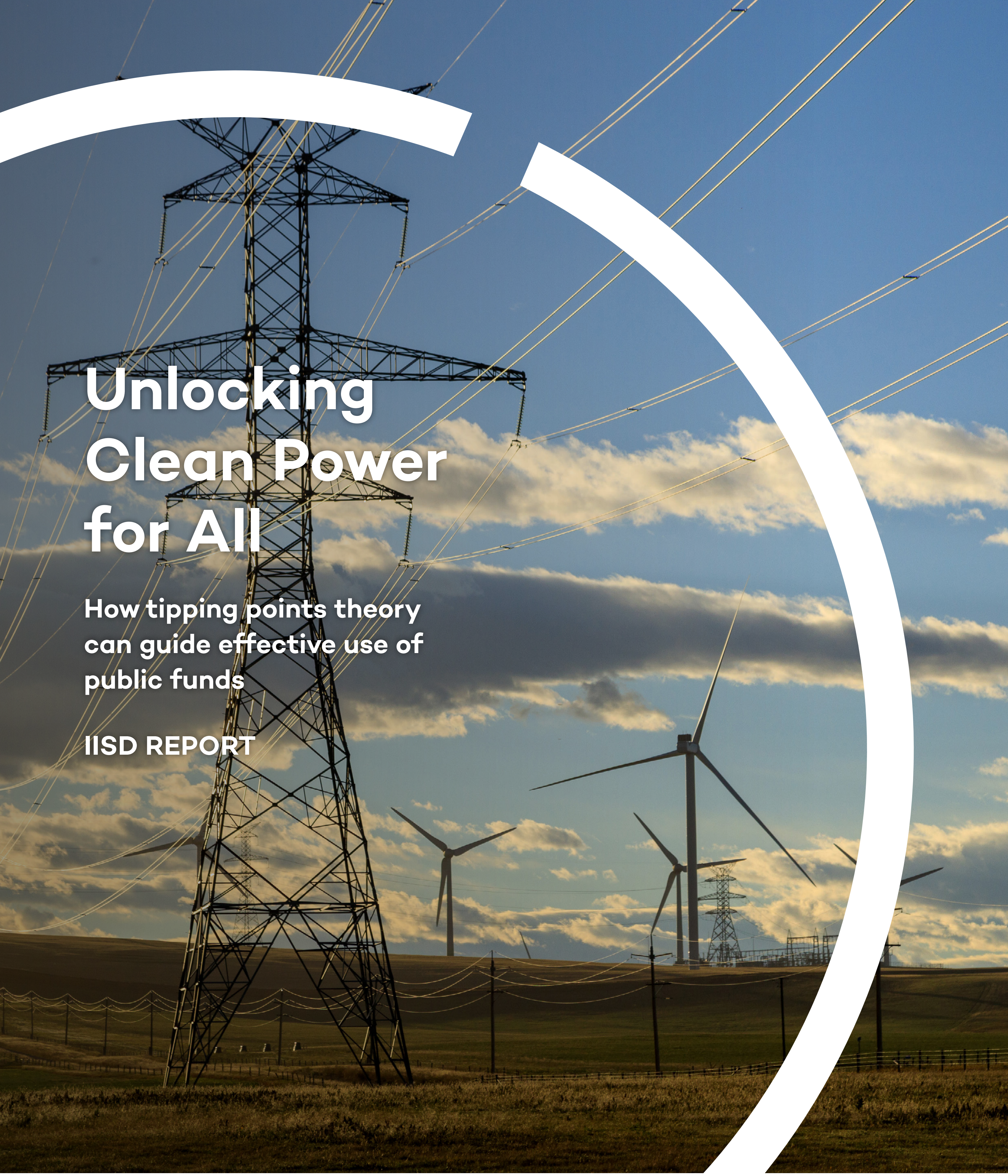


Unlocking Clean Power for All

How tipping points theory can guide effective use of public funds

IISD REPORT

Indira Urazova
Tara Laan

International Institute for Sustainable Development

September 2024

Published by the International Institute for Sustainable Development

International Institute for Sustainable Development

The International Institute for Sustainable Development (IISD) is an award-winning, independent think tank working to accelerate solutions for a stable climate, sustainable resource management, and fair economies. Our work inspires better decisions and sparks meaningful action to help people and the planet thrive. We shine a light on what can be achieved when governments, businesses, non-profits, and communities come together. IISD's staff of more than 200 people come from across the globe and from many disciplines. With offices in Winnipeg, Geneva, Ottawa, and Toronto, our work affects lives in more than 100 countries.

IISD is a registered charitable organization in Canada and has 501(c)(3) status in the United States. IISD receives core operating support from the Province of Manitoba and project funding from governments inside and outside Canada, United Nations agencies, foundations, the private sector, and individuals.

Head Office

111 Lombard Avenue, Suite 325
Winnipeg, Manitoba
Canada R3B 0T4

Tel: +1 (204) 958-7700
Website: iisd.org
X: @IISD_news

Unlocking Clean Power for All: How tipping points theory can guide effective use of public funds

September 2024

Written by Indira Urazova and Tara Laan

Photo: iStock

Acknowledgements

We thank Ana Diaz Vidal, Dave Jones, Janne Piper, Natalie Jones, Nhat Do, and Shruti Sharma for their thoughtful comments on this publication.

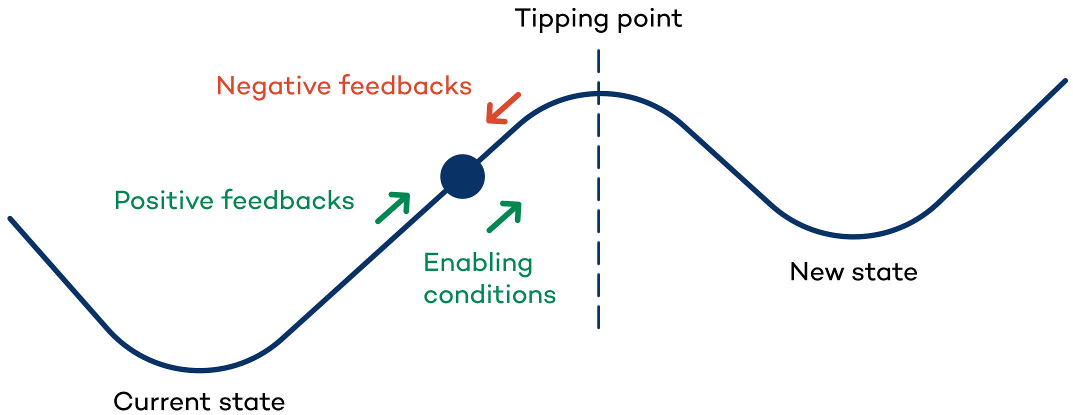
Executive Summary

Supportive government policies, including subsidies and other financial incentives, have been instrumental in the development and deployment of renewable energy (RE). These policies have been so successful that grid-scale solar photovoltaic (PV) and onshore wind are now cheaper options for generating electricity in some countries than new coal and gas plants, even when battery storage is included in project costs. Falling costs and rising levels of installation have led some to conclude that the electricity sector has passed a tipping point where the dominance of renewables is now inevitable.

This report uses tipping point theory to assess the role of public financial support in the rise of solar PV and onshore wind technologies and their ongoing deployment in emerging market and developing economies (EMDEs). We argue that, despite these technologies achieving cost parity with fossil fuels at the global scale, enabling policies continue to be needed because:

1. Tipping points have been reached only in some countries, with RE capacity heavily concentrated in advanced economies and China, Brazil, and India.
2. RE still faces substantial barriers in most EMDEs.
3. Interventions are needed to achieve a tripling of RE capacity by 2030 as part of efforts to keep average global temperature increases to less than 1.5°C above pre-industrial levels.

Figure ES1: Tipping points conceptual framework



Source: Authors, based on Lenton et al., 2022.

The tipping points literature and experience in advanced economies and China indicate that a suite of policies is likely to be needed. System-wide shifts may appear to occur due to a single intervention, but change is usually the result of multiple interacting causes, when positive feedbacks that work in favour of the new technology outweighs the negative feedbacks that sustain the incumbent. A holistic strategy to “force” tipping requires measures that strengthen positive feedback mechanisms (reinforce virtuous cycles of deployment, economies of scale, and cost reductions), remove negative feedback (those that lock in fossil power) and create enabling conditions (such as infrastructure for RE integration) (see Figure ES1). All three tipping aspects can be influenced by policy-makers.

National-level analysis is needed to determine where interventions are most needed to create tipping effects. While each country's pathway will be unique, tipping point theory and experience successful deployment of RE can be used to determine where public funding can be strategically directed to catalyze energy system change (Table 1). Public financial support might be needed to both incentivize RE producers and consumers, and to the remove the barriers to adoption.

Table ES1. A suite of policies is likely to be needed for system-wide change to renewable power

Tipping point category	Policy aim	Type of measure
Amplify positive feedbacks	Reduce cost of capital	Concessional financing, loan guarantees, and other risk mitigation instruments
	Long-term policy and price certainty	Power purchase agreements
	Measures that discover market prices in local contexts	Auctions, feed-in-premiums, contracts for difference
	Build up local supply chain	Skilling workforce and business support
	Trade policies that balance access to low-cost imports with domestic manufacturing objectives	Custom duties, local content requirements
Remove negative feedback	Ensure fossil fuel prices reflect their negative impacts	Fossil fuel subsidy reform and taxation (accompanied by support for vulnerable groups)
	Restructure state-owned enterprises (SOEs) so they are technologically neutral	Transition plans, RE mandates, regulations
	Retire or retrofit fossil capacity	Structural adjustment and just transitions funding
	Address vested interests and political bias	Increase transparency, implement regulations to disentangle fossil and political interests

Tipping point category	Policy aim	Type of measure
Create an enabling environment	Grid modernization	Budget transfers, concessional financing, SOE investments
	Financially viable utilities that can invest in grids and RE	Tariff reform, cash transfers, or tax cuts for vulnerable groups
	Ancillary services and storage	Budget transfers, concessional financing, SOE investments

Source: Authors.

Given the unique challenges faced by EMDEs, our analysis suggests that public financial support measures most likely to facilitate tipping in EMDEs are

- international concessional finance, grants, and risk mitigation instruments to compensate for high upfront investment needs and cost of capital in EMDEs;
- investments in grids to facilitate integration of variable RE;
- fossil fuel subsidy reform to level the playing field and generate revenue to fund a just energy transition.

The international donor and finance community can assist by increasing transfers to lower-income countries, including by reallocating international finance from fossil to RE and by committing to an ambitious new climate finance goal at the next United Nations Climate Change Conference, COP 29.

Table of Contents

List of Figures

List of Tables

List of Boxes

1.0 Introduction and Objectives

Climate change mitigation presents multiple challenges and requires concerted efforts from policy-makers, investors, and other stakeholders. An emerging body of literature on “tipping points” offers a useful perspective on how to plan mitigation efforts and drive sustainability transitions. Drawing on systems thinking, some researchers have argued that it is possible to accelerate the deployment of climate mitigation solutions—from clean energy to low-carbon food systems—by intentionally forcing technology adoption toward so-called positive tipping points (Meldrum et al., 2023).

Positive tipping points occur when a certain threshold is reached in the adoption of new technology or practices beyond which their uptake increases exponentially, ousting the incumbent from its dominant position (Lenton et al., 2022). For this to happen, enabling conditions need to be put in place and reinforcing feedback loops that favour the newcomer need to outweigh the balancing feedback loops that work for the incumbent. Consumers, investors, and other market participants shift their preference to the new technology, raising their stake in the new solution and further driving the growth in its adoption. Once the tipping point is reached, progress is hard to reverse. However, barriers can still occur that can slow or stall deployment. Public policy can have a role in pushing systems toward tipping points and addressing impediments that threaten to halt desirable change (Lenton et al., 2022).

In the renewable energy (RE) sector, installations of grid-scale solar PV and onshore wind have grown exponentially, with global capacity multiplying more than 10 times from 2010 to 2023 (International Renewable Energy Agency [IRENA], 2024). Recent auction results for paired solar and battery storage suggest that these installations can now be cheaper than coal-fired power plants and faster to build (Colthorpe, 2024). The International Energy Agency (IEA) projects that renewable generation will pass coal for the first time in 2025 (IEA, 2024c). This has led some to declare that the tipping point for RE in the electricity sector has already been reached (Meldrum et al., 2023).

While this might be true in select countries, the uptake of renewables at the global level is still below that needed to achieve global temperature targets. To meet the Paris Agreement goal of limiting global warming to 1.5 °C from pre-industrial levels by the end of the century, installed RE capacity needs to triple to at least 11 terawatts (TW) by 2030 (IRENA et al., 2023). In response, at the 28th United Nations Climate Conference (COP 28) in 2023, 198 parties committed to triple RE capacity and double energy efficiency improvements by 2030. Based on current investment plans and targets, the world is projected to fall short of the target by around 30% (IEA, 2024b).

In addition, progress so far has been uneven across geographies. In 2023, China and advanced economies accounted for 90% of solar PV and wind capacity installations (IRENA, 2024), 85% of investment in RE (IEA, 2024d), and 96% of public financial support for renewable energy (Laan et al., 2024). To achieve the tripling target, the level of ambition needs to increase from a growth factor of 1.9 to 2.5 for advanced economies and from 2.4 to 3.4 for emerging market and developing economies (EMDEs) (IEA, 2024b).

The public sector has a pivotal role to play in crowding in the private investment needed to accelerate the deployment of RE. Public financial support—including subsidies and concessional financing—has been instrumental in the rise of RE. In some countries and for some technologies, such support is still needed to ensure that the rollout of RE is rapid and universal. In addition, governments need to fund the associated grid infrastructure, implement regulations, streamline permitting, and create favourable price signals (such as through fossil fuel subsidy reform and taxation). A tipping points approach can identify intervention points where public funds can be best utilized to promote system-wide change in favour of RE.

1.1 Objectives

In this report, we assess the role of public financial support in driving RE toward positive tipping points in developing countries. We provide

- an overview of the main insights from the tipping points literature
- analysis of how the tipping points framework can be harnessed by policy-makers in EMDEs to use public resources strategically to catalyze system-wide change
- an overview of global RE deployment and investment trends through the lens of tipping points
- identification of barriers that slow the uptake of RE and how these can be overcome
- analysis of the role of public financial support, including international public finance, in increasing RE deployment
- insights for solar and wind deployment in EMDEs.

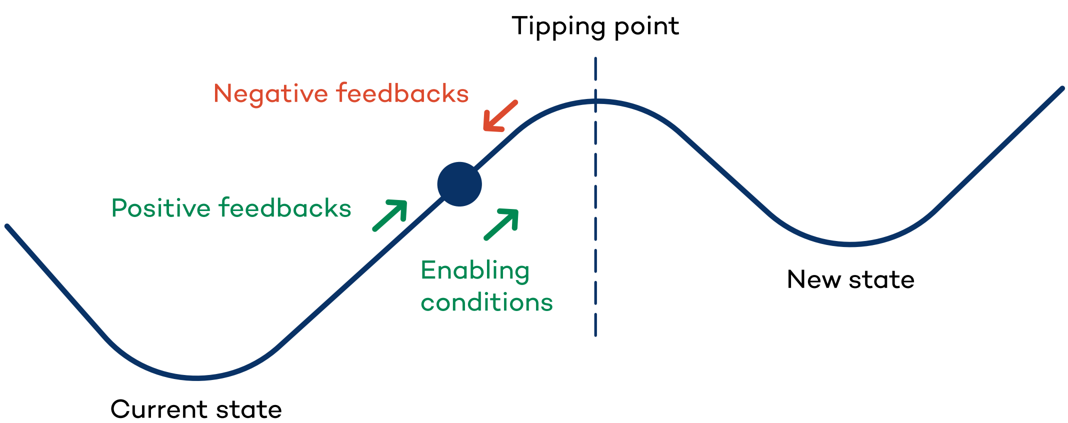
2.0 How Change Happens Through Tipping Points

The tipping points concept and other terms describing fast and systemic transformations have been used in different academic disciplines for over a century, but it is only recently that these have been applied to favourable sustainability transitions. Milkoreit et al. (2018) highlighted the main characteristics of systems where tipping points occur: multiple stable states, abruptness and non-linearity of change, feedback mechanisms, and limited reversibility.

When a system is tipped, it shifts from one stable state to another, structurally different state, with a limited possibility to reverse this shift. The change is usually abrupt, with a seemingly small intervention causing a large exponential and non-linear impact. The change happens because multiple feedback mechanisms accumulate and bring the system to a critical threshold. But the transformation only becomes apparent when a small trigger sets off a chain reaction to tip the system. Therefore, while the observer might only see a small intervention producing a disproportionately large impact, the change is triggered by multiple interacting causes (Winkelmann et al., 2022), rather than simple bivariate causality (one cause and one effect).

Building on systems thinking and leverage points framework (Meadows, 2008), Lenton et al. (2022) conceptualize these multiple interacting causes as positive feedback mechanisms that together shift the balance of the socio-technical system toward the sustainable disruptor. With an increasing uptake of a new technology, producers improve its performance, optimize production processes to lower its costs, attracting more consumers and investors and further increasing the technology's market share in a reinforcing feedback loop. Triggering such virtuous cycles of improvements and increased rollouts could lead the way for an exponential growth in sustainable solutions.

Figure 1. Forcing tipping through policy interventions



Source: Authors, based on Lenton et al., 2022.

The mechanism underlying such "reinforcing feedback loops" is often that of increasing returns (Lenton et al., 2022), driven by

- learning by doing, i.e., the more one does/produces something, the better one can do/produce it
- economies of scale, i.e., the higher the production levels, the more efficient and cheaper the production per unit of product
- technological reinforcement, i.e., the higher the technology uptake, the more technologies and practices emerge that rely on said technology.

Other reinforcing feedbacks are also highlighted in the literature; for instance, in the political space, emerging industries are better able to advocate for improved policy support as their size and political influence grow (Geels & Ayoub, 2023; Meckling, 2019).

Elements that create an environment conducive to amplifying positive feedback mechanisms—the so-called "enabling conditions"—are important for change. Enabling conditions are practices, institutions, and infrastructure that facilitate the desired policy change. In the case of RE, any interventions that facilitate tipping are enabling conditions and their absence can slow innovation and deployment (Lenton et al., 2023). Public support, both regulatory and financial, is a key enabling condition for sustainable solutions, and it was crucial for the creation of reinforcing feedback that propelled RE technology to achieve the economic success evident in solar PV and onshore wind (see Box 1).

Box 1. The role of public financial support in achieving tipping points in solar PV

Policy support was instrumental in encouraging innovation and technological improvements that drove down the costs of solar PV (Nemet, 2019; Trancik et al., 2015). The development of the industry has been punctuated by the trends in public financial support, growing and adapting to government incentives. Even today, despite significant cost reductions and its widespread adoption, solar energy remains dependent on price certainty provided by government incentives, support for domestic manufacturing, or auxiliary infrastructure.

It took the industry more than 50 years of government incentives to now outcompete fossil generation sources. The United States paved the way for solar PV's commercialization with R&D funding in the 1970s (Nemet, 2019). Japan's 1994 subsidy program for rooftop solar expanded the consumer base for the technology, increasing its commercial attractiveness and motivating other countries to invest. Solar's watershed moment came in 2000 when the German Renewable Energy Law (EEG) introduced the feed-in-tariff (FiT) for wind and solar PV. This innovative measure guaranteed a stable purchase price for renewable electricity. The policy brought certainty to the nascent manufacturing industry, incentivizing the development of automated manufacturing equipment and creating a market for domestic firms with economies of scale and subsequent cost reductions.

The FiT program in Germany also created a market for the growth of solar PV start-ups in China, which focused on scale-up and mass production of solar components (Nahm, 2021, 2023). Taking advantage of tax breaks, an FiT scheme, under-pricing of land, and incentives for manufacturing and R&D, Chinese entrepreneurs developed innovative mass production methods for components (Nahm, 2021).

China's central government intervened during the global financial crisis in 2009–2010 to prevent domestic solar manufacturers from going bankrupt (Nemet, 2019). The Golden Roofs Initiative covered up to 50% of costs for domestic rooftop solar PV installations, while the Golden Sun Program covered up to 70% of costs for utility-scale projects. The government included solar PV in its list of strategic industries in the 2011–2015 Five-Year Plan, which incentivized local governments and state-owned banks to provide state-backed loans to local solar PV firms at subsidized rates (Nahm, 2021). Such measures led to virtuous cycles of increasing economies of scale and sharp drops in the levelized cost of energy (LCOE).

Other policies that enabled the deployment of renewables have also been successful, such as long-term uptake targets, standards, carbon pricing, and regulations. For instance, the FiT scheme in Germany was accompanied by long-term targets for the share of RE in the final electricity mix. In China, utilities have been mandated to purchase a share of electricity from renewables (IRENA et al., 2023). Instruments ranging from RE portfolio standards and grid priority access to emissions trading schemes and carbon tax can be used to enable faster deployment. A comprehensive analysis of 1,500 climate policies from 41 countries has shown that successful interventions come in complementary policy mixes that combine tax and price incentives with PFS and regulations (Stechemesser et al., 2024). For instance, in the United Kingdom, significant carbon emissions reductions and increased RE uptake were achieved through a combination of a carbon price floor, renewable portfolio standards and stricter air pollution standards, an FiT and auction scheme, and a planned phase-out of coal power plants.

Reaching one tipping point can create conditions for triggering similar thresholds in a different but related sector, with the potential to set off other tipping points in an "upward-scaling" tipping cascade (Sharpe & Lenton, 2021). Thus, public policy aimed at activating one tipping point can increase the chances of producing larger-scale decarbonization across sectors. For instance, policy support for electric vehicles (EVs) could drive further tipping points in the uptake of renewables with battery storage (Meldrum et al., 2023). Incentives for EV adoption would increase the production of batteries worldwide, driving economies of scale and reducing the cost of battery solutions used in conjunction with renewables.

When reinforcing feedback loops are still nascent, system inertia and barriers to entry are high. This is because strong feedback loops support established practices and technologies—the so-called negative or dampening feedback, ensuring system "lock-in" (Lenton et al., 2022; Meldrum et al., 2023). Investors and consumers have no incentives to buy-in on the new technology because costs are high, the demand is low, and the policy architecture is geared toward the incumbent (Klitkou et al., 2015) (see more in Section IV).

For a long time, energy analysts and fossil fuel incumbents did not see intermittent renewables as a viable alternative to coal and natural gas generation partly because renewables were expensive but also because electricity infrastructure was and continues to be geared toward centralized baseload generation, and institutions are built around fossil fuels.

A system can be tipped only when reinforcing feedback loops outweigh the dampening feedback supporting the incumbent. However, this is difficult to achieve in the absence of policy support—because of dampening feedbacks, new technologies often emerge and develop in small clusters in the presence of supportive public policies (Geels & Ayoub, 2023). A holistic strategy to "force" tipping, therefore, requires measures that create enabling conditions, strengthen reinforcing feedback mechanisms, and remove negative feedback (see Figure 1). Ultimately, all three tipping ingredients can be influenced by different stakeholders, but the primary responsibility is with policy-makers, especially in the early stages.

The tipping points framework has clear implications for the planning and assessment of decarbonization policies:

1. Strong dampening feedbacks favour environmentally harmful incumbents. Therefore, it is essential to create and amplify positive feedbacks that work for sustainable solutions and remove feedbacks that dampen the transition. In short, because of system inertia, **tipping requires intentional forcing** from policy-makers and other actors (Lenton et al., 2022, 2023).
2. Because change is triggered by multiple interacting causes, policies that aim to propel the development of RE should not be judged based on their direct results but rather on their **potential to create enabling conditions for tipping and set off positive amplifying feedbacks and tipping cascades** (Sharpe & Lenton, 2021) as part of an overall decarbonization strategy.
3. Policy-makers should not expect to be able to produce large-scale sustainability transitions with one small intervention exploiting marginal efficiency. Instead, a holistic policy framework is needed with measures targeted strategically at the **overall structure and purpose of the system** (Fesenfeld et al., 2022).

3.0 Current Trends in RE Deployment

3.1 Utility-Scale Solar PV and Onshore Wind Have Reached Tipping Points in Some Geographies

Over the past decade, solar and wind capacity additions have consistently surpassed expert predictions including by the IEA (2024e). Globally, solar installed capacity grew from a total of around 41 GW in 2010 to over 1,400 GW in 2023, with capacity additions rising 28% per year on average during this period (IRENA, 2024). In 2023 alone, newly added capacity from solar increased 74% compared to 2022 levels, adding over 346 GW to the power systems worldwide (IRENA, 2024).

Wind capacity grew from 181 GW in 2010 to around 1,017 GW in 2023. The uptick in wind capacity additions has been less pronounced, with a noticeable dip in 2022 mainly attributed to rising inflation, an increase in interest rates, and post-pandemic supply bottlenecks that drove up the costs of key equipment and critical minerals. Before these challenges appeared, wind was growing exponentially, with new additions rising 21% in 2019 and 88% in 2020 (IRENA, 2024). In 2023, wind installations saw a noticeable recovery, with new additions 47% higher compared to 2022 levels (Wiatros-Motyka et al., 2024), suggesting the industry is bouncing back.

A record 30% of electricity was generated from renewables in 2023, with a large part of this increase coming from solar and wind generation (Wiatros-Motyka et al., 2024). This positive trend is already putting a downward pressure on power sector emissions and is expected to slow down the growth in fossil electricity in 2024, potentially marking the beginning of the end of fossil fuels for electricity generation (Wiatros-Motyka et al.). Net additions in solar and wind capacity have generally moved in step with their falling costs per unit of electricity.

Meldrum et al. (2023) argued that tipping points in the power system will be mainly driven by dips in the LCOE[1] produced from solar and wind, with the biggest contribution coming from falling costs for building new capacity. They suggested that reaching the following thresholds would trigger distinct tipping points, leading to an exponential increase in solar and wind penetration:

- LCOE of new wind and solar becomes lower than the LCOE of new coal/gas
- LCOE of new wind and solar with new storage becomes lower than the LCOE of new coal/gas
- LCOE of new wind and solar becomes lower than the LCOE of existing coal/gas
- LCOE of new wind and solar with new storage becomes lower than the LCOE of existing coal/gas.

There are indications that most of the world already passed the first of these thresholds in 2018 (Meldrum et al., 2023). Analysis from Lazard (Bilicic & Scroggins, 2023) indicates that

[1] LCOE refers to an average cost of a unit of energy generated by a power plant over the course of its lifetime.

the LCOE for utility-scale solar PV and onshore wind has been declining since 2009, reaching cost parity with new coal and natural gas sometime around 2018. As of 2023, generation costs for most newly added utility-scale solar PV and onshore wind (96%) were lower than generation costs for new coal and natural gas plants (IEA, 2024e).

The second threshold proposed by Meldrum et al. (2023) was reached in India in July 2024, when an auction for solar with battery storage resulted in winning bids of around USD 0.041 per kWh: cheaper than new coal plants and faster to build (Colthorpe, 2024). This value of USD 41 per MWh is close to parity with the LCOE of new gas (combined cycle, USD 33–108/MWh) and much lower than the LCOE of newly built coal (USD 64–171/MWh) (Bilicic & Scroggins, 2023). The cost of batteries has plunged 99% over the past 30 years, while the energy density of best-performing cells increased five times (Walter et al., 2023).

The third and fourth thresholds might also be in view soon: IEA's analysis shows that in 2023, electricity produced by 75% of new wind and utility-scale solar PV units was cheaper than electricity from existing fossil fuel plants (IEA, 2024e). This year is expected to see further declines in the cost of combined renewables and storage solutions. For instance, as mentioned above, recent auctions for solar PV paired with battery storage in India resulted in winning bids as low as INR 3.41–3.42 (USD 0.04) per kWh (Colthorpe, 2024), potentially dropping below the costs for existing coal generation reported at INR 4.26 (USD 0.05) per kWh (Rodrigues & Lolla, 2023).

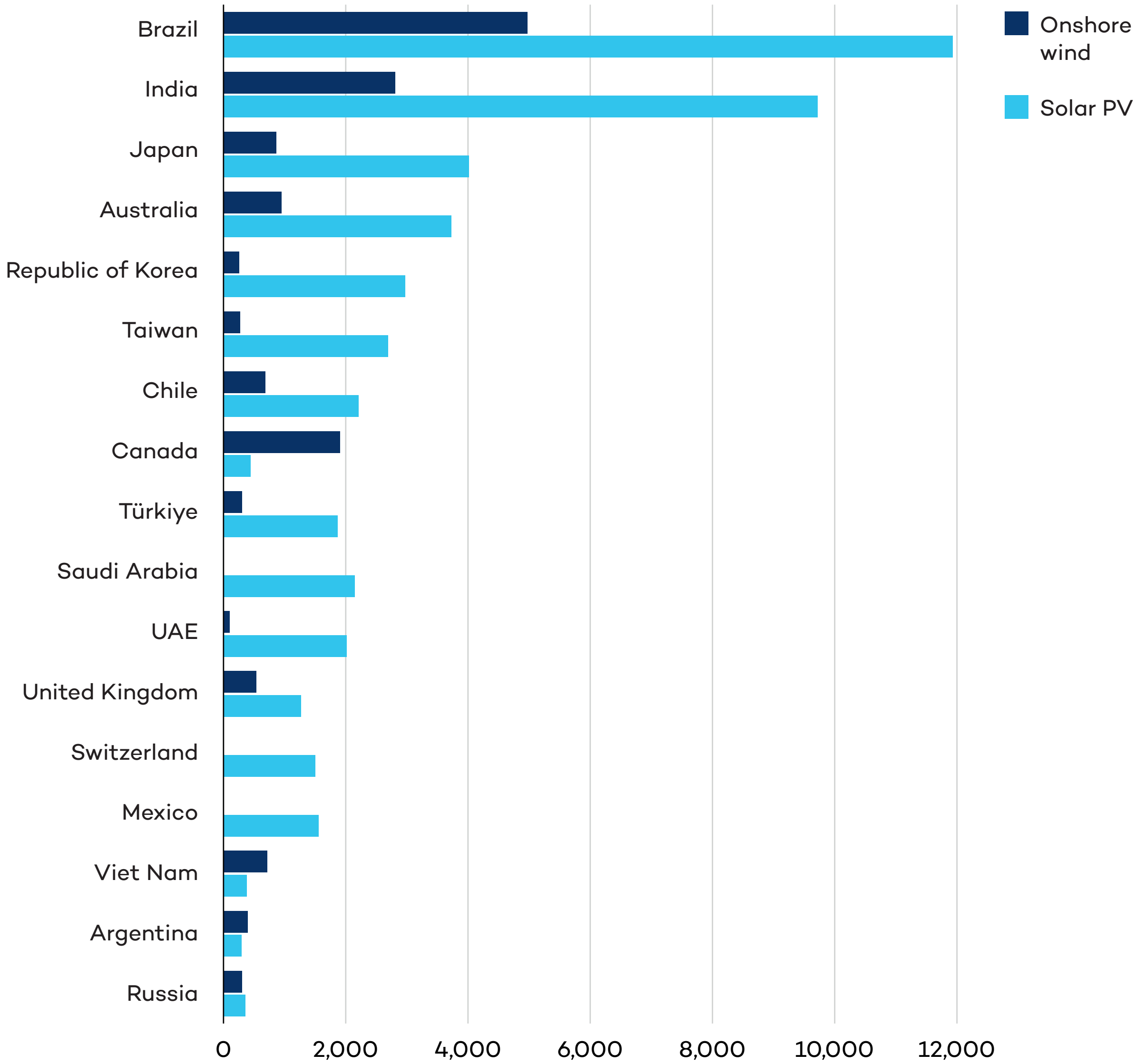
3.2 RE Capacity and Investment Are Heavily Concentrated in Advanced Economies and China

Despite falling LCOE of new RE capacity compared to fossil generation, most countries have not passed tipping points in RE uptake. Since LCOE is a range, there is high variability in actual installation costs across geographies. While it is a useful indicator that can reveal future tipping trends, LCOE can hide significant disparities between countries and the barriers they face in RE deployment.

Many advanced and large emerging economies have been embracing RE and storage. Solar and wind generation could cover up to three-quarters of electricity demand growth in 2024, and renewable power generation is projected to pass coal generation for the first time in 2025 (IEA, 2024c). As a result, the eventual phase-out of fossil fuels from the power sector seems inevitable. However, not all countries are experiencing the rapid uptake, and most electricity systems are far from reaching RE tipping.

At present, the bulk of new solar PV and wind capacity is being built in China, the European Union (EU), the United States, and, to a lesser extent, Brazil and India. Close to 90% of the total solar and wind stock is concentrated in these countries (IRENA, 2024) (Figure 2). At present, China accounts for over 80% of solar manufacturing capacity globally, with dominance all along the supply chain (IEA, 2022) and a growing influence in wind manufacturing. Chinese RE producers have been instrumental in bringing down the costs of RE equipment and making these technologies accessible to EMDEs, but such market concentration could also pose risks for the availability of supplies in the long term if trade barriers or supply chain disruptions were to restrict exports. This risk will decline with increasing market diversification arising from domestic manufacturing policies in economies including Australia, the EU, Indonesia, India, and the United States (Laan et al., 2024). In the meantime, China remains the main source of cheap components that the rest of the world is using to accelerate deployment.

Figure 2. Highest solar PV and onshore wind net capacity additions in 2023 (excluding China, the EU, and the United States), MW



Source: Authors, based on data from IRENA, 2024.

The geographic concentration of new solar PV and wind installations is closely mirrored in investment flows. Spurred by the ongoing public financial support for renewables, most clean energy investment (around 85%) is directed toward China and advanced economies (REN21, 2024). According to BloombergNEF (BNEF) data, in 2023, the world invested USD 623 billion in renewable energy and fuels (BNEF, 2024, as cited in REN21, 2024a). A large share of this investment—USD 609 billion—went to solar PV (USD 393 billion) and wind energy projects (USD 217 billion), including USD 140 billion for onshore wind (REN21, 2024).

In contrast, EMDEs outside of China accounted for less than 15% of the total clean energy investment globally (IEA, 2024d) and an even lower share of solar PV and wind investments in 2023 (BNEF, 2024). Notable exceptions are large EMDEs, such as India and Brazil, although investments have tapered off in some EMDEs. If the current trends continue, there is a risk that EMDEs will miss out on the multiple benefits of the RE revolution that is underway in wealthier countries.

The geographic concentration of new solar PV and wind installations is closely mirrored in investment flows. Spurred by the ongoing public financial support for renewables, most clean energy investment (around 85%) is directed toward China and advanced economies (REN21, 2024). According to BloombergNEF (BNEF) data, in 2023, the world invested USD 623 billion in renewable energy and fuels (BNEF, 2024, as cited in REN21, 2024a). A large share of this investment—USD 609 billion—went to solar PV (USD 393 billion) and wind energy projects (USD 217 billion), including USD 140 billion for onshore wind (REN21, 2024).

In contrast, EMDEs outside of China accounted for less than 15% of the total clean energy investment globally (IEA, 2024d) and an even lower share of solar PV and wind investments in 2023 (BNEF, 2024). Notable exceptions are large EMDEs, such as India and Brazil, although investments have tapered off in some EMDEs. If the current trends continue, there is a risk that EMDEs will miss out on the multiple benefits of the RE revolution that is underway in wealthier countries.

4.0 Barriers to Tipping

The lack of deployment of solar PV and onshore wind in lower-income countries indicates that impediments remain. Multiple regulatory, socio-economic, infrastructural, and political challenges can delay the achievement of RE tipping points in EMDEs. Barriers can be caused by system inertia due to long-standing dependence on fossil fuels, the inherent differences between fossil and renewable installations, or the financial, fiscal, or regulatory challenges faced by individual EMDEs. Some barriers, such as long regulatory and permitting times, are common to both advanced economies and EMDEs (IEA, 2024b).

4.1 Dampening Feedbacks 1: Barriers related to fossil fuel incumbency

System inertia is often overlooked in discussions on the pathways for RE acceleration, but the tipping points approach helps bring it to light. Electricity systems and socio-political structures are built around coal and gas as the incumbents. Multiple "dampening feedbacks" hold back the build-out of RE, including

- electricity infrastructure built around a centralized baseload supply of energy and the perception of incompatibility of variable renewable energy (VRE) sources with such a system
- financing architecture and markets geared toward fossil fuels (Oil Change International, 2023; Polzin et al., 2017)
- public financial support for fossil fuels, including subsidies but also through SOEs (Laan et al., 2023)
- existing and sometimes young coal or gas power generation infrastructure (i.e., sunk costs stifling a switch to RE sources)
- long-term fossil fuel contracts in some EMDE that make the switch to renewables costly (IEA, 2024b)
- the potential cost of just transitions
- influence of vested interests and other elements of a carbon lock-in (Erickson et al., 2015; Sovacool, 2017; Unruh, 2000).

Public support for fossil fuels creates multiple feedbacks that solidify their incumbent status. Some have argued that removing fossil fuel subsidies would only marginally reduce GHG emissions (Jewell et al., 2018). However, such assessments do not take into account the reform's ability to change the overall "purpose" of the energy system and the potential to break down economic and political feedback loops reinforcing fossil fuel incumbency (Erickson et al., 2020). Subsidy beneficiaries defend continued fossil fuel subsidization, creating political barriers to subsidy reform and broader decarbonization efforts (Geels, 2014; Koplow, 2014). Producer subsidies incentivize spending on new fossil fuel infrastructure, leading to a carbon lock-in and requiring further subsidization down the line (Newell & Johnstone, 2018; Sovacool, 2017).

4.2 Dampening Feedbacks 2: Barriers related to the mismatch between variable RE and existing institutions and infrastructure

Barriers also arise from the mismatch between the existing energy infrastructure, institutions, and policy architecture and the intermittent nature of solar and wind energy. In most systems, transmission and distribution infrastructure is built for centralized baseload generation, financial institutions are geared toward investing in energy sources with costs distributed over the plant's lifetime, and policy frameworks and grid codes are meant to regulate dispatchable power sources. Some of the roadblocks faced by VRE stem from the perceived risks of integrating them into power systems. In systems with increasing shares of wind and solar capacity, VRE has been much less disruptive for the power system flexibility than predicted by some RE pessimists. However, some challenges exist, and it is necessary to adapt components of the power system to better accommodate VRE. The types of barriers faced by countries often depend on the stage of VRE penetration, along with their economic profile (see Box 2).[2]

Box 2. IEA's system integration of renewables framework

The IEA groups countries into six different integration "phases" based on the level of VRE penetration in the system and the country's economic characteristics that affect power system flexibility. This is done primarily to highlight the different challenges faced by countries as the share of VRE increases in the power system and to offer differentiated responses to such challenges in the interest of maintaining system flexibility. Power system flexibility is the ability of a power network to sustain uninterrupted service despite sudden and significant fluctuations in supply or demand, regardless of the cause.

In Phase 1, the impact of VRE on power systems is negligible. In Phase 2, the share of VRE increases and starts affecting system operations, but the impact is manageable with minor adjustments and operational procedures. In Phases 3 and 4, integration of VRE requires more sophisticated demand response measures, as well as investments in grids and storage solutions. Finally, in Phases 5 and 6, VRE become the main source of electricity, necessitating a redesign of existing infrastructure, market structures, and regulatory frameworks, along with extensive storage capacity, expanded grids, and cross-sectoral integration (IEA, 2019).

Most EMDEs are in Phases 1-3 of IEA's classification (IEA, 2024a). Most advanced economies, China, and a few large EMDE have moved to Phases 2-4. For now, only a handful of countries have reached Phase 4 of VRE integration: Germany, Ireland, Spain, and the United Kingdom. Denmark is the only country in Phase 5, with over 60% of electricity generation coming from VRE.

Source: IEA, 2020.

[2] It is important to distinguish between VRE and other forms of RE like hydroelectric power, which can provide non-variable base load and therefore can be the primary source of electricity in a system without impacts on the power system (assuming no droughts).

The barriers faced by countries with a high penetration of VRE could be a good indicator of the issues that other EMDEs would need to address when they reach substantial levels of solar and wind capacity. As the capacity of VRE grows, they are increasingly confronted with the need to manage intermittency, as well as permitting delays due to grid capacity concerns. According to the IEA, the installation of some 1,500 GW of RE capacity is being delayed as it awaits transmission connection worldwide (IEA, 2024f). In the United States alone, new solar and wind capacity in the "interconnection queues"[3] ballooned to 1,480 GW by the end of 2023, with the average time between the interconnection request and commercial operations growing from 3 to 5 years during the 2015–2023 period (Rand et al., 2024).

Many advanced economies—especially those with merit-based order dispatch in wholesale electricity markets—may be facing another dilemma. As the share of VRE increases in the grid, the "bankability" of RE projects is under question because of increasing volatility and the influx of generating capacity with almost zero operating costs, true for all VRE sources (Christophers, 2024; Halttunen et al., 2020; Heptonstall & Gross, 2020). As competition among VRE generators during peak output times drives down spot prices, their profit margins are getting thinner. This may discourage private investment in new solar PV and wind projects in the absence of guaranteed profits. A string of announcements from European energy producers planning to slow down RE capacity additions highlights this trend (Novik & Millard, 2024). Until a solution is found (such as the manufacture of green hydrogen to absorb excess capacity at peak times), countries might need to continue providing support to RE generators to ensure that flawed market design does not prevent ongoing deployment.

4.3 Barriers Related to EMDEs

The high cost of capital is one of the most significant barriers to energy transition in EMDEs (IEA, 2024d). High upfront capital investment needs mean that RE deployment depends on the availability of capital. Country-specific and sector-related risks, whether perceived or real, hinder investment flows and add a risk premium. These include policy and regulatory uncertainty, currency risks that necessitate additional hedging costs, and financial viability of state-owned off-takers. In the current high-interest environment, the issue is ever more pressing. Capital for utility-scale solar PV projects is more than twice as expensive in EMDEs as in advanced economies (IEA, 2024d).

In addition to limited capital availability, efforts to tip power systems in EMDEs are facing many of the dampening feedbacks mentioned above—those related to fossil fuel incumbency and VRE intermittency. These include additional firming costs for ensuring flexibility, limited grid capacity, supply chain disruptions, social resistance, public financial support for fossil fuels, and vested interests. In addition, electricity utilities in EMDEs are often highly indebted as a result of decades of providing electricity at below-cost tariffs. As such, they are unable to invest in grids and RE infrastructure. Fossil and RE are also highly politicized in many countries, leading to decisions based on ideology rather than economics.

[3] In the United States, large-scale capacity development does not start before the authorization to connect to the grid is granted, and a large share of capacity in the interconnection queues is never built.

5.0 Public Financial Support: Status and trends

Some interventions to address barriers may have limited budgetary impacts, such as streamlining permitting and approval processes. However, increased government spending is likely to be required for three main reasons.

1. Paris-aligned pathways require a rapid energy transition that would surpass the typical rate of capital stock turnover: RE needs to be more cost-effective than both new and existing fossil fuel capacity.
2. Investment in grids will be crucial to accommodate the growing share of distributed and variable energy sources. Grid modernization and expansion is not a subsidy directly for the RE industry but requires major public investment.
3. Fossil fuel prices do not reflect their externalities, including climate and health impacts; therefore, government intervention is essential to reallocate capital toward cleaner technologies.

Public financial support can play a role in addressing most, if not all, of the barriers faced by EMDEs in reaching RE tipping, either through the direct allocation of funds through subsidies and other incentives or through reforms that would require an indirect increase in resource allocation, for instance, by reforming the regulatory framework for electricity systems or streamlining the processes for processing installation permits or supporting new storage infrastructure that would reduce the need for curtailment.

According to IISD's analysis, in the period from 2020 to 2022, G20 members spent an average of USD 168 billion a year on public financial support for RE (Laan et al., 2024). This included direct budgetary transfers, tax concessions, FiT, feed-in premiums, and renewable auction schemes. This is likely to be an underestimate, given many support measures could not be quantified due to a lack of data; plus, it does not include other major forms of public spending on energy such as public finance or capital investments by SOEs. Solar PV and wind energy were the largest recipients of support (Laan et al., 2024).

Analysis of public money allocations shows that 96% of support was concentrated in advanced economies and China. This is not surprising given resource constraints in many EMDEs, but it is a worrying trend that underscores the risk of a stalled energy transition in many countries, especially in the Global South. Finance and technology transfers from developed economies would be necessary to ensure that developing countries can reap the full benefits of the clean energy transition and that the world manages to triple RE capacity by 2030.

There are indications that public support for new installations is changing in response to falling LCOEs of renewables. In mature markets, there has been a shift from generation-based incentives to support for grids, integration, local manufacturing, and storage (Laan et al., 2024). For instance, China's central government has aimed to reduce the industry's reliance on consumer subsidies since 2018. Instead, the government has emphasized public support for innovation and improved efficiencies (Zhang et al., 2021). 2021 marked the end of sizable subsidy programs (mostly FiTs) for newly built solar PV and wind plants and record capacity additions continue (although funding continues for earlier projects built under different cost conditions).

In European countries, too, there is a notable shift to instruments with competitive elements, such as renewable auctions or tender schemes instead of FiTs (Council of European Energy Regulators, 2023), with mixed results. In recent years, policy-makers have faced undersubscribed RE auctions after placing auction price caps, forcing them to raise or remove price caps to attract bidders (REN21, 2024; van Renssen, 2023). Some auction design challenges have since been resolved, with the introduction of the EU's "Fit-for-55" package and adjustments in the auctions and permitting rules, leading to a 50% increase in the approval rate for new utility-scale RES projects (IEA, 2024g).

These observations indicate that enabling conditions continue to be helpful for RE deployment, even in countries where tipping points have been achieved for onshore wind and solar. Withdrawing policy support too early could jeopardize the speed of RE uptake and broader decarbonization goals.

6.0 The Role of Public Finance in Forcing Tipping

Both domestic and international public finance will be crucial to bridge the gap in RE investment in developing countries due to its ability to de-risk funding opportunities and crowd in much larger flows of private investment. Developed countries would need to deliver an estimated USD 100 billion in concessional finance to leverage USD 1 trillion of private investment in clean energy in EMDEs every year (BlackRock Investment Institute, 2021). Similarly, to reach climate and energy goals in the IEA's Net Zero Emissions Scenario, EMDEs outside China would need to mobilize USD 0.9 trillion–1.1 trillion in private finance annually by 2030, with around a third of this amount going toward renewables and a third toward grid upgrades and other RE integration measures. For this to happen, annual concessional funding for RE in EMDEs from developed economies and development finance institutions (DFIs) would need to reach USD 80 billion–100 billion (IEA & International Finance Corporation [IFC], 2023).

Experience shows that debt instruments are more prevalent in financing mature, cost-competitive and less risky technologies, such as solar PV and onshore wind (IEA, 2024g). However, emerging economies with strained budgets would require effective funding mechanisms that do not increase their reliance on debt financing. DFIs would need to play a proactive role in increasing the amount of funding allocated to RE, especially of a concessional nature. DFI financing accounts for only 1% of all energy investments but has a significant potential to leverage private investment (IEA & IFC, 2023). In recent years, DFI financing for fossil fuels has notably declined (REN21, 2024), mainly due to a decrease in such financing from China (IEA, 2024g). At the same time, there was no increase in clean energy financing from DFIs, despite its tremendous potential to catalyze private investment (IEA & IFC, 2023). Additionally, most DFI financing for energy is provided as debt, with only a portion being concessional, and only 6% of total financing is provided as grants. More needs to be done to target DFI investments in clean energy, especially mature solar PV and wind technologies.

In 2021, 34 countries and five public finance institutions formed the Clean Energy Transition Partnership (CETP) with the goal of ending international public finance for fossil fuels and prioritizing financing of clean energy. Most members have significantly decreased financing for fossil fuels, with a CETP total of USD 5.2 billion in 2023 (Jones et al., 2024; Jones & Mun, 2023). At the same time, there was only a slight increase in clean energy financing from the average of USD 18.4 billion annually in 2019–2021 to USD 26 billion in 2022 and USD 21.3 billion in 2023. Moreover, most recipients of clean energy finance from CETP signatories are upper and upper-middle income countries, with Spain, Poland, and the United States receiving most clean energy financing in 2023 (Jones et al., 2024). CETP members need to do more to ensure their clean energy financing is scaled up and directed to a fair and transformative clean energy transition in the countries that need it most. Meanwhile, the CETP does not include some large fossil fuel financiers, such as China, Japan, and South Korea. Countries that are not members of the CETP should consider how they can join and end their international public finance for fossil fuels.

A new climate finance goal (the "New Collective Quantified Goal") is being considered for agreement at COP 29. This will likely include a core public finance element. A transfer of at least USD 1 trillion per year in grants and grant-equivalent terms is being called for from developed to developing countries to address mitigation, adaptation, and loss and damage as part of inclusive just transition pathway (Climate Action Network, 2024). If a fair and ambitious climate finance goal is agreed upon in Baku, this could significantly boost public finance provision toward reaching RE tipping points. In addition, financing is being provided through Just Energy Transition Partnerships to help coal-dependent EMDEs transition away from fossil energy and toward clean energy in a way that also addresses social issues associated with the transition (Kramer, 2022).

7.0 Insights for Solar and Wind Deployment in EMDEs

The achievement of socio-technical tipping points for solar and onshore wind at the global level is a hugely positive development for decarbonization of the energy sector, lower-cost energy, pollution reduction, and establishment of clean energy industries. However, lower-income countries are being left behind in the clean energy transition. For these countries, policy-makers at the international, national, and subnational levels need to put in place the policies that can allow low-cost solar PV and wind to enter the market.

Lessons from the tipping points literature and experience in advanced economies and China indicate that system-wide shifts may appear to occur due to a single intervention that causes tipping, but a suite of policies is needed to create the conditions for change. National-level analysis is needed to determine where interventions are most needed to create tipping effects. While each country's pathway will be unique, experience from previous successful support to RE and current trends suggest that measures are likely to be needed that reduce risks or increase the returns for investors, address key barriers to integration, and create an enabling environment for RE production and consumption (Table 1).

Table 1. Types of policy aims and measures to reach them

Tipping point and policy category	Policy aim	Type of measure
Create positive feedbacks by encourage a virtuous cycle of deployment, economies of scale, and cost reductions	Reduce cost of capital	Concessional financing or loan guarantees
	Long-term policy and price certainty	Power purchase agreements
	Measures that discover market prices in local contexts, thereby reducing public costs	Auctions, feed-in premiums (FiPs), contracts for difference (CfDs)
	Build up local supply chain	Skilling workforce and new business support
	Trade policies that balance access to low-cost imports with domestic manufacturing objectives	Custom duties, local content requirements
Remove negative feedbacks	Ensure fossil fuel prices reflect their negative impacts	Fossil fuel subsidy reform and taxation, carbon taxation, (accompanied by cash transfers or tax cuts for vulnerable group)
	Restructure SOEs so they are technologically neutral	Transition plans, RE mandates, regulations

Tipping point and policy category	Policy aim	Type of measure
	Retiring or retrofitting fossil capacity	Structural adjustment and just transitions funding
	Address vested interests and political bias	Increase transparency, regulations to disentangle fossil and political interests
Create an enabling environment	Grid modernization	Budget transfers, concessional financing, SOE investments
	Electricity sector reform to ensure utilities are financially viable and can invest in RE and grids	Tariff reform, cash transfers, or tax cuts for vulnerable groups
	Ancillary services and storage	Budget transfers, concessional financing, SOE investments

Source: Authors.

The IEA (2024b) provides an extensive list of recommendations for addressing challenges to RE uptake in developing countries. Policy-makers could consider a range of measures to reduce risks and increase the bankability of RE projects, from providing clear visibility for projects through power purchase agreements and regulations to guarantee RE projects are executed on schedule to improving off-taker cost recovery and facilitating pre-development permitting of projects. To improve uptake in areas with weak grids, countries could incentivize off-grid and mini-grid RE solutions and harness unused hydropower resources, where possible.

In low-income countries, funding for these reforms will need to be provided by international and domestic sources. Public finance for RE will need to be scaled up and directed to low-income countries, with an increased share of concessional and grant financing (see earlier section). Countries can also mobilize domestic revenues through fossil fuel subsidy reform. In 2023, public financial support for fossil fuels reached USD 780 billion (Black et al., 2023).

Repurposing public money from fossil fuels to RE has the double benefit of de-risking and crowding in private investment for RE deployment on the one hand and removing the support from incumbent fossil fuels, on the other. Shifting capital investments by SOEs from fossil fuels to renewables can also accelerate the energy transition. IEA estimates that governments and state-owned utilities are responsible for nearly half of all energy investments made in EMDEs, with a high share of government money in some economies going toward financing fossil fuels (IEA, 2024g). Reforming such spending could free up the much-needed resources to fund solar PV and wind deployment.

8.0 Conclusion

The rapid cost reductions and deployment of solar PV and wind energy suggest that electricity generation has tipped irreversibly toward RE at the global level. But the pace of change is not sufficient to achieve 2030 targets for the climate or to ensure access to affordable, reliable, sustainable, and modern energy for all (Sustainable Development Goal 7). Concerted efforts from policy-makers, including public financial support, are required to align the uptake of RE with these goals.

The tipping point literature suggests that there is unlikely to be a single policy that can tip a system in favour of a new technology over an established incumbent: a combination of policies—both financial and non-financial—is needed to create the conditions for systems to tip and to remove barriers. The whole-systems approach indicates that decarbonization policies are most effective when introduced in concert with other instruments in a coherent and consistent manner. The tipping points framework can help policy-makers identify where interventions are most needed to "force" system tipping in favour of renewables in lagging countries or to accelerate deployment in mature markets based on individual country circumstances.

Policy support and public investment are also needed to balance the conditions that favour the incumbent, fossil fuels. Most energy systems have been constructed around fossil fuels, creating significant inertia that must be overcome to allow change. The mismatch between fossil-based electricity systems and the intermittency of renewables is not as noticeable at the initial stages of VRE adoption. As the share of VRE in the system increases, this discrepancy needs to be addressed to avoid the stalling of the transition.

Policy-makers should strive to prepare the ground early and implement the changes to the existing infrastructure and institutions, such as grid modernization and demand-side management for grid flexibility and energy mix diversification to include non-variable RE sources, such as hydro and geothermal power. Interventions are also needed to overcome the social and political barriers to change.

In countries with strained public budgets and indebted utilities, allocating budgetary resources for RE subsidies and supporting infrastructure will be challenging. Fossil fuel subsidy reform may be a viable policy option for governments to mobilize domestic revenue while noting that any reforms need to be undertaken in a socially responsible manner (see Beaton et al., 2013). At the same time, finance and technology transfers from developed economies, including through support from DFIs, will be crucial to support the transition in EMDEs.

References

Beaton, C., Gerasimchuk, I., Laan, T., Lang, K., Vis-Dunbar, D., & Wooders, P. (2013). *A guidebook to fossil-fuel subsidy reform for policy-makers in Southeast Asia.* https://www.iisd.org/gsi/sites/default/files/ffs_guidebook.pdf

Bilicic, G., & Scroggins, S. (2023). *Lazard's levelized cost of energy analysis—Version 16.0.* Lazard. https://www.lazard.com/research-insights/2023-levelized-cost-of-energyplus/

Black, S., Liu, A. A., Parry, I. W. H., & Vernon, N. (2023, August 24). *IMF fossil fuel subsidies data: 2023 update.* https://www.imf.org/en/Publications/WP/Issues/2023/08/22/IMF-Fossil-Fuel-Subsidies-Data-2023-Update-537281

BlackRock Investment Institute. (2021). *The big emerging question: Financing the transition to net zero.* BlackRock. https://www.blackrock.com/corporate/literature/whitepaper/bii-the-big-emerging-question-2021.pdf

BloombergNEF. (2024). *Energy transition investment trends 2024.* https://about.bnef.com/energy-transition-investment/

Christophers, B. (2024). *The price is wrong: Why capitalism won't save the planet.* Verso.

Climate Action Network. (2024). *Climate Action Network submission: NCQG.* https://climatenetwork.org/resource/climate-action-network-submission-ncqg/

Colthorpe, A. (2024, July 17). *SECI tender a 'game changer' for low-cost renewables and energy storage in India*. Energy Storage News. https://www.energy-storage.news/seci-tender-a-game-changer-for-low-cost-renewables-and-energy-storage-in-india/

Council of European Energy Regulators. (2023). *Status review of renewable support schemes in Europe for 2020 and 2021*. https://www.ceer.eu/publication/status-review-of-renewable-support-schemes-in-europe-for-2020-and-2021/

Erickson, P., Kartha, S., Lazarus, M., & Tempest, K. (2015). Assessing carbon lock-in. *Environmental Research Letters, 10*(8), Article 084023. https://doi.org/10.1088/1748-9326/10/8/084023

Erickson, P., van Asselt, H., Koplow, D., Lazarus, M., Newell, P., Oreskes, N., & Supran, G. (2020). Why fossil fuel producer subsidies matter. *Nature*. https://doi.org/10.1038/s41586-019-1920-x

Fesenfeld, L. P., Schmid, N., Finger, R., Mathys, A., & Schmidt, T. S. (2022). The politics of enabling tipping points for sustainable development. *One Earth, 5*(10), 1100–1108. https://doi.org/10.1016/j.oneear.2022.09.004

Geels, F. W. (2014). Regime resistance against low-carbon transitions: Introducing politics and power into the multi-level perspective. *Theory, Culture & Society, 31*(5), 21–40. https://doi.org/10.1177/0263276414531627

Geels, F. W., & Ayoub, M. (2023). A socio-technical transition perspective on positive tipping points in climate change mitigation: Analysing seven interacting feedback loops in offshore wind and electric vehicles acceleration. *Technological Forecasting and Social Change, 193*, Article 122639. https://doi.org/10.1016/j.techfore.2023.122639

Halttunen, K., Staffell, I., Slade, R., Green, R., Saint-Drenan, Y.-M., & Jansen, M. (2020). *Global assessment of the merit-order effect and revenue cannibalisation for variable renewable energy* (SSRN Scholarly Paper 3741232). https://doi.org/10.2139/ssrn.3741232

Heptonstall, P. J., & Gross, R. J. K. (2020). A systematic review of the costs and impacts of integrating variable renewables into power grids. *Nature Energy, 6*(1), 72–83. https://ideas.repec.org/a/nat/natene/v6y2021i1d10.1038_s41560-020-00695-4.html

International Energy Agency. (2019). *Status of power system transformation 2019: Power system flexibility*. https://www.iea.org/reports/status-of-power-system-transformation-2019

International Energy Agency. (2020). *Introduction to system integration of renewables.* https://www.iea.org/reports/introduction-to-system-integration-of-renewables/technology-options

International Energy Agency. (2022). *Solar PV global supply chains.* https://www.iea.org/reports/solar-pv-global-supply-chains/executive-summary

International Energy Agency. (2024a). *Annual variable renewable energy share and corresponding system integration phase in selected countries/regions, 2022.* https://www.iea.org/data-and-statistics/charts/annual-variable-renewable-energy-share-and-corresponding-system-integration-phase-in-selected-countries-regions-2022

International Energy Agency. (2024b). *COP28 tripling renewable capacity pledge: Tracking countries' ambitions and identifying policies to bridge the gap*. https://www.iea.org/reports/cop28-tripling-renewable-capacity-pledge

International Energy Agency. (2024c). *Electricity mid-year update-July 2024.* https://www.iea.org/reports/electricity-mid-year-update-july-2024

International Energy Agency. (2024d). *Reducing the cost of capital.* https://www.iea.org/reports/reducing-the-cost-of-capital

International Energy Agency. (2024e). *Renewables 2023: Analysis and forecast to 2028.* https://www.iea.org/reports/renewables-2023

International Energy Agency. (2024f). *Strategies for affordable and fair clean energy transitions.* https://www.iea.org/reports/strategies-for-affordable-and-fair-clean-energy-transitions

International Energy Agency. (2024g). *World energy investment 2024.* https://iea.blob.core.windows.net/assets/60fcd1dd-d112-469b-87de-20d39227df3d/WorldEnergyInvestment2024.pdf

International Energy Agency & International Finance Corporation. (2023). *Scaling up private finance for clean energy in emerging and developing economies.* https://www.iea.org/reports/scaling-up-private-finance-for-clean-energy-in-emerging-and-developing-economies

International Renewable Energy Agency. (2024). *Renewable capacity statistics 2024* [Dataset]. https://www.irena.org/Publications/2024/Mar/Renewable-capacity-statistics-2024

International Renewable Energy Agency, Global Renewables Alliance, & COP28 Presidency. (2023). *Tripling renewable power and doubling energy efficiency by 2030: Crucial steps towards 1.5°C*. International Renewable Energy Agency. https://www.irena.org/Publications/2023/Oct/Tripling-renewable-power-and-doubling-energy-efficiency-by-2030

Jewell, J., McCollum, D., Emmerling, J., Bertram, C., Gernaat, D. E. H. J., Krey, V., Paroussos, L., Berger, L., Fragkiadakis, K., Keppo, I., Saadi, N., Tavoni, M., van Vuuren, D., Vinichenko, V., & Riahi, K. (2018). Limited emission reductions from fuel subsidy removal except in energy-exporting regions. *Nature, 554*, 229–233.

Jones, N., & Mun, B. (2023). *Putting promises into practice: Clean Energy Transition Partnership signatories' progress on implementing clean energy commitments.* International Institute for Sustainable Development. https://www.bankingsupervision.europa.eu/ecb/pub/pdf/ssm.202011finalguideonclimate-relatedandenvironmentalrisks~58213f6564.en.pdf

Jones, N., O'Manique, C., McGibbon, A., & DeAngelis, K. (2024). *Out with the old, slow with the new: Countries are underdelivering on fossil-to-clean energy finance pledge*. International Institute for Sustainable Development. https://www.iisd.org/system/files/2024-08/countries-underdelivering-fossil-clean-energy-finance-pledge.pdf

Klitkou, A., Bolwig, S., Hansen, T., & Wessberg, N. (2015). The role of lock-in mechanisms in transition processes: The case of energy for road transport. *Environmental Innovation and Societal Transitions, 16*, 22–37. https://doi.org/10.1016/j.eist.2015.07.005

Koplow, D. (2014). Global energy subsidies. In A. Halff, B. K. Sovacool, & J. Rozhon (Eds.), *Energy poverty* (pp. 316–337). Oxford University Press. https://doi.org/10.1093/acprof:oso/9780199682362.003.0016

Kramer, K. (2022). *Just energy transition partnerships: An opportunity to leapfrog from coal to clean energy.* International Institute for Sustainable Development. https://www.iisd.org/articles/insight/just-energy-transition-partnerships

Laan, T., Do, N., Haig, S., Urazova, I., Posada, E., Wang, H. (2024). *Public financial support for renewable power generation and integration in the G20 countries.* International Institute for Sustainable Development. https://www.iisd.org/publications/report/renewable-energy-support-g20

Laan, T., Geddes, A., Do, N., Cameron, L., Goel, S., & Jones, N. (2023). *Burning billions: Record public money for fossil fuels impeding climate action*. Energy Policy Tracker. https://www.energypolicytracker.org/burning-billions-record-fossil-fuels-support-2022/

Lenton, T. M., Armstrong McKay, D. I., Loriani, S., Abrams, J. F., Lade, S. J., Donges, J. F., Milkoreit, M., Powell, T., Smith, S. R., Zimm, C., Buxton, J. E., Bailey, E., Laybourn, L., Ghadial, A., & Dyke, J. G. (2023). *The global tipping points report 2023.* University of Exeter. https://global-tipping-points.org

Lenton, T. M., Benson, S., Smith, T., Ewer, T., Lanel, V., Petykowski, E., Powell, T. W. R., Abrams, J. F., Blomsma, F., & Sharpe, S. (2022). Operationalising positive tipping points towards global sustainability. *Global Sustainability, 5*(e1). Cambridge Core. https://doi.org/10.1017/sus.2021.30

Meadows, D. H. (2008). *Thinking in systems: A primer* (D. Wright, Ed.). Chelsea Green Publishing.

Meckling, J. (2019). Governing renewables: Policy feedback in a global energy transition. *Environment and Planning C: Politics and Space, 37*(2), 317–338. https://doi.org/10.1177/2399654418777765

Meldrum, M., Pinnell, L., Brennan, K., Romani, M., Sharpe, S., & Lenton, T. (2023). *The breakthrough effect: How to trigger a cascade of tipping points to accelerate the net zero transition.* Environmental Studies Institute. https://www.systemiq.earth/wp-content/uploads/2023/01/The-Breakthrough-Effect.pdf

Milkoreit, M., Hodbod, J., Baggio, J., Benessaiah, K., Calderón-Contreras, R., Donges, J. F., Mathias, J.-D., Rocha, J. C., Schoon, M., & Werners, S. E. (2018). Defining tipping points for social-ecological systems scholarship—An interdisciplinary literature review. *Environmental Research Letters, 13*(3), 033005. https://doi.org/10.1088/1748-9326/aaaa75

Nahm, J. (2021). *Collaborative advantage: Forging green industries in the new global economy*. Oxford University Press.

Nahm, J. (2023). *How solar developed from the bottom-up in China.* IGCC Blog. https://ucigcc.org/blog/how-solar-developed-from-the-bottom-up-in-china/

Nemet, G. F. (2019). *How solar energy became cheap: A model for low-carbon innovation.* Routledge. https://doi.org/10.4324/9780367136604

Newell, P., & Johnstone, P. (2018). The political economy of incumbency: Fossil fuel subsidies in global and historical context. In J. Skovgaard (Ed.), *The politics of fossil fuel subsidies and their reform* (1st ed., pp. 66–80). Cambridge University Press. https://doi.org/10.1017/9781108241946.006

Novik, M., & Millard, R. (2024, May 19). European utilities cut renewable targets as high costs and low power prices bite. *Financial Times.* https://www.ft.com/content/625042f5-131e-434c-9d11-af0d39e8cb60

Oil Change International. (2023). *Public finance for energy database.* https://energyfinance.org/#/data

Polzin, F., Sanders, M., & Täube, F. (2017). A diverse and resilient financial system for investments in the energy transition. *Current Opinion in Environmental Sustainability, 28*, 24–32. https://doi.org/10.1016/j.cosust.2017.07.004

Rand, J., Manderlink, N., Gorman, W., Wiser, R., Seel, J., Kemp, J. M., Jeong, S., & Kahrl, F. (2024). *Queued up: Characteristics of power plants seeking transmission interconnection as of the end of 2023*. Lawrence Berkeley National Laboratory. https://emp.lbl.gov/queues

REN21. (2024). *Renewables 2024 global status report collection.* https://www.ren21.net/wp-content/uploads/2019/05/GSR2024_GlobalOverview_Full_Report_with_endnotes_web.pdf

Rodrigues, N., & Lolla, A. (2023). *India's solar adoption entering accelerating growth phase.* Ember. https://ember-climate.org/insights/research/india-solar-uptake/

Sharpe, S., & Lenton, T. M. (2021). Upward-scaling tipping cascades to meet climate goals: Plausible grounds for hope. *Climate Policy, 21*(4), 421–433. https://doi.org/10.1080/14693062.2020.1870097

Sovacool, B. K. (2017). Reviewing, reforming, and rethinking global energy subsidies: Towards a political economy research agenda. *Ecological Economics, 135*, 150–163. https://doi.org/10.1016/j.ecolecon.2016.12.009

Stechemesser, A., Koch, N., Mark, E., Dilger, E., Klösel, P., Menicacci, L., Nachtigall, D., Pretis, F., Ritter, N., Schwarz, M., Vossen, H., & Wenzel, A. (2024). Climate policies that achieved major emission reductions: Global evidence from two decades. *Science, 385*(6711), 884–892. https://doi.org/10.1126/science.adl6547

Trancik, J. E., Brown, P. R., Jean, J., Kavlak, G., Klemun, M. M., Edwards, M. R., McNerney, J., Miotti, M., Mueller, J., & Needell, Z. (2015). *Technology improvement and emissions reductions as mutually reinforcing efforts: Observations from the global development of solar and wind energy.* Institute for Data, Systems and Society, Massachusetts Institute of Technology. https://energy.mit.edu/publication/technology-improvement-and-emissions-reductions-as-mutually-reinforcing-efforts/

Unruh, G. C. (2000). Understanding carbon lock-in. *Energy Policy, 28*(12), 817–830. https://doi.org/10.1016/S0301-4215(00)00070-7

Van Renssen, S. (2023, April 14). *EU: Undersubscribed renewable energy auctions call for action.* Energy Monitor. https://www.energymonitor.ai/finance/regulation-policy/eu-undersubscribed-renewables-auctions-call-for-government-action/

Walter, D., Bond, K., Butler-Sloss, S., Speelman, L., Numata, Y., & Atkinson, W. (2023). X-change: Batteries. *The battery domino effect.* RMI. https://rmi.org/insight/x-change-batteries/

Wiatros-Motyka, M., Fulghum, N., & Jones, D. (2024). Global electricity review 2024. Ember. https://ember-climate.org/app/uploads/2024/05/Report-Global-Electricity-Review-2024.pdf

Winkelmann, R., Donges, J. F., Smith, E. K., Milkoreit, M., Eder, C., Heitzig, J., Katsanidou, A., Wiedermann, M., Wunderling, N., & Lenton, T. M. (2022). Social tipping processes towards climate action: A conceptual framework. *Ecological Economics, 192*, 107242. https://doi.org/10.1016/j.ecolecon.2021.107242

Zhang, Y., Xie, P., Huang, Y., Liao, C., & Zhao, D. (2021). *Evolution of solar photovoltaic policies and industry in China.* IOP Conference Series: Earth and Environmental Science, 651(2), 022050. https://doi.org/10.1088/1755-1315/651/2/022050

Published by the International Institute for Sustainable Development

Head Office

111 Lombard Avenue, Suite 325
Winnipeg, Manitoba
Canada R3B 0T4

Tel: +1 (204) 958-7700
Website: www.iisd.org
X: @IISD_news

IISD

iisd.org