/over-shoots the predicted production. While cost of capital is fairly easy to calculate, how does one quantify the cost of firming? The answer to this may lie in a redesign of the energy markets, as illustrated in the following.

Firmed supply bidding into the market can potentially lay a key role in a future energy market and enable a market-based discovery for the price of firming.

[2]One solution approach is to supplement the existing markets with an additional layer of auctions-based forward capacity markets (Bhagwat et al., 2017) with the specific intention to provide guaranteed capacity payments to new investments, e.g., such as those implemented by the system operator, ISO New England (England, 2025).

It could generate the correct long-run investment signals for flexibility providers to ensure renewables can *"truly replace"* the dispatchable fossil-fuel based power producers[3].

Incorporating firmed supply bidding into electricity markets could take several forms; three of which are briefly outlined in the following.

Hybrid and virtual power plants: One possible adaptation to the energy markets is to enable new flexibility-centric market participants such as wind-solar-storage hybrid power plants, power-to-x hybrid power plants, virtual power plant aggregations, demand response aggregations etc. to bid while expressing their full range of operational feasibility and therefore, their ability to deliver a firm supply. This would require a significant change to the market-clearing algorithm and the bidding framework.

Such hybrid power plants essentially act as a *physical hedge* against adverse renewable production forecast realisations, while additionally bringing new revenue streams to the renewable projects, as discussed in Section 4. More importantly, they help alleviate the high price volatility, thus bringing revenue stability for renewable energy projects. As an immediate effect, one can expect occurrences of negative prices and curtailment to become less frequent, which will be a great booster for profits of renewable energy projects.

Uncertainty-aware market-clearing algorithms: Another possible incorporation of firmed supply bidding could be the adoption of market-clearing algorithms that endogenously consider uncertainty and perform a joint clearing of energy and flexibility, as discussed previously. In such a future market, renewables may be mandated to hold physical trade positions that stack up to a firmed supply delivery across the various jointly-cleared market products. Several academic works have delved deeply into such market redesign proposals in recent years; a survey can be found in Silva-Rodriguez et al. (2022).

Mandated flexibility procurement: Lastly, without necessitating a complete overhaul of the market-clearing algorithm, firmed supply bidding could be implemented within the existing market framework via regulation-mandated and location-specific flexibility procurement linked to renewable production bids.

In such a future, renewables are responsible for and are explicitly charged for (preferably in a market-based price discovery framework) firming their production to match their energy market bids. They would be required to participate in *flexibility trades* (and incur risk payments associated with those), where they take positions based on their confidence on forecast accuracy, i.e., asymmetric positions of over-/under-production estimated by them are matched by the flexibility trades they undertake.

Flexibility trades, in the above context, behave similar to a combination of *state-price securities* or *Arrow-Debreu securities* of some form, which have been used in the financial markets for a long time as effective risk hedging instruments. This is particularly relevant and has strong foundations in microeconomic theory, since for an energy system dominated by weather-dependent producers, internalising the forecast risk is an essential contributor to reach *completeness* of the market. In the long-run, such a market sends signals that eventually penalise the risk payments, i.e., incentivise investments in improved production forecasting methods, which, in turn, improve the overall social welfare.

Needless to say, the adaptions discussed above are incomplete, non-exhaustive, and need further evaluations. Besides the role of flexibility and firmed supply bidding, the survey by Zhou et al. (2025) provides an account of the challenges, recent works, and the open research questions on market redesign and price formation in the new paradigm of energy systems, primarily composed of zero-marginal cost power producers.

Now that we have discussed a few possible pathways to enable energy markets to become future-ready (or rather, just *"catch up"*, because a renewable-dominant energy system is already a reality in several geographies), let's reflect on the relevance of this topic to conclude.

6 Bitter pills for a healthy future

Recalling the role of markets in steering rational and self-interested actors towards building social utility as discussed in Section 1, it is necessary to elaborate the other facet of that story here.

It is also well-known that markets are typically not great at accounting for long-term risks, i.e., rational and self-interested market participants act while excluding such risks from their decision-making, since the impact of such risks on their current utility is negligible, when considered time discounted over the long term.

Adverse impacts of climate change, which poses a long-term socio-economic risk, are often neglected in the decisions made by actors in capitalist markets. Therefore, if energy markets have to facilitate the transition to cleaner energy transition, they have to be designed not only with carrots (financial support) for renewable energy but also have proverbial stick (taxes) for fossil-fuel based energy sources. This could, for example, take the form of a carbon tax which is levied on all goods and services based on the emissions incurred in delivering them. Undoubtedly such a step is bold and has been talked about for several years now and requires a global consensus to be built for it to be effective.

However, above all, it requires tremendous courage and conviction from general population — the willingness to sacrifice short-term utility to preserve the long-term health of our planet.

[3] This is relevant because renewable power producers are already (or will soon be) *balance responsible*, i.e., they will be required to inject into the grid exactly as much as they had previously bid and were cleared by the market, otherwise face penalties. This paradigm shift is well-supported by firmed supply bidding, since it contributes to internalise the negative externality of uncertainty and variability of renewable energy.

> *We must agree and accept as a society that consuming goods and services, that are cheap in monetary terms, but whose bill of the associated carbon emissions is charged forward to the next generations, is not sustainable. Bitter pills and compromises must be swallowed by all of us to ensure a healthy future for our planet.*

How do we put that into play? First comes awareness, and with it comes action. We must make our local leaders and decision-makers accountable for climate change mitigation steps; ensure that our planet's long-term future must always be a part of the agenda, irrespective of the short-term issues facing us.

Ultimately, given that societal de-growth is unpalatable to almost everyone, the only solution we have is faster decarbonisation, driven by a massive upscaling of investment in renewable capacity growth. For that to happen, we have to urgently start treading along one of (or a mix of) the two paths: either we correctly internalise the price of climate change externality in all our economic decisions as individuals and economies, or we welcome regulation that overrides the shortsighted profit-seeking behaviour that is characteristic to actors in market frameworks.

Call me ruined-by-education, but I would much rather prefer only the first solution. And I believe with an open and constructive dialogue among all stakeholders involved, we can get there.

We must. We cannot afford not to.

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