

The Struggle to Achieve Net Zero Emissions

– While Balancing Security, Affordability and Sustainability

“It costs a lot of money to look this cheap.” – Dolly Parton.

In early 2021, we published a White Paper on the energy transition, arguing that although it was possible to reach the target of net zero emissions of greenhouse gases by mid-century, the current policy pathway would not get us to the target. In this and a follow-up white paper, we will update our outlook on the path to net zero and share our views on what’s needed to get back on track, as well as any relevant investment implications.

Key Insights

- *Despite rapidly rising investments, the decarbonization of our energy systems continues to progress too slowly. The transition is failing because the chosen strategy is not aligned with the Energy Trilemma constraints of security, affordability, and sustainability.*
- *Focusing solely on solar and wind will not get us to the net zero target. Measured in primary energy terms, renewables have very low power density, and therefore, solar and wind should only be used for direct electrification where the energy losses are lowest.*
- *Taking intermittent¹ electricity production above a certain threshold in the grid leads to rising electricity prices and instability and potential blackouts of the grid.*
- *Underinvestment in primary energy will lead to energy scarcity, and the poorest part of the global population will pay the highest price in capped human development.*
- *Inequality in access to energy is probably the most significant human development issue.*

Morten Springborg,
Global Thematic Specialist,
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“We should not blindly pursue short-term CO₂ reduction targets, which can only be met at excessively high costs to our societies.”

In this paper, we will begin describing our predicament today, and in a follow-up paper, we will focus on the solutions: Diversified energy systems, technology, and improved energy efficiency. Advanced nuclear fission, and fusion from the 2030s, as well as nature-based carbon sinks, natural gas, and energy efficiency as described in our White Paper from 2021. We should not blindly pursue short-term CO₂ reduction targets, which can only be met at excessively high costs to our societies; the price is long-term decarbonization, and there will be a hockey stick development when the right technologies are available.

Why is the energy transition failing

From Main Street media to academia and Wall Street brokerage research, an unrelenting chant has been heard for years: wind and solar are the cheapest forms of electricity. In more technical terms, solar and wind are claimed to have the lowest “levelized cost of energy”

(LCOE), and therefore transitioning to a renewable-based energy system is not only good for the environment but also good for the economy as it lowers the cost of energy. Politicians, NGOs, and, importantly, more and more dominant “green companies” have been claiming this so loudly that arguing the opposite has become highly controversial. Canceled off-shore wind auctions, declining share prices of renewable energy companies, and the extremely volatile – and over time - higher electricity prices and degraded grid reliability almost everywhere where wind and solar have achieved meaningful market penetration have gone almost unnoticed by this green agenda.

Our point of view is “everything in moderation,” including wind and solar power, which, although they are important components in a diversified energy system, can’t be the pillars on which a modern society bases its energy system.

¹ Any source of energy, for example, solar or wind, that is not continuously available for conversion into electricity

One comes to think of the “Dead Parrot Sketch” from Monty Python’s Flying Circus: “The parrot is dead, no it’s not, is just sleeping.” Today’s relevant version of the sketch would substitute “parrot” with “wind and solar are the cheapest forms of electricity.” Let us uncover why this narrative is so faulty.

The Energy Trilemma

The energy transition must be analysed in an Energy Trilemma framework: decarbonizing our energy system must happen under the constraints of security, sustainability, and energy affordability. If the energy transition cannot deliver abundant, inexpensive, and secure energy to a growing population, economic development will suffer, and support for the transition will evaporate. Unfortunately, the transition is failing despite the urgency to reduce carbon emissions. This is because the chosen strategy is not aligned with the Energy Trilemma constraint due to:

“The energy transition must be analysed in an Energy Trilemma framework.”

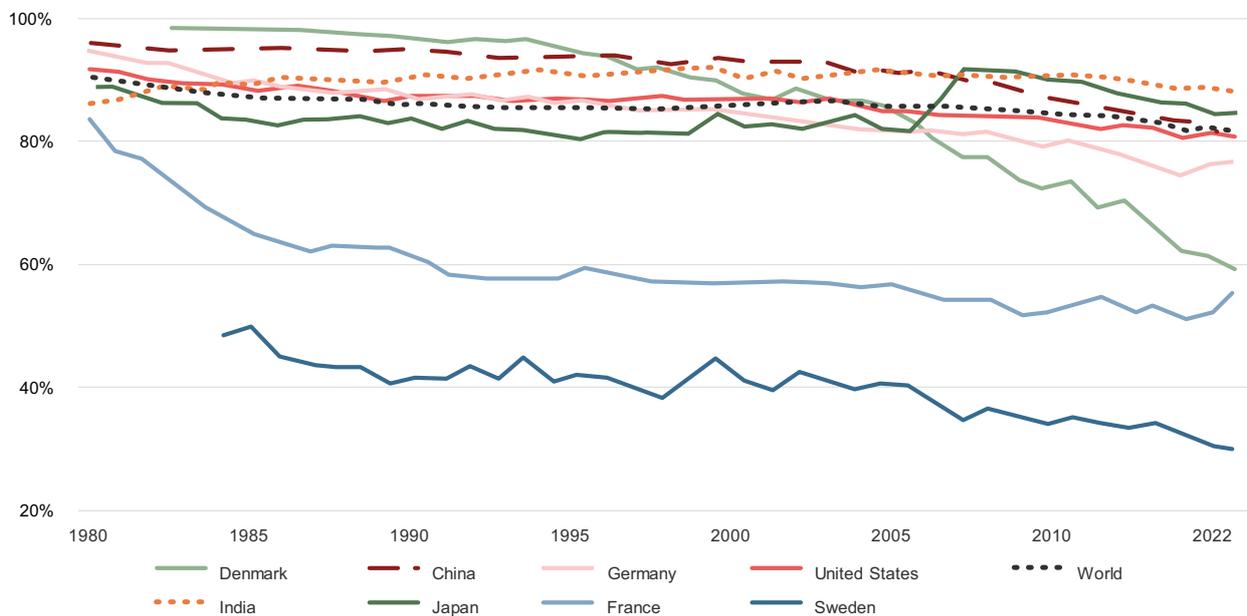
1. the high costs of the chosen pathway,
2. the insufficient security of supply,
3. and the questionable sustainability pathway.

How much have we decarbonized?

More than USD 4 trillion has been invested in the energy transition over the past 20 years², but this has only reduced the share of fossil primary energy globally from 85.6% in 2000 to 81.8% in 2022, see figure 1 below. The world is still predominately running on fossil energy.

A few countries, however, are decarbonizing well. Sweden, for example, has one of the cleanest energy

Figure 1
Share of primary energy from fossil fuels



Source: Energy Institute - Statistical Review of World Energy, September, 2023

2 Source: Statista (“New investment in renewable energy worldwide from 2004 to 2022”) as of February 2023.

“We believe natural gas has a place in the energy transition.”

systems globally because of a high share of nuclear and hydropower. France, although showing a deteriorating trend more recently due to an aging and underinvested nuclear fleet, also performs well because of its large nuclear buildout in prior decades.

The US has reduced its fossil primary energy share from 87.5% to 81.0% over the last decade. It is the country globally with the highest absolute reduction, taking CO₂ emissions from 6 GT in the early 2000s to 5 GT today. This is not the result of building out non-fossil energy but rather a result of switching from coal-generated electricity to gas-powered electricity because of the Shale Revolution and the boom in natural gas production. This led to a halving of US coal consumption over the past decade³. Gas is a 50% lower-carbon emitting fuel than coal per unit of energy output. The reason is that 54% of all the energy in the methane molecule (CH₄) comes from hydrogen atoms, which combust into innocuous water vapor. Hydrogen atoms are 12x lighter than carbon atoms. Thus, burning 1 ton of natural gas (CH₄) releases 2x more energy than burning 1 ton of pure carbon (C) in the form of the purest anthracites. For this reason, we believe natural gas has a place in the energy transition.

It is worth mentioning Denmark, which has seen steep decarbonization since 2010 and is considered one of the global leaders in decarbonization, having reduced its share of fossil in primary energy from 84% to 57%. Approximately half of this reduction comes from a buildout of wind capacities, so today, more than 60% of electricity generation comes from wind (and a bit of solar). However, the remaining 50% reduction in fossil share is less real because of a massive buildout of biomass generation. Around 1/3 of the biomass is imported, and whether imported or not, the procurement, transportation, and burning of the biomass emits CO₂. Therefore, biomass’ sustainability and CO₂ reduction merits are



“Successful decarbonizing countries have relied on dense energy from nuclear and hydropower, or in the case of the US, a significant switch from coal to natural gas.”

questionable and not scalable due to the inherent low density of biomass and lack of feedstock.

Based on the small sample in Figure 1, we can preliminarily conclude that the successful decarbonizing countries have relied on dense energy from nuclear and hydropower, or in the case of the US, a significant switch from coal to natural gas. The buildout of renewables so far has not materially reduced the fossil intensity of primary energy systems, except maybe for Denmark, depending on one’s views on biomass.

There is no way of getting around physics

Fundamentally, the reason for the poor payback from the large investments in renewables can be found in the laws of physics. The power density of renewables is much lower than fossil energies, so reducing investments in fossil

“Power density is perhaps physics’ most essential and least understood concept.”

and growing investments in renewables has created scarcity in energy markets⁴ but has not contributed much to lowering the fossil share of energy systems. We will delve into some of the underlying data to give some more clarity.

Global energy demand today is approximately 75,000 TWH of useful energy⁵. Demand is expected to grow to 120,000 TWH in 2050⁶, or 2% growth per year, driven by 1% population growth and 1% growth in energy use per person, from 9.3 MWH pp p.a. to 12.6 MWH pp p.a.

To understand the physical constraints of shifting from fossil to renewables, one can contrast these numbers with the past five years’ average investments in renewables and fossil energies and what levels of incremental energy this has delivered.

For example, as illustrated in table below, the global gas industry has, on average, invested USD 134 billion annually and added a gross of 4,836 TWH of energy annually before depletion. Solar and wind have invested a somewhat higher amount yearly but only incrementally increased production by 150-200 TWH per annum or less than 4% of the incremental primary energy output from natural gas. While the electric output from solar and wind is much more directly useful than natural gas because natural gas has energy losses associated with its use in combustion, before the energy becomes useful, there is no way to get around the fact that the power density and energy return on investment of fossil is far superior to renewables. We estimate the difference in power density to be around 10X, something we will explore further in a follow-up note.

The constraints of power density

Power density is perhaps physics’ most essential and least understood concept. Power density measures the energy flow that can be harnessed from a given area, volume, or mass. And unfortunately, the lower the power density, the greater the resource intensity. This can easily be seen in figure 2 a on the mineral intensity of various methods of electricity generation.

	Annual Investment (\$ bn)	Size (TWH)	Added (TWH pa)	\$ M/TWH pa
Coal	89	41.655	2.378	37,5
Oil	283	51.828	7.430	38,1
Gas	134	41.370	4.836	27,8
Wind	140	1.458	197	713,2
Solar	152	721	154	988,2
Nuclear	38	2.726	75	447

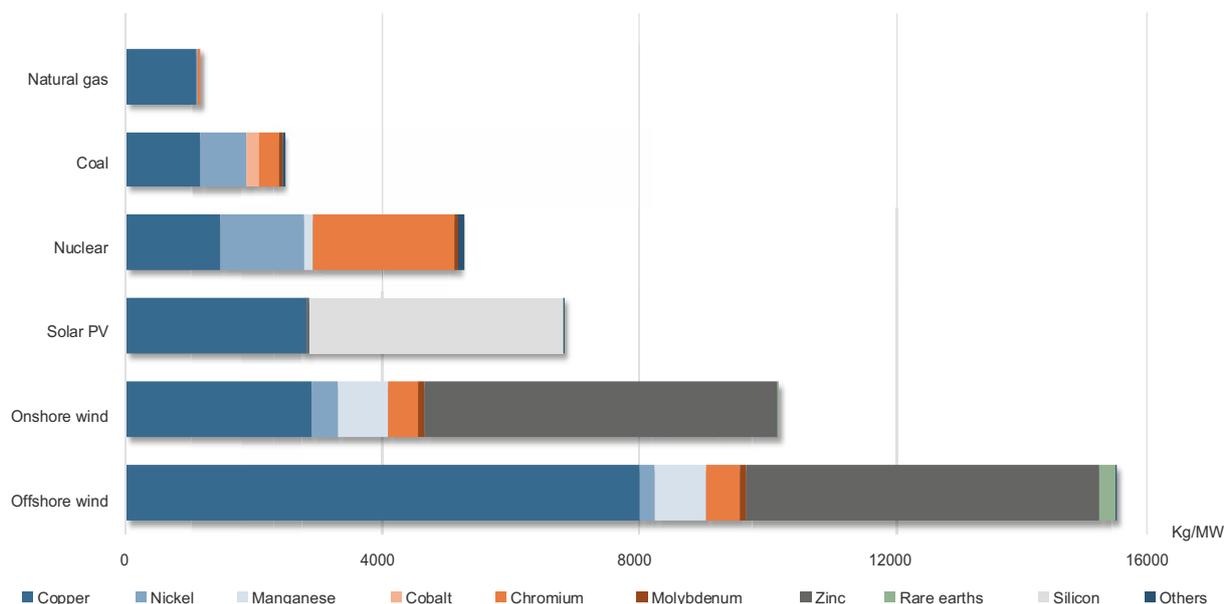
⁴ Source: C WorldWide (“The energy transition has brought on a new energy crisis”) as of September 2022.

⁵ In contrast to produced energy of approx. 160,000 TWH. The difference is energy loss, as energy efficiency is only 47%, a metric that can be improved significantly

⁶ Source: Thunder Said Energy (“Global energy demand: by region and through 2050?”) as of December 2023.

Figure 2

Different Energies Resource Intensity



Source: IFA IME, SG Cross Asset Research/Equity Strategy, October, 2022

“Declining commodity prices and falling interest rates over the last decade have distorted and partially hidden the actual costs of wind and solar.”

Offshore wind capacity is 13 times more material-intensive than natural gas-generated electricity. On top of this, renewable energy is also the most interest-rate-sensitive form of energy. Amazingly, few have connected declining energy costs and cheap capital with the proliferation of low-density, material and capital-intensive projects such as wind and solar manufacturing over the last decade.

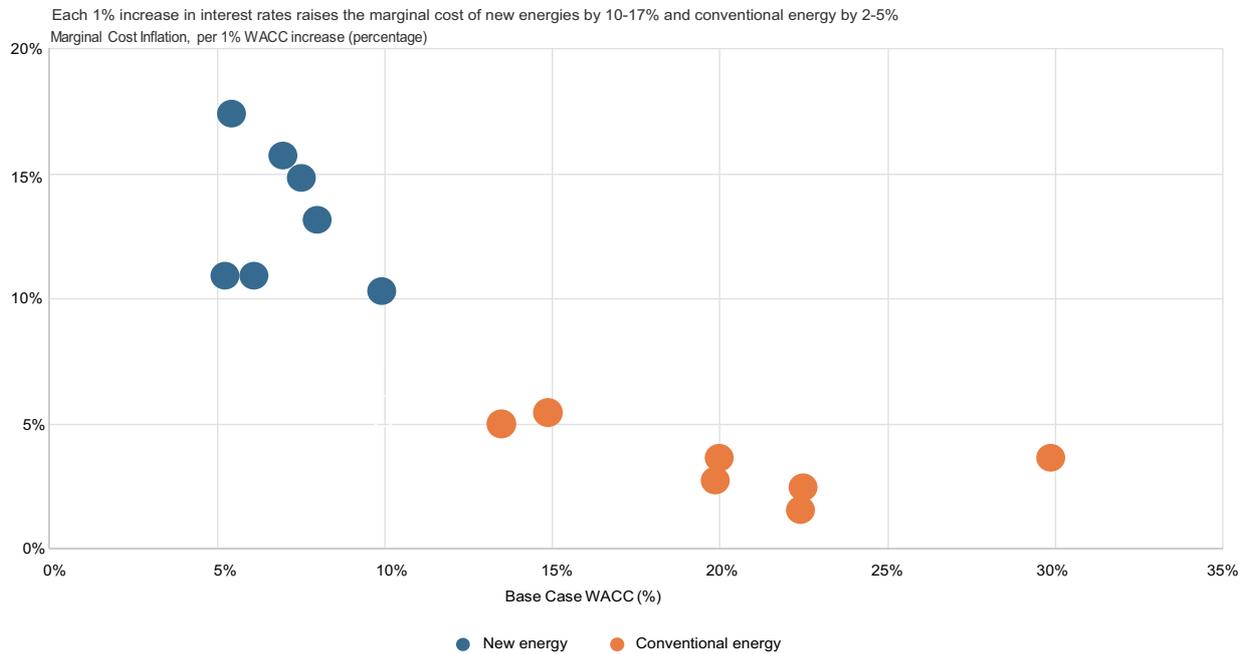
Suppose your power plant requires ten times more material inputs than other forms of power generation. In that case, it’s readily apparent why – as materials, energy, and capital become more expensive - low-density, high-resource-intensive energy sources become more costly and why developers of renewable energy have faced severe headwinds the last two years.

For a while, declining commodity prices and falling interest rates over the last decade have distorted and partially hidden the actual costs of wind and solar.

After energy prices and interest rates increased again, the actual cost of renewables became obvious. As well, rising interest rates have played havoc with renewables because the lower the power density, the greater the capital intensity and interest rate sensitivity.

The impact of a 1% interest rate increase is most pronounced at longer-life assets valued using lower discount rates, and it is less pronounced at shorter-cycle assets valued using high discount rates. The fact is that up-front capex costs dominate wind and solar costs. They have very minimal ongoing operating expenses once they are built. They also tend to get financed at lower capital costs (since investors saw these investments as alternatives to very low bond yields), which means they are more sensitive to interest rates. A 1% interest rate increase on a 5% baseline is a 20% increase, while a 1% increase on a 20% baseline is only a 5% increase. So, renewables are hit hardest. No doubt this is all familiar

Figure 3
Interest Rate Sensitivity



Source: Interest Rate Sensitivity, November, 2022

“The impact of a 1% interest rate increase is most pronounced at longer-life assets valued using lower discount rates, and it is less pronounced at shorter-cycle assets valued using high discount rates.”

to seasoned investors. But it bears repeating. Assets with low discount rates, long duration, and low pricing power suffer due to rising rates, and that is precisely what has happened to renewables over the last two years.

As 10-year interest rates have risen from 1-2% to a peak of around 5%, this has raised the capital cost for valuing future cash flows of a fully developed wind project with fixed-price PPAs⁷ from perhaps 5% to 8%. This potentially dent the project’s valuations by 50%. The worst-case scenario will occur in a project that has managed to saddle itself with fixed-price PPAs, unhedged floating-rate debt, and an open order book for equipment and labor. While it might sound nonsensical that any project developer might

have opened themselves up to this mismatch between cash inflows and cash liabilities, this is probably what has happened in the cases where offshore wind projects have been canceled recently.

Recently, interest rates have trended lower and given respite to developers of renewable energies. What has not changed, however, is that renewables are energies with very low density, and this will always be the fundamental constraint on large-scale deployment of renewables. Therefore, if we continue to shift our energy investments away from dense fossil towards renewables without at least one order of magnitude increase in renewable investments, we will eventually run into large

⁷ A Power Purchase Agreement (PPA) refers to a long-term electricity supply agreement between a power producer and a customer.

“Today, the growth in renewable energy covers less than 25% of the growth in energy demand.”

energy deficits, making it impossible to meet the economic development goals for all humankind. This becomes clear if we compare the yearly growth in primary energy demand of approx. 1,500 TWH (2% growth) to the total incremental growth in renewables at approx. 350 TWH (see figure 3). Today, the growth in renewable energy covers less than 25% of the growth in energy demand. These numbers make it clear why the reduction in fossil intensity of our energy systems has been so disappointing and that the low density of renewables makes a decarbonized energy system based only on renewables a pipe dream.

High costs of renewable energy and the LCOE fallacy

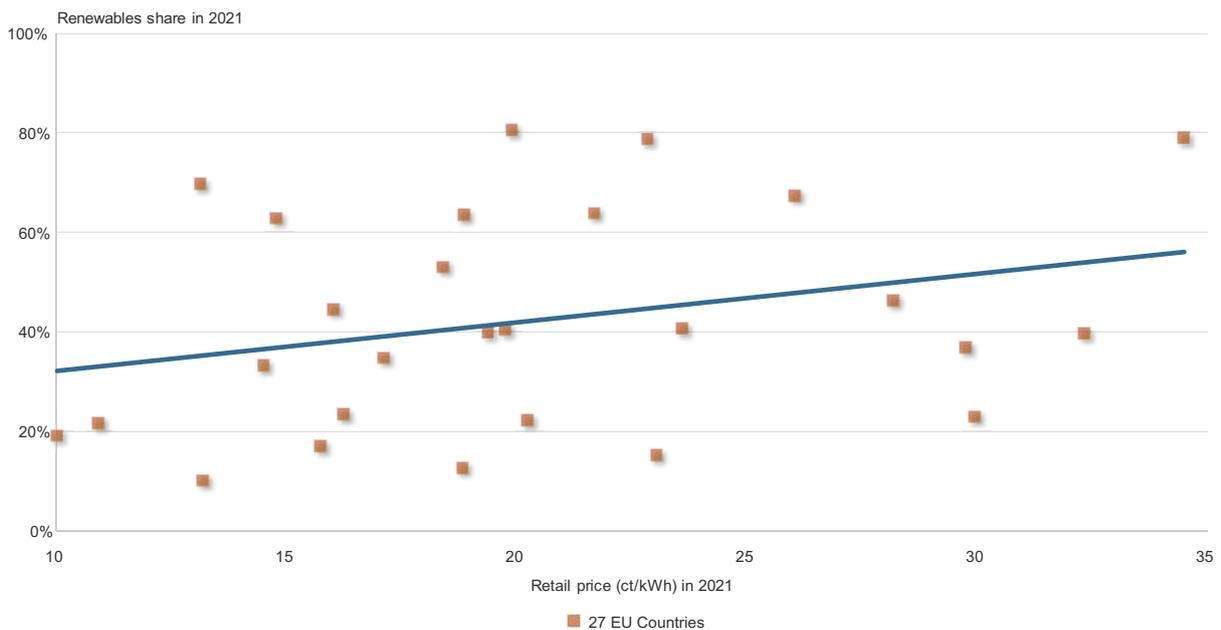
The LCOE “represents the average revenue per unit of electricity generated that would be required to recover

the costs of building and operating a generating plant during an assumed financial life and duty cycle” and is calculated as the ratio between all the discounted costs over the lifetime of an electricity generating plant divided by a discounted value of the actual energy delivered.

It is said that renewables have the lowest levelized energy cost of any new energy source, so one would assume countries with high shares of renewable energy would, on average, have low electricity prices. However, this is not the case, as the highest retail electricity prices tend to be found in countries with the highest renewable energy penetration, such as Denmark and Germany. This seems paradoxical, but the problem is that LCOE calculations are fundamentally flawed when analysing intermittent energies. LCOE is inadequate to compare intermittent forms of energy generation with dispatchable ones.

The chart below shows a relatively low correlation between the share of renewables and the retail price of electricity in European economies in 2021. The chart is not a “smoking gun” of proof that renewables lead to higher electricity prices. Still, it disproves the statement

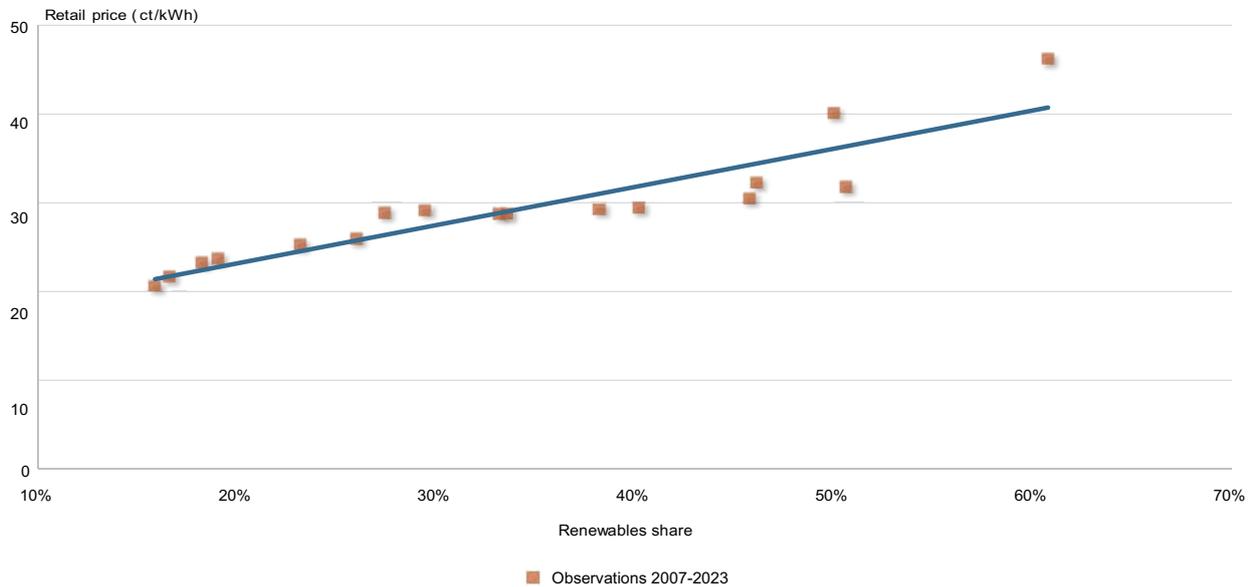
Figure 4
Retail price vs renewables share in EU27



Source: Bernstein, December, 2021

Figure 5

Germany renewables penetration vs retail price



Source: Bernstein, October, 2023

that renewables drive down electricity prices since the correlation is positive.

The chart above shows Germany’s electricity prices for 2007-23 with the associated renewable energy market shares. As can be seen, the relationship is positive, although there was a slowdown in price appreciation in the mid-2010s. This was a period when renewable penetration in Germany accelerated, and apparently, this did not, in any meaningful way, increase the cost of electricity in Germany. However, one must understand that the marginal price setters for electricity in this period were coal and natural gas and both fell dramatically. All things equal, this should have driven down electricity prices, but it didn’t.

The LCOE calculation averages production over the lifetime of wind and solar installations and thus suffers from an immediate and fatal flaw: it assigns no time value to electricity. Intermittent energy like solar and wind turns the law of supply and demand on its head, assuming that electricity is needed only when available. Rather than responding to demand, the grid in a renewable energy system is expected to react to the production variance of

“LCOE does not take into account baseload grid requirements and disregards all the costs associated with keeping the grid running despite the volatility of renewable production.”

these weather-dependent intermittent renewables. LCOE does not take into account baseload grid requirements and disregards all the costs associated with keeping the grid running despite the volatility of renewable production.

The total cost of electricity is only marginally affected in the early phases of the rollout of renewables. The system can accommodate the marginal new production without significantly reducing other production sources. However, as intermittent renewable energy becomes a larger share of electricity, other generative assets must step back to give room for renewable electricity. However, since the renewables are intermittent, their capacity factors are low and very volatile, so the large incumbent baseload capacities must be on standby to compensate for when

the sun is not shining, or the wind is now blowing. This adds to system costs.

Beyond a certain point, usually around a share of 30%, the cost to a nation's electricity system always increases with higher shares of variable renewable energy, such as wind and solar⁸. The reasons include but are not limited to low power density and efficiency, intermittency and thus backup/storage requirement, low-capacity factors, interconnection costs, and material and energy costs. The IEA confirmed in December 2020 that "...the system value of variable renewables such as wind and solar decreases as their share in the power supply increases"⁹.

A less efficient energy system adds to the costs

The rising share of wind and solar in the grid leads to a falling utilization rate for fixed-cost assets, both electricity plants and the grid. The figure on the following page plots the average utilization factor across different power grids. The methodology divides total annual generation by the total possible generation in different countries. Utilization appears to have peaked in 1998 at around 55%, including an average appx. 78% utilization factor from nuclear and an average of approximately 55% utilization factor for fossil sources, and has now declined by 30% to an average of 38% in 2022. This fall is the result of adding renewables with low utilization rates. Across the countries in this sample, wind has averaged a utilization rate of 30% in the past five years, while solar has an average utilization rate of 15%.

Every country that has added renewables to its grid has seen declining utilization rates, while the countries adding the most renewables have seen the largest declines.

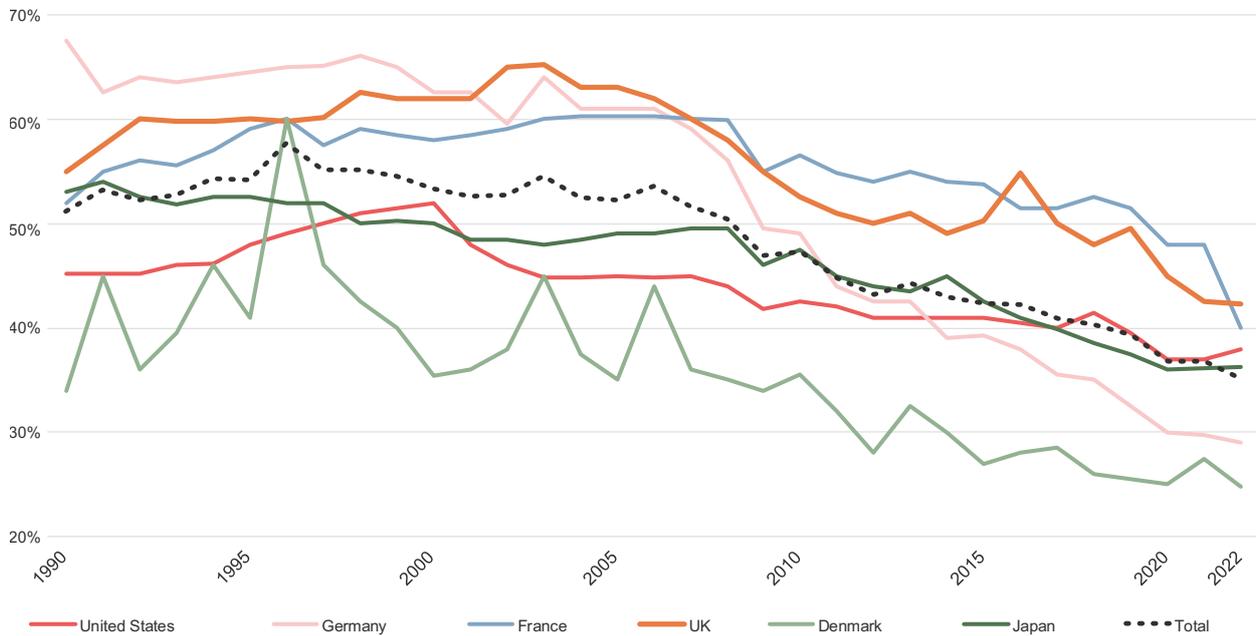
The trend in Germany and Denmark has been remarkable with utilization rates declining below 30% in 2022. In other words, the utilization of the average GW of installed capacity – and, by extension, much of the transmission



8 IEEJ Outlook 2020 p 15ff

9 Projected-Costs-of-Generating-Electricity-2020.pdf (windows.net) p 13

Figure 6
Power Grid Capacity Utilization (%)



Source: Thundersaidenergy, November, 2023

and distribution network – has halved as renewables ramped up to supply 46% of the German grid and 60% of the Danish grid in 2022. The same countries with the highest electricity prices – Germany and Denmark – also have the lowest aggregate grid utilization rates, below 30%.

System costs in Denmark almost doubled between 2021 and 2022, and since the early buildout of wind power in Denmark in 2010, system costs have increased from a mere 0.5 bn DKK (70 m EUR) to 2.7 bn DKK (360 m EUR) or 440%¹⁰.

Rising Instability and risk of blackouts

A high share of intermittent energy will lead to instability and potential collapse of our electrical grids. Mitigating these risks requires significant investments in backup capacity, the densification of the grid, and storage

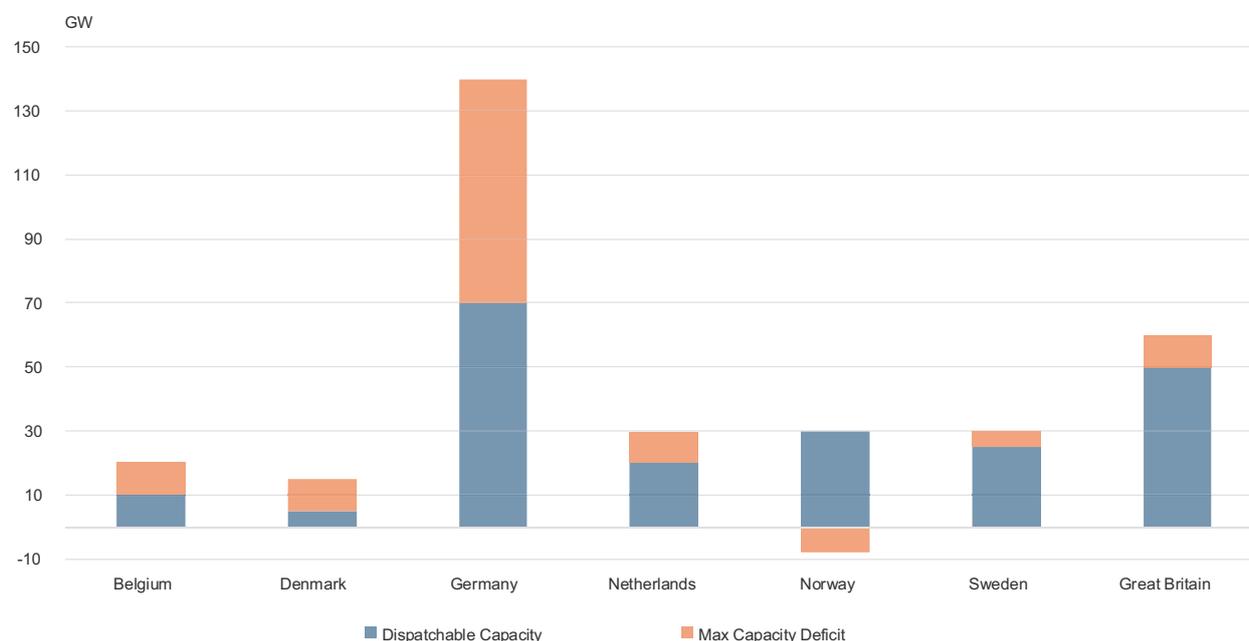
solutions, either in the form of batteries or hydrogen, all costs that are disregarded when renewables are being promoted as the lowest-cost options for energy.

Recently, the Danish Transmission System Operator (TSO) Energinet, responsible for the operation and stability of the Danish grid, published a rather disturbing report¹¹ on the longer-term consequences of reduced dispatchable energy production, increased intermittent energy production, and rising electricity demand in the Northern European region. The chart on the next page was published showing that the region will need additional construction of 80 GW of dispatchable energy capacities by 2033 to safeguard the integrity of the grid and avoid brown-or blackouts in adverse weather events. As a rule of thumb, a nuclear plant has 1 GW of capacity (as an example, now prematurely retired Swedish Barsebäck had two times 600 MW), so Energinet is saying that countries in Northern Europe over the coming decade will need to

10 LinkedIn (in danish)

11 Redegørelse for elforsyningsikkerhed 2023 (energinet.dk) (in danish)

Figure 7
Maximum Capacity Demand 2033



Source: Energinet, December, 2023

“Energinet is saying that countries in Northern Europe over the coming decade will need to add the equivalent of 80 nuclear plants to eliminate the risk of brown – or blackouts.”

add the equivalent of 80 nuclear plants to eliminate the risk of brown – or blackouts. This is not some theoretical futuristic exercise; two times in 2023, Denmark was on the brink of grid failure due to big fluctuations in weather¹² and, therefore, in the ability to keep a constant frequency in the grid.

Violating the Energy Trilemma puts sustainable development goals at risk

Inequality in access to energy is probably the biggest human development issue. Today, energy consumption runs at 20 MWH pp p.a. in Europe and Japan and as much as 40 MWH pp p.a. in North America. Conversely, the

poorest four billion people in the world, in Africa, India, and other Asia, consume an average of 2.5 MWH pp p.a. today¹³. Energy scarcity is being felt the hardest at the bottom of the income distribution because they are the ones who can’t afford expensive energy.

1 billion tons per year of wood is harvested as a heating fuel, mainly in low-income countries¹⁴, but also exported to countries in Europe, where burning wood is considered to be carbon neutral. Wood is not a good fuel, as it doesn’t burn cleanly and releases little energy but a lot of CO₂. Wood is more CO₂-intensive than coal. Worse, around 10 million hectares continue to be deforested each year, releasing 6.5 GT p.a. of CO₂ emissions, the largest source of

12 Som vinden blæser | Weekendavisen (in danish)

13 Source: Thunder Said Energy (“Energy shortages: priced out of the world?”) as of February 2022.

14 Source: Thunder Said Energy (“Energy shortage: fear in a handful of dust?”) as of November 2022.



anthropogenic CO₂ emissions. It destroys pristine natural habitats. It is less environmentally damaging to combust a tree that has been dead for 400 million years in the form of coal than to cut down and burn a living one⁴⁵. Modern energies, even fossil ones, are essential for human development and decarbonization!

Conclusions

Decarbonizing our energy systems is progressing too slowly. The prime reason is that we have focused on technologies that, at best, only partly contribute to the energy transition. Investments have been tilted toward less dense energy systems, creating a risk of structural energy undersupply and energy crises in the coming decade.

The world is starting to understand the unsustainable nature of the current pathway. Rising interest rates and raw material price increases have led to the cancellation of wind projects and decimated the stock prices of many renewable companies. A more realistic view of the energy transition is now leading to a gradual reappraisal of the need to invest in denser baseload power like nuclear with existing 3. generation technologies and future 4. generation SMR and Fusion.

An upcoming follow-up insight will discuss these and other essential solutions to the energy transition.

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