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**| RESEARCH ARTICLE**

# Financing the Future of Energy: Capital Allocation, Risk, and Economic Impacts of LNG Infrastructure and Modern Grid Expansion

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## | ABSTRACT
Financing LNG infrastructure and the modernization of the electricity grid is increasingly shaped by energy security, energy markets, technological developments, and the global shift toward a lower-carbon energy system. This study discusses the allocation mechanisms, financing structures, risk management frameworks, economic impacts and sustainability issues of LNG terminals, LNG liquefaction and regasification plants, storage facilities, pipelines and modern grid infrastructure. The mechanisms used to make projects bankable and share financial risk are reviewed, including project finance, special purpose vehicles, equity and debt financing, long-term offtake agreements, public-private partnerships, development finance, and climate-aligned instruments. Special emphasis is on construction, regulatory, currency and market, performance, delay, and stranded asset risk and digital monitoring strategies. The analysis also explores the interplay between LNG infrastructure and the modernization of the grid, and how the two have an impact on energy security, electricity resilience, renewable penetration, electricity price formation, and investment incentives. The diverse market structures, transmission restrictions, resource availability and regulatory environments that are observed in different regions are seen as evidence of different outcomes of infrastructure investments for energy systems. Economic effects encompass employment, industrial expansion, trade, energy costs, and other financial risk propagation. Transition finance, environmental goals, methane reduction and possible consequences of reduced fossil fuel demand are also taken into account in the study. In general terms, financing infrastructure needs demands a diversification of funding structures, risk management, flexibility in contractual arrangements and long-term consideration of the economic and climate related risks.

## | KEYWORDS
LNG infrastructure; Grid expansion; Project finance; Risk management; Transition finance.

## | ARTICLE INFORMATION
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## 1. Introduction
In the case of large scale liquified natural gas (LNG) infrastructure and the modernization of the electric grid, significant investments, complex financial arrangements and coordinated governance are needed. The energy landscape is evolving due to energy security, geopolitical developments, electrification and a shift to lower carbon energy systems and LNG terminals, regasification facilities, pipelines, storage systems and associated grid upgrades are being developed, and they will be integral to this evolving energy landscape [Arellano, 1995]. Such projects are typically financed with a mix of public and private funds, special purpose vehicles, non-recourse project finance, long term offtake agreements, tolling, export credit and development banks. They are designed to enhance project bankability and to share financial and operational risks between the energy buyer, the developer, the government,

the lender and the contractor. Risk allocation is important because LNG and grid infrastructure generally has a long construction period, high initial investment and assets that have a long operational life [Tasnia, 2026]. Projects can be secured with long term take or pay contracts or other forms of contracts which ensure steady income and buffer the project from market fluctuations. They can, however, generate a chance of stranded asset risk if demand for natural gas slows down or if it is more heavily regulated due to climate policies or if other energy sources become more competitive. When considering the viability of a project, investors should consider the market demand, fuel price volatility, regulatory changes, carbon policies, geopolitical instability, interest rates, and technological advances [Blundell, 1998]. However, the role of project governance and contractual arrangements is also very important as some of these lead to better financing than others. The roles of engineering, procurement, construction, commissioning, start up and performance testing must be clearly defined, and the roles that are delegated to various design, equipment, data, ownership, delays, and performance, and of warranties and corrective works must be appropriate. Various standard contractual clauses like FIDIC, NEC4, IChemE and LOGIC offer different ways of handling construction risk and operational risk [Windmeijer, 2005]. Good risk allocation can help increase cost certainty, lessen disputes, help safeguard the interests of the lender, and enhance cooperation among project owners and contractors. Financial protection throughout the project lifecycle is further supported by insurance, performance guarantees, liquidated damages and other risk transfer arrangements. LNG projects are also intricately linked to upgrade of the electricity grid. Increased gas supply can also help provide system reliability and electricity generation, especially in areas with intermittent renewable energy production and limited transmission resources [Mozakka, 2022]. Meanwhile, grid expansion is needed for growing electrification and to integrate renewable energies. Gas and electricity markets must be taken together when making investment decisions, not as separate markets. In general, the investment in LNG and the grid is a balance between the short-term energy security and economic requirements, and the long-term financial sustainability, technological developments and decarbonization goals.

## 2. Financing of LNG Infrastructure

LNG infrastructure financing refers to the investment in the development of LNG liquefaction terminals, regasification facilities, LNG storage systems, pipelines, ship connections and distribution networks to facilitate international natural gas trade, which involves high capital investment that requires extensive government support [Md Yeasir, 2026]. The financing of these assets is influenced by the large amounts of capital needed, by the long time period and by the relation between capital needs, potential return, market demand and long-term risk. Investment continues to be driven by greater security of supply, operational flexibility and resiliency in LNG supply chains (Table 1). Scalability and flexibility of infrastructure is also becoming more significant as this enables investments to be made depending on the demand and the market situation in the region [Wood, 2012]. In the development of the large LNG projects, long-term offtake contracts and project financing are still playing a key role. Predictable cash flow from long term contracts with reliable buyers can enable lenders to evaluate future cash flows and thus facilitate debt repayment and investor returns. Project finance structures can be designed in such a way that project liabilities are separated by creating separate entities and the repayment is mainly from the project revenues. They are especially beneficial for projects that require a lot of capital and the cash flow is needed to be consistent to cover construction and market risks [Gupta, 2023]. Investments are also moving towards digitalization, automation of systems, monitoring and operational technologies in the LNG value chain. These investments may increase efficiency, lower operating expenses, enhance safety, and aid in more effective asset management. LNG infrastructure financing is maturing and the capital structure is becoming more diversified, which includes private financing, institutional finance, public involvement, and contractual protection of revenues [Hönig, 2019]. The success of these arrangements is dependent on the ability to synchronize financing structures to project size, market dynamics, project risks, and longer-term energy needs.

Table 1. Financing mechanisms for LNG infrastructure and modern grid expansion

| Infrastructure / Financing area | Major financing mechanism | financial benefit | Reference |
|---|---|---|---|
| LNG infrastructure | Project finance | Separates project liabilities and enables repayment primarily from project revenues | [8] |
| LNG infrastructure | Export credit financing | Supports large infrastructure investments and improves financing capacity | [1], [37] |
| Modern grid expansion | Equity and debt financing | Provides capital for transmission, distribution and grid modernization | [15], [42] |
| Modern grid expansion | Green bonds | Mobilizes capital for renewable integration and environmentally oriented grid projects | [16], [32] |
| Modern grid expansion | Sustainability linked loans | Links financing conditions with sustainability performance | [16], [32] |
| Both LNG and grid | Hybrid and multi tranche financing | Combines different sources of capital and distributes financial exposure | [15], [42] |

## 3. Infrastructure Types and Market Segments

The LNG infrastructure market can be segmented based on infrastructure type and project size. The liquefaction terminals are some of the most capital intensive facilities due to the need for advanced processing technologies, specialized equipment, storage system, and supporting infrastructure to liquefy natural gas into LNG for export [Hossain, 2026]. Regasification terminals are used to convert LNG into gas, and are vital to the importation of LNG into domestic networks. Different storage types like underground caverns, above ground tanks and smaller scale storage units can be used to manage any disruptions in seasonal demand and supply. Different LNG sections of the supply chain are connected by transportation and distribution infrastructure such as LNG carriers, pipelines, loading facilities and related networks to ensure reliable energy delivery [Raj, 2016]. The size of the project has a significant impact on the financing strategy. Investment of more than USD 1 billion can be needed for large scale projects of liquefaction and regasification and may be shared between governments, international energy companies, infrastructure developers, financial institutions and various contractors. This type of project normally demands complex project finance, high equity stakes, long term offtake contracts and big debt facilities [Dai, 2021]. They also have extended development times, which also demands careful management of construction, market, regulatory and financial risks. The LNG infrastructure market is currently in a process of strategic reorganisation whereby companies are trying to find economies of scale, optimisation of portfolio, new markets and better operational efficiency. In a quest for repositioning infrastructure portfolios and optimizing capital allocation, mergers, acquisitions, and asset divestment are becoming a more frequent option [Uddin, 2026]. LNG operations are also being digitalized, automated, and enriched with advanced analytics to enhance performance, lower costs, boost monitoring capabilities, and enable better asset management.

## 4. Financing of Modern Grid Expansion

Investment models for modernisation of the grid need to ensure economic efficiency, financial returns, system reliability, and long-term public benefits. Transmission and Distribution Systems involve huge investment and usually take a long time to develop and operate; thus, the management of cost recovery and risk allocation in these systems is crucial [Langshaw, 2020]. Good electricity market design can enhance investment incentives by easing congestion, enhance resource allocation and create better signals for the development of transmission. Expansion of renewable energy also drives an increased need for coordinated grid investments as low investment in transmission capacity can result in congestion, reduce renewable integration, and drive up curtailment. The methods used to finance the expansion of the grid generally include equity, debt, public private partnerships, project financing and hybrid financing instruments (Figure 1) [Zhang, 2021]. Green bonds and sustainability-linked loans are becoming increasingly relevant in the context of projects for the grid that include renewable integration, electrification, emissions reduction and other measures related to the environment. The financing tools can be tailored to the nature of the projects, such as long-distance transmission corridors, substations, distributed energy generation and storage facilities [Al-Saadoon, 2009]. Further steps to improve access to long term debt and lower financing costs for large-scale infrastructure are through the use of government guarantees, credit enhancements, and multi tranche financing. Transmission investment can also have broader economic impacts, including decreased concentration and market power in the electricity markets, increased efficiency in the electrical system, and decreased wholesale price volatility [Tcvetkov, 2020]. In the short term, there are costs to transmission development for the consumer, but these costs can be offset by reliability improvements, congestion reductions, better use of generation capacity, and long-term efficiency improvements. Project approval and cost-recovery systems are thus integral to the questions of whether projects can secure private investment. There are other indicators that can be used to identify the most economically valuable location for grid capacity, such as locational pricing, reliability needs, and the clear rules of investment [Islam, 2026].


Figure 1. The current energy situation through strategic recommendations to future prospects [Lam, 2019].

**5. Risk Management and Mitigation Tools**

Risk management in energy infrastructure projects is the process of identification, quantification, allocation and mitigation of uncertainties that can impact project cost, schedule, quality, safety and performance [Fioriti, 2021]. In the LNG and modern grid projects, multiple stakeholders are involved in the project, complex technologies will be used, and the project will be constructed over long periods of time with significant financial commitments, which makes it crucial to manage risks to ensure the project remains viable. Appropriate allocation ensures accountability, minimises disputes and facilitates effective project delivery. Insurance is one of the major methods of risk shifting a financial burden that may come from an unforeseen event [Strantzali, 2018]. An energy infrastructure contract can cover construction activities, equipment, materials, injuries to personnel, and liabilities related to the activities of the project. Offshore LNG operations may necessitate special insurance policies for marine hull and machinery, protection and indemnity, wreck and debris removal, and pollution liability (Table 2) [Lee, 2016]. All risks insurance might also be included in project agreements, and responsibilities for deductibles will be determined between the employer and the contractor. Professional Indemnity Insurance may be used to offer extra cover for design liabilities where contractors or designers have taken on substantial professional or fitness for purpose responsibilities. Another significant risk mitigation mechanism is contractual risk allocation [Gordon, 2003]. The common forms, like FIDIC, IChemE, NEC4 and LOGIC, define various methods for sharing the responsibilities between the project owner, the contractor, engineers and other parties involved in the project. Generally, allocation decisions take into account those who control the relevant activity, who is responsible for design and verification, whether the risk can be reasonably expected, and who is most likely to be able to manage the consequences [Nduka, 2020]. The focus tends to be on the distribution of the consequences of an event rather than the assignment of responsibility in circumstances like a force majeure. Project governance and financing confidence may be enhanced by clear identification of construction delays, cost overruns, design flaws, unexpected issues, and performance issues.

Table 2. Major risks, mitigation measures and economic implications

| Risk / issue | Potential impact on LNG and grid projects | Risk mitigation | Economic or strategic implication | Reference |
|---|---|---|---|---|
| Construction delay | Increases project cost and postpones revenue generation | Clear contractual responsibilities, performance guarantees and liquidated damages | Improves cost and schedule certainty | [19], [22], [23] |
| Cost escalation | Can weaken project returns and increase financing requirements | Appropriate risk allocation, insurance and contractual controls | Protects project bankability | [20], [24] |
| Market and price volatility | Creates uncertainty in LNG revenues and electricity prices | Long term contracts, futures, forwards, options and other hedging instruments | Reduces exposure to commodity price fluctuations | [25], [38] |
| Regulatory change | May affect project revenues, operating conditions and asset value | Scenario analysis, flexible contracts and regulatory assessment | Reduces long term policy and transition risk | [3], [36] |
| Currency and financing risk | Exchange rate movements and financing costs can increase project liabilities | Hedging, suitable capital structures and credit support | Strengthens financial resilience | [3], [36] |

## 6. Implications for LNG Infrastructure and Modern Grid Expansion

LNG developments and modernization of the grid are characterized by many complex supply chains, long construction periods, high capital intensity and evolving regulatory requirements. By mitigating financial and operational risk, suitable insurance, well-defined contractual obligations, financial protection and flexible risk management plans can enable project sponsors to react to unforeseen changes in the market, technology, and regulations [Le Leuch, 2013]. Good risk governance also helps to build investor confidence and makes infrastructure projects bankable on the long-term basis. Financial and commercial flexibility is therefore crucial in dealing with economic exposure from LNG. Flexible supply and destination contracts can be used in conjunction with futures, forwards, options, and other hedging products to reduce price volatility and mitigate regional market differences [Tasnia, 2026]. These enable energy companies and energy traders to adjust to varying demand, supply issues, geopolitical events and regional price spreads. This flexibility of changing LNG supplies or changes in contractual agreements can then enhance infrastructure resiliency and economic benefit. The economic value in modern grid expansion comes in the form of better electricity reliability, less congestion, better integration of renewable electricity, and better utilization of generation resources [Blyschak, 2015]. Planning for transmission, storage, and distribution can help support electrification and minimize transmission and distribution constraints to renewable energy. These advantages need to be weighed against the significant construction costs, uncertainty regarding regulations, and long asset lives. In general, investments in LNG infrastructure and in modernisation of grid expansion can provide significant economic and strategic returns, provided there is effective risk management, proper financing arrangements, flexible contracting, and proper regulatory governance [Weems, 2013]. As the long-term performance of these investments starts to rely more on their energy security and economic value to withstand market volatility, technological change, and decarbonization needs, their performance will become more critical.

## 7. Interaction Effects Between LNG and Grid Expansion

LNG infrastructure and modern electricity grid expansion are becoming more and more dependent on each other in the context of a resilient energy system. Liquefaction, storage, pipelines and regasification capacity can also provide flexibility and reliability of natural gas supply and gas fired generation can offer balancing capacity where renewable electricity generation is variable [Agarwal, 2017]. Seasonal variation and unexpected supply disruptions can be accommodated by LNG storage since the daily volume of gas available can be managed as needed. For that, investments in LNG infrastructure can affect the reliability of the electricity system, energy security, and response to varying electricity demands. Typically project financing, long term offtake contracts and mix of equity and debt financing are used for large LNG projects and smaller or modular projects may have different financing structures [Molnar, 2022]. These facilitate investment in pipelines, storage, terminals and infrastructure, and spread financial risk among the sponsors, lenders, governments and energy buyers. Natural gas financing strategies must also take into account the potential to reduce methane, renewable natural gas, biomethane, storage, and other technologies that play a growing part in the natural gas landscape. Examples from the region suggest that the economic linkages between gas infrastructure and electricity networks are highly dependent on the availability of gas resources, the type of gas market, transmission capacity, and policies [Sharma, 2017]. A variety of financing models also illustrates the diversity of LNG infrastructure development across the region. North America has benefitted from established financial markets and strong export capabilities, whereas Europe has expanded regasification capacity for energy security requirements, and energy policies. The region in Asia Pacific is still a significant investment area due to industrial growth, escalation in energy consumption and favourable infrastructure policies [Bhuiya, 2004].

## 8. Sustainability, Climate, and Transition Finance

Financing the transition toward lower carbon energy systems requires substantial investment in sustainable infrastructure, modern electricity networks, renewable energy, energy efficiency, and technologies that can reduce emissions from existing energy systems. Transition finance increasingly combines conventional project finance with sustainability linked loans, green bonds, climate focused investment funds, and other instruments designed to connect financial returns with environmental objectives [Tasnia, 2025]. Volatile natural gas prices and differences in willingness to pay can affect industrial competitiveness and determine how quickly cleaner technologies are adopted. Consequently, transition finance needs to consider local market conditions rather than relying exclusively on uniform technology targets or broad policy objectives. Investment priorities are also changing as new areas of energy demand emerge (Figure 2) [Wallace, 2019]. Increasing investment in electricity infrastructure associated with data centers, electrification, digital technologies, and advanced industrial systems can compete with traditional energy investments for available capital. This creates a need for flexible financing strategies that can respond to changing economic, geopolitical, technological, and energy security conditions. Strong counterparties, appropriate credit support, reliable contracts, and balanced risk allocation remain important for attracting private capital to large infrastructure projects [Uddin, 2026]. Environmental, social, and governance considerations are increasingly incorporated into financing decisions. Financial institutions may require environmental assessments, mitigation measures, remediation plans, and appropriate governance procedures before providing project finance.

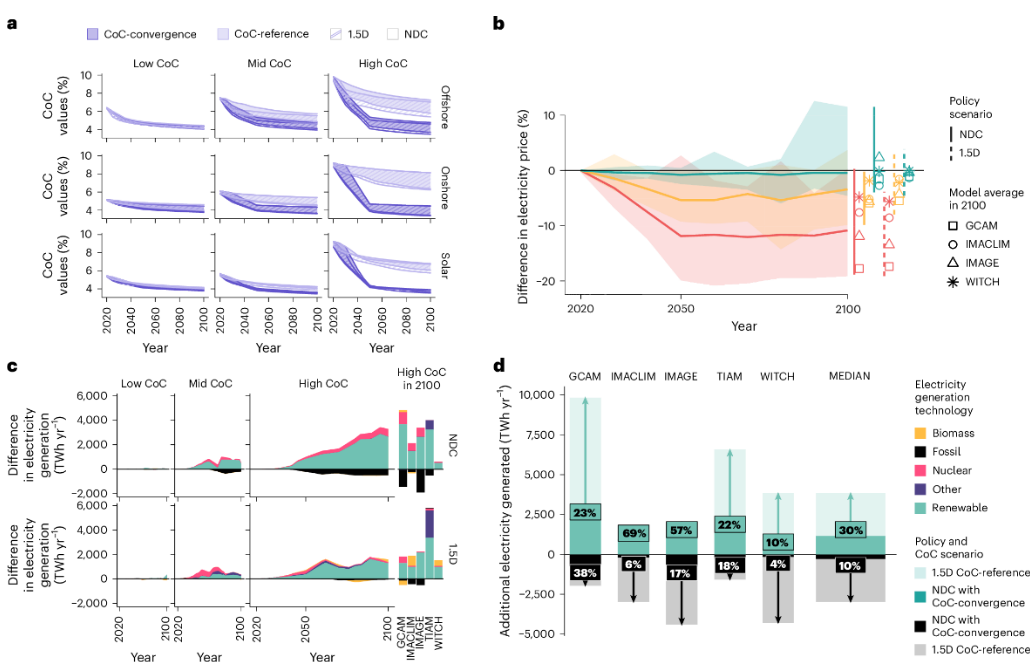


Figure 2. Reducing the cost of capital to finance the energy transition in developing countries [Zadeh, 2024]

## 9. Discussion

Financing for LNG infrastructure and the modernization of the grid is a complex nexus of energy security, capital allocation, infrastructure development, risk management and the international energy transition [Karlsson, 2023]. The cost of large scale LNG terminals, liquefaction facilities, regasification systems, storage, pipelines and electricity transmission networks are high initial costs and are long-term structures that last for decades. Therefore, it is not possible to make investment decisions solely based on short term financial gains. Financial and strategic decisions need to take into account long term demand, regulatory environment, technology, geopolitical conditions, environmental considerations, and the evolving electricity and gas market [Aguilera, 2014]. The evidence gathered in the various aspects of this study shows that successful infrastructure development requires project-specific risk matching of financing structures and sufficient flexibility in doing so as energy conditions change. Typical sources of funding for LNG projects include sponsor equity, commercial debt, institutional investment, public financing, export credit, and development finance [Bueger, 2023]. A Special Purpose Vehicle can separate project assets and project revenues from the sponsoring companies' general balance sheets, thereby reducing the exposure of the sponsoring company and providing large projects with significant debt financing. Long-term offtake agreements and tolling arrangements are of special significance since there is greater assurance for lenders of debt repayment capacity as a result of predictable revenues. Although a higher debt component can lower the amount of equity the sponsor has to bring in, high leverage can result in even higher financial vulnerability when market conditions sour [Şahin, 2024]. The correct capital structure should be determined based on future cash flows, the strength of the counterparty, the country risk, regulatory requirements, and the project-specific uncertainties. Funding needs for LNG infrastructure are significantly different for different types of infrastructure and project sizes. The most expensive capital expenses are normally incurred for liquefaction terminals due to the high level of technology and supporting facilities required to liquefy natural gas into LNG [Tasnia, 2025]. The level of investment and the nature of revenue on regasification terminals, storage facilities, pipelines, transportation systems and loading facilities varies. A large project will typically involve multi tranche financing, involving multiple financial institutions, governments, energy companies and long-term buyers. Modular LNG and floating storage and regasification installations, on the other hand, can be deployed faster and might need less initial capital investment [Pospíšil, 2019]. These disparities show that one financing model can not be used throughout the LNG value chain. A similar, although separate, financing issue is posed by the expansion of the modern grid. While there can be a number of public and system-wide benefits that can be realized from transmission and distribution networks, the benefits received from these networks may not be directly linked to their economic value. Grid investments can alleviate congestion, enhance electricity reliability, ease the integration of renewable energy and promote market dispersion [Heilig, 2017]. These benefits, however, can be shared with consumers, generators, utilities, and regional markets instead of being appropriated by a single project's owner. This means that there is a need for regulatory mechanisms that offer a level of revenue predictability that will result in long term capital. Conventional financing methods can then be complemented by public investment, regulated cost recovery, public private partnerships, project finance and climate aligned debt [Basulo-Ribeiro, 2024]. The other key factor in infrastructure financing outcomes is risk allocation. LNG projects and grid projects face construction delays, cost escalation, design mistakes, equipment failures, lack of resources, changes in regulations, currency fluctuations, financing difficulties and market uncertainty. In project governance, it is a good rule that the risk should be borne by the party who can control, predict, mitigate or insure it. The FIDIC, IChemE, NEC4 and LOGIC are standard contractual format that give various options for the allocation of these risks to owner, contractors, engineers, etc [Anwar, 2025]. Clearly defined contractual allocation can help minimize conflict and ensure cost and schedule certainty, thereby directly helping lenders to have more confidence in the project. The cost of LNG facilities is not just the revenue from the sale of natural gas. The investment in a large LNG project can create construction jobs, jobs for the shipping industry, jobs for working at the terminals, jobs for LNG storage, pipeline construction, and jobs for industrial production down stream from the LNG terminal [Tijan, 2021]. The exporting regions may benefit from increased trade and industrial activity and government revenues; the importing regions may benefit from diversification in supply and energy security. But LNG facilities can also make economies vulnerable to international gas price fluctuations. In many markets, natural gas is an important fuel to generate electricity and, therefore, LNG price changes can be cascaded onto electricity prices. The broader financial and systemic risks might thus stem from strong gas and electricity price linkages [Tasnia, 2025]. The regional market structures illustrate the importance of considering the investment in infrastructure within a specific economic and regulatory context. Hydropower resources can substantially decrease the sensitivity of electricity markets to natural gas prices, while high gas fired generation can result in more of a "pass-through" effect of LNG price changes into electricity markets. Substantial differences in electricity prices between locations may also be caused by transmission constraints [Iris, 2019]. The past shows that fluctuations in generation capacity, renewable deployment, hydropower availability, transmission constraints, and regulatory structure can impact investment incentives and cause financial strain for merchant projects. Long term contracts offer revenue stability, and destination flexibility, futures, forwards, options and other hedging tools can help mitigate the risks of price volatility. Flexible capacity arrangements, performance based financing and revenue mechanisms also can be taken to grid infrastructure. The financing of LNG infrastructure and the modernization of the grid demands a careful balance of financial prudence and energy security, system reliability, environmental sustainability, and long-term adaptability [Di Vaio, 2020]. Above all, future investment needs to be based on scenario analysis and assessment of the changing demand, technology, market and climate policy. An integrated approach may help maximize the use of capital for infrastructure that is designed for economic and energy security benefits, and flexible to the ongoing changes in the global energy system.

## 10. Conclusion

Financing LNG infrastructure and modern grid expansion requires an integrated approach to capital allocation, risk management, governance, and sustainability. Diversified financing structures, long term contracts, effective insurance, and balanced risk allocation can improve project bankability and financial resilience. LNG infrastructure can strengthen energy security and support economic activity, while modern grids enable renewable integration, electrification, and system reliability. However, changing energy demand, climate policies, technological development, and geopolitical conditions create significant transition risks. Future investment should therefore prioritize flexible, risk adjusted, and climate conscious financing strategies that balance immediate energy needs with long term economic, environmental, and energy security objectives.

## Author Contributions

M.N.H.: Conceptualization, literature search, investigation, analysis and interpretation of the literature, manuscript drafting, critical revision, and final approval of the manuscript.

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