Symbiosis Of Climate Finance And Technological Innovations To Foster The Energy Transition

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Abstract

As climate change intensifies, it becomes increasingly critical to address its impacts through climate finance and technological innovation. This article delves into the symbiotic relationship between climate finance and digital technologies, focusing on their role in the decarbonization of the energy sector. By examining the case of Singapore, a nation facing unique constraints, we elucidate the significance of innovations in climate finance and digital technologies in increasing cleaner energy generation, greener technologies, and interconnection infrastructure. We further elaborate the discussion to other countries. Despite a promising future, integrating climate finance with technology mechanisms encounters formidable challenges, including the need for clearer incentives, inadequate pace and scale of investments, shortage of quality skilled human capital, considerations of ecological impacts, and alignment with short-term investor perspectives. To surmount these hurdles, concerted efforts from both public and private sectors are crucial to facilitate climate finance in steering the transition towards a sustainable and decarbonized energy future.

Introduction

In recent decades, climate change has become a pressing global concern, driven by natural processes and human activities. This has led to unprecedented ecological shifts, including but not limited to extreme weather events, wildfires, biodiversity loss, disruptions to the Earth's life support systems, and rising sea levels (Pörtner et al., 2022; Clarke, Otto, Stuart-Smith, & Harrington, 2022). To date, the Paris Agreement has been ratified by 193 nations, and 194 Parties have submitted their Nationally Determined Contributions (NDCs). With the inclusion of these newly revised NDCs, the combined effect of current and announced net zero commitments is anticipated to lead to a further reduction in emissions by 2030. This has the potential to cap global warming at 2.1°C, preventing a more severe increase beyond 2.8°C, as outlined in the initial NDCs (IRENA, 2022). In the ASEAN region, although the member states have established their NDCs for Greenhouse Gas (GHG) emission reduction (Figure 1), there is a substantial gap in achieving net zero emissions for the power sector as the share of low-carbon technologies is less than 25% (Handayani et al., 2022). Several ASEAN member countries have set renewable energy targets and are taking steps to increase the share of renewable energy in their respective energy mixes. This includes investments in solar, wind, and hydroelectric projects. However, the pace and extent of this transition can vary from country to country due to factors like policy frameworks, available resources, and infrastructure.

While there is a pressing necessity to address climate issues, many decisions around climate actions are still driven by financial considerations (Giglio, Kelly, & Stroebel, 2021). For instance, the pricing of risk mitigation measures, the attitudes of investors towards transitions, and government decisions for taxation plans. Climate actions need to be supported by funding mechanisms such as investments, subsidies, and loans, collectively known as climate finance. The Global Commission on Adaptation has presented that an investment amount of $1.8 trillion would provide $7.1 trillion in benefits, in return (Global Commission on Adaptation, 2019). Nonetheless, existing studies have presented that there is a significant financial shortfall to execute the transition plans and develop green technologies (Bhandary, Gallagher, & Zhang, 2021). Indonesia's struggle to secure funding for coal retirement (Sudarshan Varadhan, 2023) is one of the many examples that mirrors the broader challenge of financing sustainable transitions. With Western nations bogged down with their own economic issues, thus showing reluctance, concerted efforts are required to garner support for this crucial shift. Bridging this gap necessitates concerted efforts from governments and public endorsement. A recent study by the National Bureau of Economic Research has shown that providing the public with information regarding the mechanics of climate policies and the allocation of climate finance results in increased public support, particularly for measures with initially low levels of support, such as carbon taxes. Therefore, it is important to understand how climate finance can be applied to facilitate technological innovation and

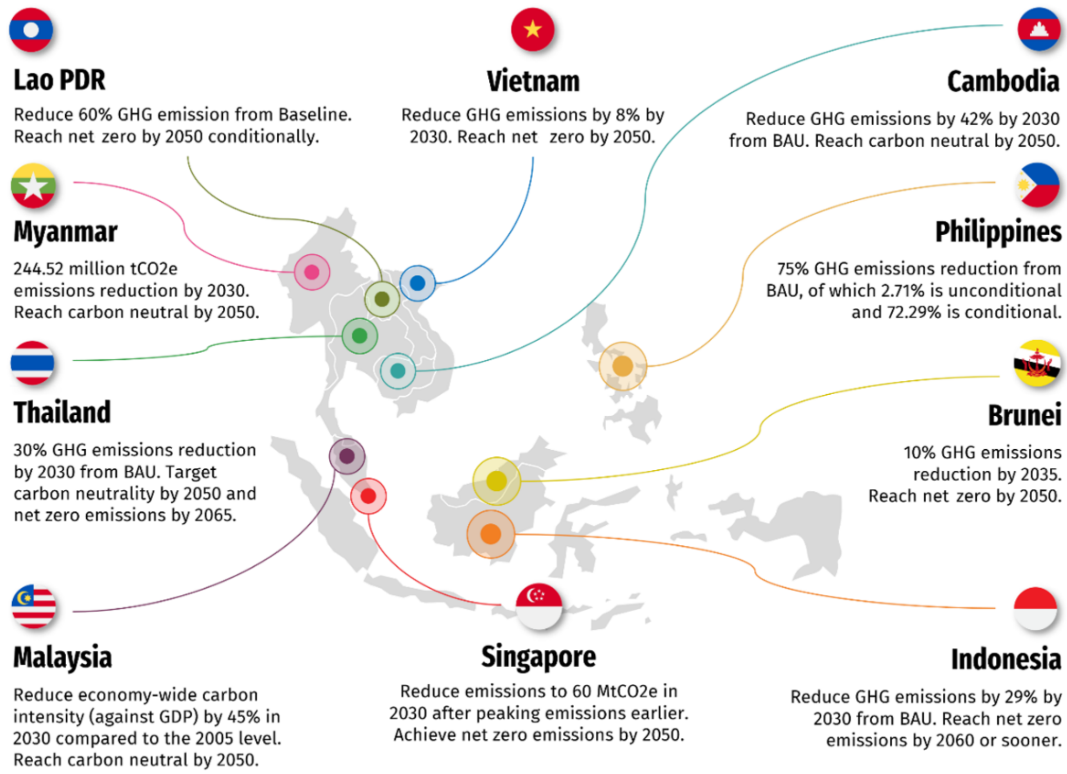

Figure 1. Nationally Determined Contributions set by ASEAN member states. Built using information from the ASEAN Centre for Energy (2022).

foster the transition toward a decarbonized economy.

Climate finance and technology innovation

Various financial instruments such as carbon markets, national climate funds, and green bonds can be employed to support climate action programs (Figure 2). Climate finance provides the essential funding for advancing research, development, and implementation of clean and sustainable technologies. In return, technology innovations benefit climate finance by creating opportunities for profitable investments. For instance, advancements in the above-mentioned technologies attract investors as clean energy projects become more economically viable. Furthermore, smart grid systems and energy-efficient technologies powered by advances in digital technologies, or fourth industrial revolution technologies enhance the feasibility of low-carbon projects, drawing investors' interest towards these initiatives.

In this article, we examine the symbiosis between climate finance and technological advancements, illustrating their role in driving the energy transition, with

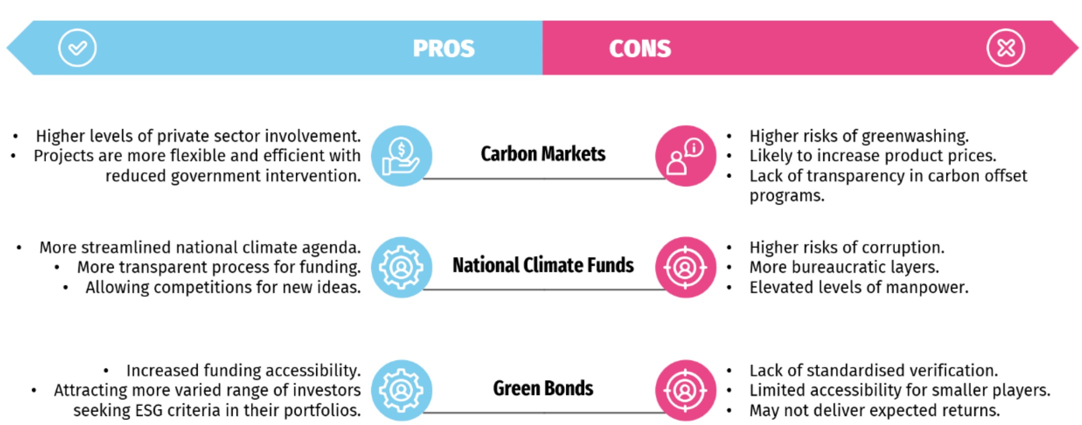

Figure 2. Pros and Cons of various climate financial instruments.

a case study on Singapore. We focus on energy transition technologies as the power sector is responsible for the highest proportion of global CO2 emissions (IEA, 2022a).

Trend of energy transition technologies

Climate finance serves as a linchpin in expediting the transition of existing power grids to an interconnected system with low-carbon energy technologies. It allocates resources to bolster the development and amplification of renewable energy infrastructure, such as solar and wind farms, hydropower dams, and green hydrogen plants. Furthermore, climate finance could also be used to fuel research and development endeavors, making these technologies more efficient and cost-effective. For instance, a recent study on the China Southern Power Grid found that power system planning by adapting hydropower operation can cut total system costs by 7% (US$28.2 billion) and result in an annual water savings equivalent to three times the capacity of the Three Gorges Dam (Liu & He, 2023).

In the past few years, despite being slowed down by the COVID-19 pandemic, the capacity of renewable electricity capacity has been growing (IEA, 2022b). The main types of renewable energy technologies include photovoltaic (PV) solar, wind, hydropower, and bioenergy (Figure 3). The implementation of clean energy technologies was one of the key drivers (Figure 4) for CO2 emission reduction in 2022 (IEA, 2023a). These advancements have been facilitated by climate finance, which operates on various fronts including incentivizing the generation of cleaner energy, providing support for green initiatives and management,

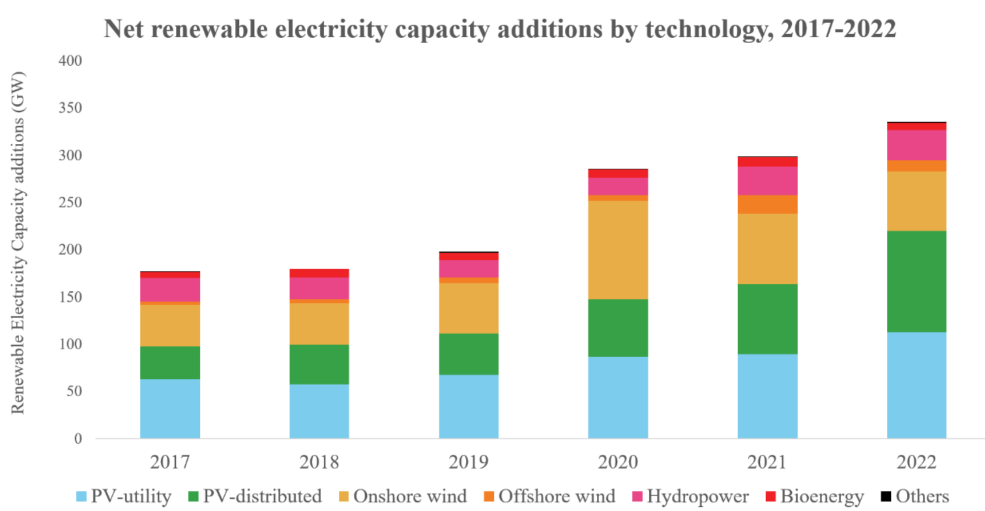

Figure 3. Net renewable electricity capacity additions by technology, 2017-2022. Built using data from IEA (2022b).

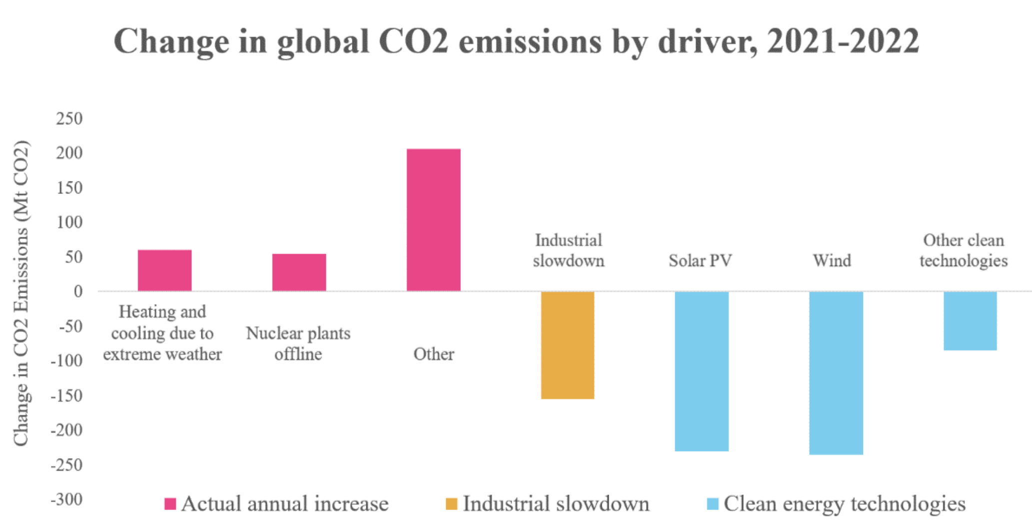

Figure 4. Change in global CO2 emissions by drivers, 2021-2022. Built using data from IEA (2023a).

and fostering regional partnerships and collaborations. This can be showcased using Singapore as an example.

Case study on Singapore

Singapore is an island country with limited land and resources. Due to its geographical location, it experiences low levels of wind speed, and tidal and hydro actions, making it a challenge to leverage the use of natural resources to its advantage. With the energy sector currently contributing more than half of total carbon emissions (IEA, 2020), Singapore must explore alternative strategies to secure its energy resilience while maintaining sustainable practices. Here, we present how climate finance, encompassing government funds, grants, tax incentives, public and private investments, and carbon pricing, acts as a driving force for technological innovations and nurtures Singapore's transition towards sustainable energy practices.

Government funds and energy-efficient technologies

Government-established funds can serve as a catalyst for the adoption and integration of energy-efficient technologies within various industries. The National Environment Agency (NEA) of Singapore has launched the Energy Efficiency Fund (E2F) to support businesses in adopting more energy-efficient technologies with different types of grants. (NEA, 2023) Examples include energy-saving lighting, boiler systems, compressed air systems, and air-conditioning systems (Figure 5).

Consequently, as of January 2022, NEA-funded initiatives facilitated the execution of 27 projects centered on energy-efficient technologies (NEA, 2023). This translated to an estimated yearly mitigation of approximately 1,600 metric tons of carbon emissions, equivalent to the environmental effect of removing 500 cars from the road.

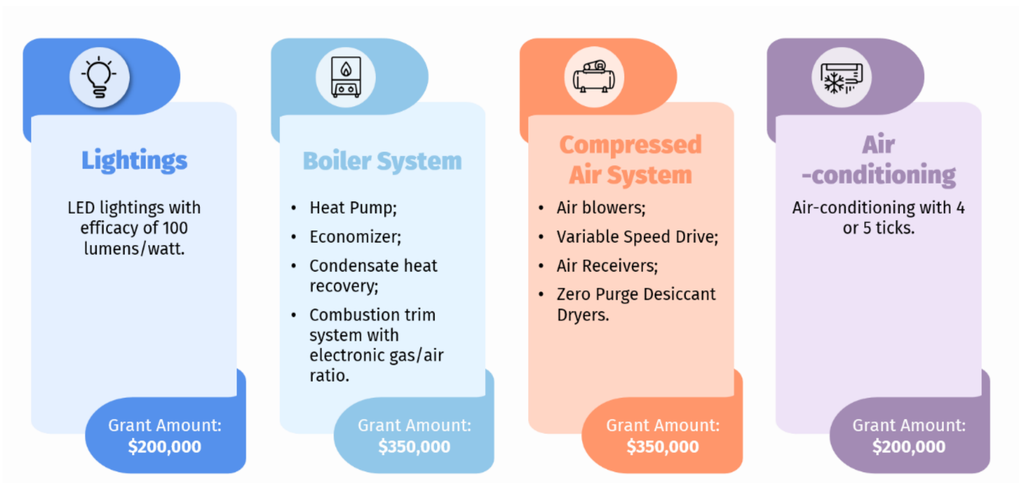

Figure 5. Examples of Energy-efficient Technologies pre-approved by NEA. Built using information from NEA (2023).

Cleaner production and environmental management supported by Government grants

Climate finance plays a crucial role in promoting Singapore's cleaner production and environmental technologies. In transportation, it can drive the shift to electric and hybrid vehicles, along with investments in public transport infrastructure like electric buses and charging stations. In the context of electricity generation, green loans and funds can support technologies that capture carbon emissions from the combustion of natural gas.

The Singapore Economic Development Board (EDB) has introduced a suite of initiatives and incentives (Singapore Economic Development Board, 2023) designed to foster sustainable economic endeavors within Singapore. One notable initiative, the Resource Efficiency Grant for Emissions (REG(E)), is specifically tailored to incentivize enhancements in energy efficiency within the domains of manufacturing facilities and data centers. Situated within the broader framework of the Enhanced Industry Energy Efficiency package, REG(E) represents a collaborative effort involving the Energy Market Authority (EMA), EDB, and NEA, with each entity launching distinct initiatives aimed at providing robust support to companies in their pursuit of heightened energy efficiency and concomitant reduction of carbon emissions.

Transitions to greener technologies motivated by carbon pricing

Climate finance also encourages transitions in electricity generation technologies. The introduction of a carbon tax acts as a strong motivator for expediting the retirement of high-carbon technologies (Xu, Pan, Li, Feng, & Guo, 2023), particularly evident in the context of fuel-powered plants. Through the imposition of a tax on each unit of carbon emissions released, operators of such facilities face direct financial repercussions for their environmental footprint. This creates a notable economic deterrent for ongoing operations, prompting them to explore cleaner and more sustainable alternatives. The financial weight of the carbon tax compels power plant operators to reevaluate the viability of maintaining aging coal-based infrastructure in comparison to transitioning towards greener, more efficient options like renewable energy sources. Furthermore, the revenue generated from a carbon tax can be strategically reinvested into renewable energy projects, providing further impetus for the shift away from coal.

In Singapore, the carbon tax rate was set at $5 per ton for 2019 to 2023, serving as an intermediary phase to facilitate business adaptation. In 2022, NEA declared an increment in carbon tax rates: $25 per ton in 2024 and 2025, $45 per ton in 2026 and 2027, aiming for $50 to $80 per ton by 2030 (Tseng, 2022). This means Singapore's electricity generators, which rely heavily on natural gas, would face increased operating costs. Under this context, one of the key generators in Singapore, Sembcorp Industries, is embarking on the construction of a hydrogen-ready power facility with a capacity of 600 megawatts (Mitsubishi Power, 2023). This power plant is anticipated to commence operations in 2026. This new power facility will be able to enhance the efficiency of power generation resources as well as set the stage for a reduction in carbon emissions through the implementation of hydrogen fuel blending techniques.

Renewable energy technologies facilitated by government-funded projects

Singapore has also been promoting clean energy technologies. In 2016, Singapore's National Water Agency, Public Utility Board, in collaboration with the Economic Development Board, initiated a pilot project at Tengeh Reservoir involving a one-megawatt-peak (1 MWp) floating solar photovoltaic (PV) array (Dörenkämper et al., 2021). Another example is the advancements in energy storage technologies, which have been crucial in making renewable energy sources more reliable and able to meet fluctuating system demands. In October 2020, Singapore deployed its first large-scale Energy Storage System (ESS) through a collaboration between EMA and Singapore Power Group (SP Group). This ESS provides a capacity of 2.4 megawatts, sufficient to provide energy for over 200 four-room Housing & Development Board (HDB) households daily (EMA, 2020).

Tax incentives for electric vehicle adoption

The Ministry of Transport established an Electric Vehicle (EV) Early Adoption Incentive (EEAI) capped at $20,000 to encourage the early adoption of EVs. This entails a 45 percent reduction in the Additional Registration Fee for owners registering fully electric vehicles from January 2021 to December 2023 (Ministry of Transport, 2020). To date, over 8,000 EVs including taxis have received rebates from this initiative. The Land Transport Authority (LTA) and NEA have jointly announced that early EV adoption will be extended to 2025 with a lower rebate from 2024 (LTA, 2023). Similarly, on a global scale, electric vehicle sales grew by 10 times (Figure 6) from 2017 to 2022, reaching a record high of more than 10 million.

Partnerships and collaborations

Climate finance fortifies regional cooperation and partnerships for grid interconnection infrastructure developments. It supplies the vital financial resources needed for joint projects among member countries, enabling collective investment in cross-border energy networks. These networks facilitate the exchange and optimization of renewable energy resources across borders. In addition, climate finance spurs private sector involvement by mitigating investment risks and offering incentives for companies to participate in infrastructure projects. This drives innovation, facilitates

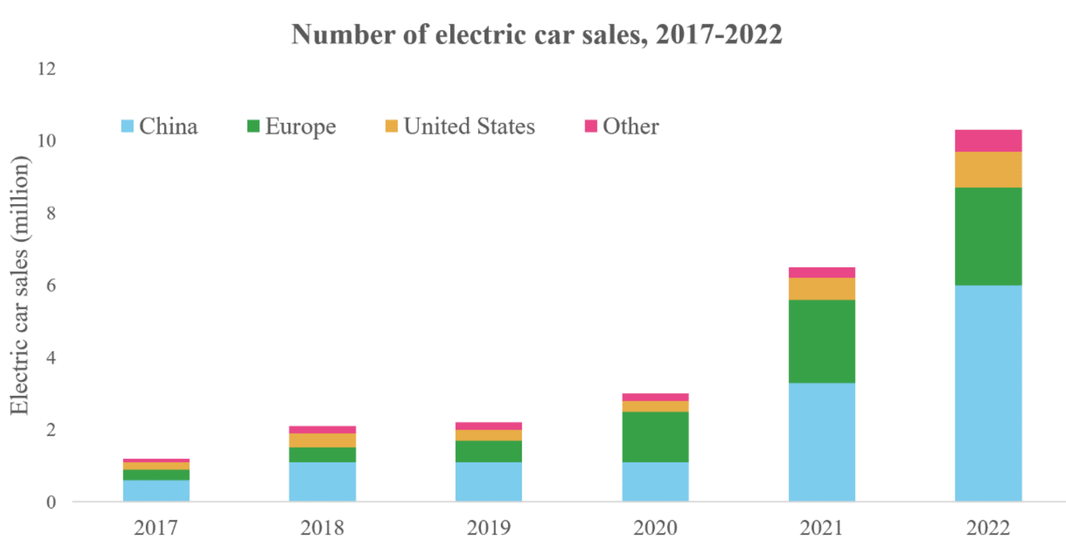

Figure 6. Number of electric car sales, 2017-2022. Built using data from IEA (2023b).

Interconnection	Capacity (MW)	Status
Laos – Singapore (via Thailand and Malaysia)	100	Existing
Malaysia – Singapore	1,000	Existing
Indonesia – Singapore	2,000	Conditionally approved by EMA in September 2023
Cambodia - Singapore	1,000	Conditionally approved by EMA in March 2023

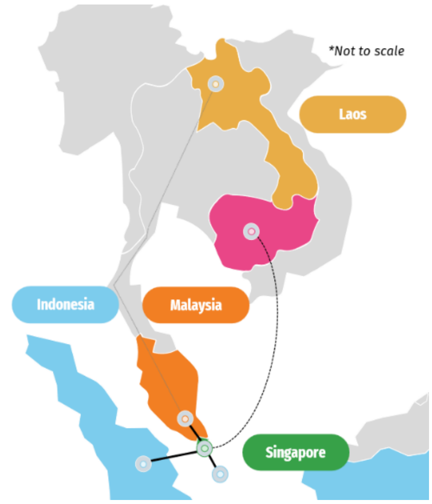

Figure 7. Singapore's existing and planned grid interconnections. Built using information from EMA (2022a, 2023a, 2023b).

technology transfer, and attracts expertise, enhancing the efficiency and effectiveness of interconnection infrastructure development. Currently, the total capacity of ASEAN's exiting interconnection projects accounts for 7,720 MW in 2020 (ASEAN Centre for Energy, 2021). This number will be doubled or even tripled to 18,369 to 21,769 MW in the foreseeable future (ASEAN Centre for Energy, 2022).

For Singapore, natural gas currently makes up about 95% of the country's electricity demand (Chen, 2020). Due to the lack of natural resources, Singapore's transition towards a net zero power sector requires access to renewable energy sources from other countries. Although there are several existing and planned interconnection projects linked to Singapore (Figure 7), more opportunities need to be explored to ensure a resilient power grid to achieve net zero emissions. In alignment with this objective, the EMA has initiated a request for proposal aimed at procuring up to 4GW of low-carbon electricity imports by the year 2035 (EMA, 2022b).

This not only showcases Singapore's dedication to sustainable energy solutions but also emphasizes the need for a cooperative approach to achieve ambitious climate goals. The procurement process requires engagement with various stakeholders, including global renewable energy providers, local utilities, regulators, and financial institutions. Through this initiative, Singapore will be able to gain access to cutting-edge technologies and expertise and also create a platform for knowledge exchange and capacity building. Here, climate finance is urgently required as a strong incentive for Singapore's local electricity importers and foreign electricity providers. Financial tools like green bonds and investment funds offer avenues for these businesses and investors to support regional interconnection projects.

Furthermore, Singapore can draw valuable insights from existing long-distance electricity interconnection projects around the world (Table 1). Learning from successful models in regions like Europe, North America, China, and India, Singapore can adopt best practices in regulatory frameworks, technical standards, and collaborative approaches. Emulating the strategies that have proven effective in maximizing the efficiency and reliability of cross-border energy networks will be crucial in achieving its net zero emissions goals.

Technological advancement enhances climate finance growth and innovations

In earlier sections, we discussed the potential of climate finance to stimulate technological innovations. In return, technological advancement also

Table 1. Examples of existing Long-distance Interconnection Projects in other countries.

Interconnection	Capacity (MW)	Distance (km)	Reference
Suldal, Norway – Northumberland, UK	1,400	748	(Zakeri et al., 2018)
Lincolnshire, UK – Jutland, Denmark	1,400	765	(Viking Link, 2023)
Quebec, Canada – New England, USA	2,000	1,480	(Imdadullah, Alamri, Hossain, & Asghar, 2021)
Nuozhadu, China – Guangdong, China	5,850	1,451	(Hennig, Wang, Magee, & He, 2016; Xue et al., 2009)
Xiluodu, China – Guangdong, China	6,400	1,251	(Shao, Lu, Lu, Zou, & Liu, 2011)
Biswanath, India – Agra, India	6,000	1,728	(Oni, Mbangula, & Davidson, 2016)

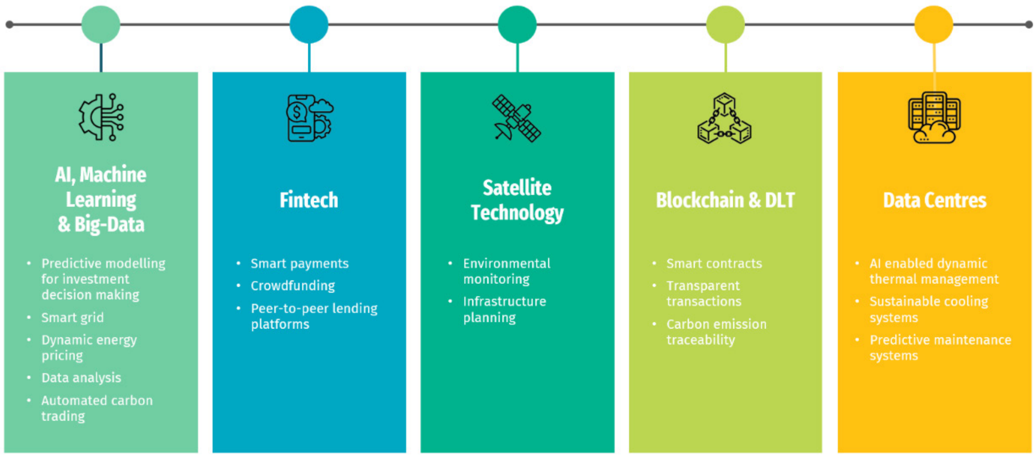

Figure 8. Examples of technologies that enhance climate finance growth and innovations.

contributes to the growth of climate finance. In this section, we discuss several emerging innovations (Figure 8) that optimize allocation of resources, improve transparency and accountability, and open up novel avenues for investments in climate-related initiatives.

Blockchain and Distributed Ledger Technology (DLT)

Blockchain is an immutable digital ledger that operates in a decentralized manner, recording transactions across numerous computers (Natarajan, Krause, & Gradstein, 2017). In the context of Climate Finance, it has the potential to establish trustworthy and secure frameworks for monitoring carbon credits, guaranteeing accurate recording of emissions reductions. Additionally, it enables peer-to-peer energy exchange, enabling direct trading of renewable energy between individuals and businesses.

Artificial Intelligence (AI) and Machine Learning

AI involves learning from data to execute tasks that conventionally demand human intelligence through learning from data. Machine learning, a subset of AI, centers on algorithms assimilating data to render predictions or decisions. When applied to climate risk assessment, AI and machine learning enhance investment decision-making by offering deeper insights. They excel at scrutinizing extensive datasets to pinpoint trends, evaluate climate-related threats to assets, and streamline resource allocation for projects related to climate change.

Fintech

Fintech covers various financial technologies, such as digital payment systems, mobile banking, and peer-to-peer lending. These solutions within the realm of fintech have the potential to enhance the accessibility and efficiency of climate finance transactions. They simplify the issuance of green bonds, enable crowdfunding for sustainable initiatives, and streamline the allocation of climate-related subsidies and incentives.

Energy-as-a-Service

The energy sector is experiencing a profound transformation towards Energy-as-a-Service (EaaS), a community-driven model (Hall et al., 2021). Unlike traditional centralized generation, EaaS manages a customer's energy assets comprehensively, creating smart energy communities for efficient market integration (Figure 9). This shift offers benefits for both customers and the deployment of low-carbon technologies. In response to the climate crisis, energy providers are seeking innovative ways to supply clean power in modern, connected cities. EaaS presents a strategic opportunity for these companies. Several scenarios could unfold: established firms may resist change, using policy and regulation to impede progress; consumers may increasingly turn to localized energy solutions, causing inefficiencies in the wider system; new players like industrial conglomerates, tech giants, and oil & gas majors could disrupt the value chain. Early collaboration and partnerships will be crucial for companies venturing into EaaS. As providers gain experience, horizontal and vertical integration may occur through mergers and acquisitions. This transformation holds promise for a more sustainable and efficient future in the energy sector.

Data Centers

Singapore currently boasts the second-largest data center market in the Asia-Pacific region. It houses 81 facilities with approximately 900 MW of operational capacity, with an additional 200 MW either in the planning stages or actively under construction (Baxtel, 2023). As the demand for climate-related information grows, data centers become essential hubs for aggregating, storing, and disseminating Environmental, Social, and Governance (ESG) data. Their high computing power and analytics capabilities enable the development of advanced climate models and risk assessments. Moreover, data centers facilitate real-time monitoring of environmental metrics, allowing for more accurate and timely decision-making in

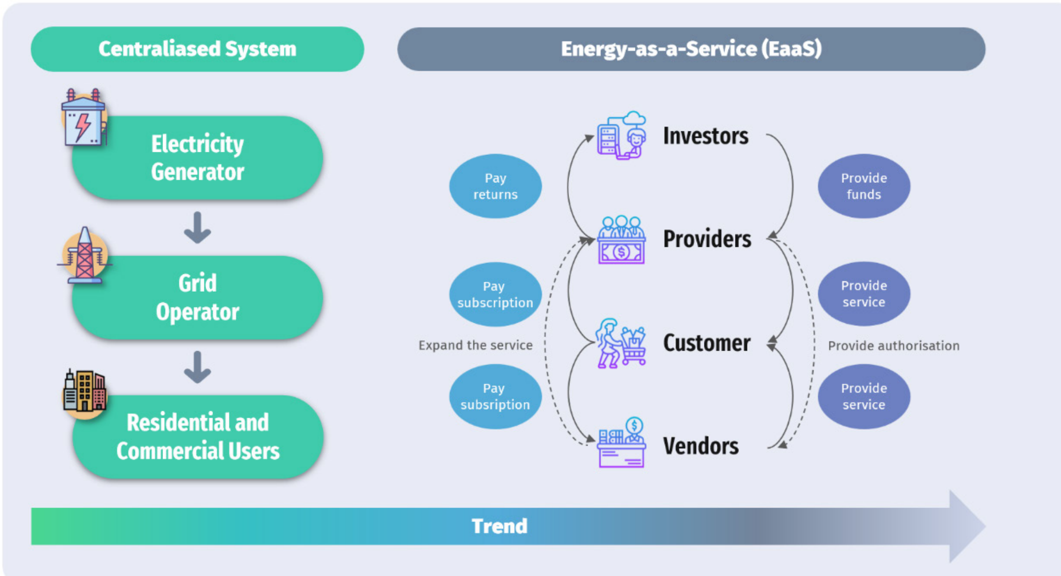

Figure 9. Centralised System and Energy-as-a-Service. Built using information from (Deloitte, 2023)

climate finance investments. Additionally, they support the validation and verification processes crucial for carbon trading and emissions reduction projects. By harnessing the capabilities of data centers, stakeholders in climate finance can make more informed and impactful investment choices, ultimately driving progress towards a more sustainable and resilient future.

However, studies have found that data centers in Singapore account for approximately 7% of the total electricity consumption (IMDA, 2016; Kandasamy, Ho, Liu, Wong, & Toh, 2022). Due to the energy-intensive nature of the development and operation of digital technologies and infrastructure, operators should prioritize sustainability and social responsibilities and undertake sustainable management measures (Figure 10). Balancing the benefits with responsible energy practices is essential in maximizing data centers' positive impact on climate finance.

Challenges and Recommendations

In earlier sections, we discussed the concerning potential for greenwashing within climate finance, emphasizing the need for transparency and accountability in fund allocation for genuine climate change

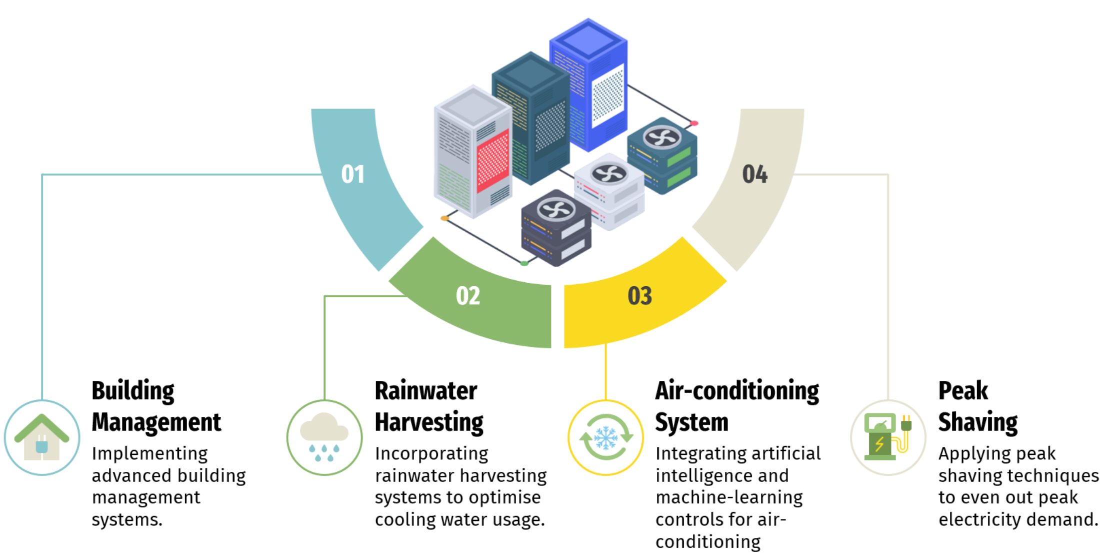

Figure 10. Examples of sustainable management measures for data centres.

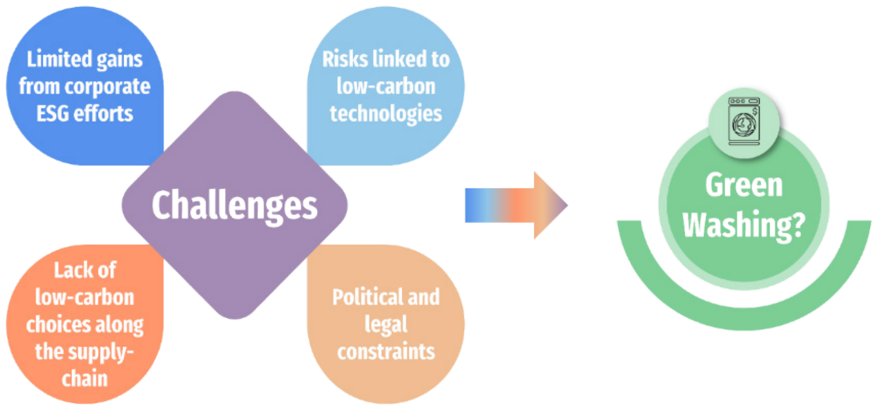

Figure 11. Challenges associated with applying climate finance.

mitigation. Effectively applying climate finance to drive technological innovations faces various hurdles as shown in Figure 11.

Firstly, there is limited, intangible gains from corporate ESG efforts, alongside apprehensions regarding risks linked to low-carbon technologies (Bhandary et al., 2021). The discrepancy between the extended payoff periods of climate projects and the short-term focus of most private investors presents another critical challenge. The scarcity of reliable data further compounds the problem, obstructing the thorough evaluation of climate-related projects. Secondly, there is a shortage of feasible low-carbon, adaptation, and resilience initiatives and sources along the supply chain. For instance, food industry leaders like McDonald's struggles to meet its net zero pledges - the company's emissions in 2021 exceeded its 2015 baseline by 12% (McDonald's Corporation, 2023). Beyond financial and technological constraints, political and legal obstacles can also impede private investments (Chawla & Ghosh, 2019).

These barriers are especially pronounced in the absence of effective policy coordination and could lead to greenwashing. To facilitate true improvements and progress, technology-driven self-help tools could be considered to assess greenwashing objectively. Blockchain technology, for instance, provides a transparent and immutable ledger for tracking and verifying sustainability-related information. Artificial intelligence, particularly in natural language processing, enables algorithms to analyze textual and numerical data, uncovering discrepancies in sustainability reporting. Additionally, IoT and sensor technologies facilitate real-time monitoring of environmental performance metrics, providing an objective basis for evaluating claims. By leveraging these technologies, we can objectively assess greenwashing practices, fostering genuine progress in climate finance towards achieving global climate goals. Addressing these multifaceted challenges necessitates a concerted effort from both public and private sectors, involving the development of clear incentives, enhanced data availability, and strategic policy coordination to facilitate the flow of private capital towards

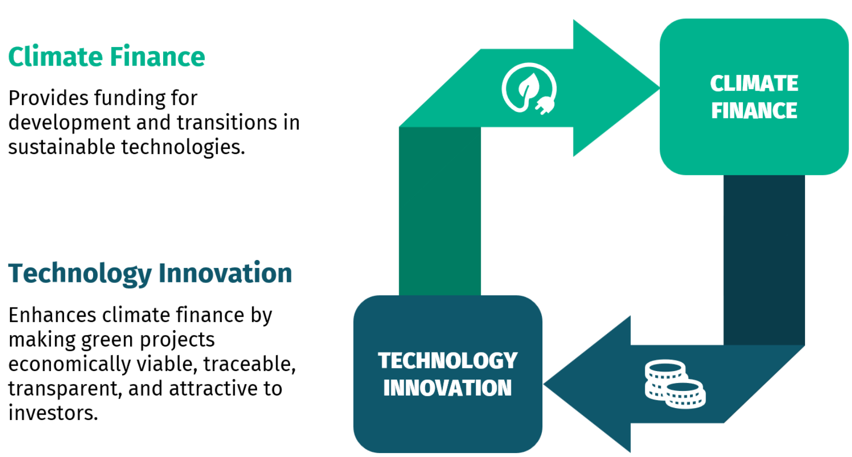

Figure 12. The symbiotic relationship between climate finance and technological innovation.

climate change mitigation and adaptation endeavours.

Conclusion

In the face of escalating climate change impacts, there is a need to understand the nexus between climate finance and energy transition technologies. This article has assessed the role of climate finance in fostering technological advancements. Through a focused case study of Singapore's, we underscore the criticality of climate finance in steering the nation towards resilient and sustainable energy solutions.

The symbiotic relationship between climate finance and technological innovation is evident in their benefits. Climate finance provides funding for research and development in sustainable technologies, empowering advancements in renewable energy, carbon capture, and energy-efficient solutions. In return, these innovations enhance climate finance by making clean energy projects economically viable, transparent, and attractive to investors (Figure 12). It is crucial to bridge the gap between short-term investor outlooks and the long-term payoff timelines of climate projects to successfully navigate the shift toward a sustainable, decarbonised energy future.

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