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Digital Transformation in Energy Sector Sustainability: Accelerating Sustainable Energy Solutions through AI and Blockchain in Emerging Markets

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ABSTRACT:

This thesis explores the combine use of artificial intelligence (AI) and blockchain technologies to accelerate the circulation of sustainable energy solutions using the international collaboration in the green energy sector in China. The paper investigates the potential of using AI and blockchain to transform the processes of cross-border energy projects, namely to render them more efficient, decentralized, and open in developing markets. With regards to the energy situation in China, the research question of the primary research focuses on how these technologies contribute to cooperation between countries. They are further sub-divided into organizational, technological and regulatory barriers and enablers to their adoption.

The study reveals the possibility of using AI and blockchain in the implementation of foreign projects by using a combination of research methods by interviewing key participants in Chinese renewable energy corporations. Along with spotting the main enablers such as the appearance of new technologies and flexible regulations, the research is also able to spot major obstacles such as issues related to the interoperability, disjointed regulations and institutional resistance. Results indicate that AI aids in prediction and system enhancement, and that blockchain creates a trusting scenario by means of secure and open energy trading and decentralized trade.

The paper recommends that legislators are trying to normalize regulations and that firms employ hybrid digital architectures, which can be efficient and compliant at the same time. The study contributes to academic knowledge as a new concept, which is called sovereign interoperability in cross-border renewable energy projects. It also provides valuable insights on how to navigate issues with the help of digital means that will ensure people across the world can collaborate to find cooperative solutions to sustainable energy. Further research is required to determine the impacts of digital transformation, policy, and cross-border energy cooperation on each other completely in the emerging markets.

KEYWORDS: Artificial Intelligence, Blockchain, Renewable Energy, Sustainability, Emerging Market

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1. Introduction

1.1 Study Background

Rapid transition to renewable energy (RE) is a matter of concern nowadays for the entire planet since nations are struggling to satisfy additional needs whilst reducing greenhouse gas emissions. Due to climate change, energy security concerns, and volatile fossil fuel markets, policymakers and business executives are concerned about identifying digital solutions that can help renewable energy systems perform better, more consistently, and more sustainably. According to the International Renewable Energy Agency (IRENA), the world must utilize new, modern technologies as well as renewable sources of energy such as solar, wind, and water power. Moreover, this will facilitate easier making of predictions, planning of the demand, and collaborating without a central authority to ensure that the net-zero goals are achieved.

China is a large component of this movement as it is not only the largest contributor to carbon emission globally but also spends the largest amount of money on renewable energy. China has successfully established a full manufacturing chain (B. Wang et al., 2024) and installed more solar (PV) and wind power than any other nation in the world to become the renewable energy superpower over the past 20 years. But, things have improved significantly, yet, the issue of grid congestion, shedding of energy, and uneven geographical uptake persist, which make hurdles for the complete adoption of renewable energy systems(Z.-Y. Zhao et al., 2011) .

Modern technologies like Artificial Intelligence (AI) and blockchain provide emerging processes to solve these systemic problems. AI's advance functions such as deep learning and predictive analytics can be utilized to improve the energy predicting process, optimize grid performance, and proactive maintenance of renewable assets(Lee et al., 2024) .Similarly, blockchain technologies develop distributed and immutable records for secure energy dealings, roboticize smart arrangements, and grow confidence among participants in decentralized energy markets (Q. Wang & Su, 2020). According to Al

Shareef et al. (2024), to combine AI and blockchain, resolving existing issues, facilitating decentralization, and allowing individuals who live in different parts of the world to collaborate on energy endeavors are necessary steps. Still these technologies are yet to be utilized simultaneously in the developing countries.

China has a huge number of studies on AI and blockchain to advance energy in comparison to other countries (Mao et al., 2023) and the country struggles to implement such ideas in practice. For the implementation the country confronts some difficulties such as regulatory complexity, institutional resistance, interoperability concerns, and high integration costs of technology (Otoum & Mouftah, 2021). This hurdle is especially present in the case of green energy, more often when countries work together since the process is significant that all data standards, energy certificates, and governance should cooperate. Therefore we found it a significant and right time to explore the way of utilizing AI and blockchain to improve international collaboration in the Chinese power generation sector.

1.2 Problem Statement

Utilization of digital technologies in the energy industry has been explored eventually, but still there remains some insufficiency that need to be resolved. First of all, many researchers investigate how AI can aid planning, scheduling, and predictive maintenance process(Li et al., 2025) ,meanwhile they haven't focused on blockchain technologies that can facilitate the decentralization and safe trading of renewable energy (Q. Wang & Su, 2020; Yu et al., 2024a). A few studies have been done on the combined use of these two technologies but only for large-scale energy systems. Hence it is pointed out by Al Shareef et al. (2024) that the combination of AI and blockchain is still just a preliminary thought, and that small scale test projects are the only real-world uses for it in the energy sector.

Secondly, we found that most of the current studies solely focused on domestic uses do not give enough attention to collaborative action across borders. Researcher Otoum and Mouftah (2021) say that joint application of AI and blockchain upgrades energy systems more trustworthy and secure, but their research mostly stays within national borders. Furthermore, Le et al. (2022) talk about AI's polyvalent role in technology, markets, and policies, still there exist some lacking as they ignore the process that talk about how these systems could work together across the border.

The third gap we found about the limitations on rules and institutions that even make the process harder. Researchers Zhu et al. (2020) found that the nation's tight regulations, incumbent controlled market, insufficient law changes to digital tools are bigger issues for utilizing blockchain in energy. If the rules are flexible and consistent in different countries then it will be easier for them to work together and get the better results of modern technologies. Otherwise the technological methods could damage this effort.

Finally, the last point is that there is a lack of real world evidence about organizational capacity and stakeholder views. Though quantitative research maps the efficiency in a controlled and theoretical sense(Z.-Y. Zhao et al., 2011), not many qualitative studies are applied for this purpose that look into companies, engineers, and policymakers to see opportunities and drawbacks of using AI and blockchain together. Accordingly, it is necessary to gather real-world information about how these technologies can help China's green energy sector to work together better across borders.

1.3 Research Purpose

The aforementioned gaps are addressed herein by exploring the potentiality of using AI and blockchian technology to assure that internationally employed individuals can more seamlessly collaborate within China's renewable energy sector. The theoretical models

mentioned here are also applied in this study for thematically alignment, imparting depth and making it coherent to the study.

Diffusion of innovation (DOI) theory developed by Rogers (2023) where the dissemination and uptake of new technologies across enterprises, sectors and nations is well discussed. For AI-blockchain adoption in green energy in China DOI stresses the role of relative advantage, compatibility, complexity, trial ability and observed ability(Chen et al., 2024) .

The other theory we applied here is Socio-Technical System theory developed by Geels (2011). This theory explores the connection between policy frameworks, workplace practices, stakeholder behavior and technological systems. Our selected country China is now undergoing the energy transition that is closely related to the market reforms, international collaborations, and state-owned institutions(Xu, 2021), which are also related with the STS theory and is particularly applicable in that context.

Incorporating the combined model of these two theories, this study does not only explore whether it is technically sound to utilize the potentiality of AI and blockchain technologies jointly, but also attempts to investigate the probable impact of institutional, regulatory, and organizational influences on adoption. The principal aim is to prepare strategies that may prove useful to policymakers and businesses that can prudently use digital technologies to work jointly on cross-border green energy efforts.

1.4 Objectives and Research Questions

Main Research Question

To what extent can the integration of AI and blockchain technologies enable international collaboration in the renewable energy sector of emerging markets, specifically in the context of China?

Sub-Question

What are the key organizational, technological, and regulatory barriers and enablers affecting the adoption of AI and blockchain for international renewable energy collaboration in China?

Research Objectives

1. To examine how selected Chinese renewable energy firms apply AI and blockchain technologies in the context of international cooperation.

2. To identify the main enablers and barriers to adopting these technologies in cross-border energy projects, including organizational capacity, data infrastructure, and regulatory conditions.

3. To assess how AI and blockchain affect collaboration outcomes, specifically in terms of:

- Efficiency (e.g., predictive forecasting, scheduling optimization)

- Decentralization (e.g., peer-to-peer trading or distributed energy coordination), and

- Transparency (e.g., smart contract usage, traceability of cross-border energy flows).

4. To provide context-based recommendations for policymakers and firms on leveraging digital technologies to enhance trust, coordination, and strategic partnerships in international renewable energy projects.

1.5 Study Scope

It is important to explicitly define the scopes of this study, so that it can be useful for further scientific and practical applications. This study is explored in three dimensions namely geographically and technologically.

1.5.1 Scope of Geography

This study solely focuses on China and its green energy market that has become one of the core networks in the international shift in the energy system. In 2023, China will account for one-third of newly installed renewable energy capacity(“International Renewable Energy Agency (IRENA). (2024).,” 2024).China is the one of the largest manufacturers and consumers of renewable electricity. Nevertheless, the considerable proportion of the study addresses the role of digital technology in sustainable energy especially to the developed countries like the US and the EU(Q. Wang & Su, 2020). Moreover, in this analysis where we focus on the Chinese energy market, a critical knowledge gap is resolved through examining the application of digital innovations in an emergent economy recognized for excellence in research and development but still suffers in terms of rules and infrastructure. Furthermore, China is the main focus of this study, yet its insights are contextualized within the broader landscape of emerging markets. Most of the core issues, such as the difficulty in collaborating with international partners, inflexible institutions, and lack of regional adoption, that obstacles faced by China are also observed in India, Brazil and South Africa (Lee et al., 2024). Therefore, countries that are facing similar challenges will get useful resources from the results of this study.

1.5.2 Technological Scope

The paper investigates the potentiality of AI and blockchain technologies in renewable energy and for this purpose we selected the following two tools due to the following reasons:

Artificial Intelligence enables the estimating of energy production and consumption, forecasts the maintenance of renewable assets, and improves the work of the grid (Li et al., 2025). Wind, solar and hybrid systems have also been efficiently executed with the help of artificial intelligence (AI).Nevertheless, this can also be used to its full potential of dealing with uncertainty in large, distributed energy systems (Lee et al., 2024).

On the other hand, decentralization, trust worthiness, and safeguard of transactions served by blockchain aid people to market energy with one another and trace green energy in a manner that can not be manipulated (Q. Wang & Su, 2020). Smart contracts may help lessen the number of intermediaries, accelerate processes, enhance confidence in global energy markets, and blockchain can improve (Otoum & Mouftah, 2021).

Other digital technologies such as the Internet of Things (IoT), big data analytics, and cloud computing are mentioned in this research but they are only considered within the framework of AI and blockchain. An example is that the IoT devices transmit data streams in real-time that are consumed by the AI model, and the blockchain ensures that the partners across countries can exchange data in a secure manner(Li et al., 2025). Meanwhile, the paper remains dedicated to the correlation between AI and blockchain as the primary means that individuals can collaborate.

1.6 Research Significance

This paper is significant for further research because it includes academic knowledge as well as it has real world applications. Moreover it affects policy, and has effects on the sustainability of the whole world. This study offers updated ideas about how the activities like digital transformation, renewable energy, and international cooperation will work

together that facilitate academic discussions, support business practices, and help to shape policy changes in developing countries like China.

1.6.1 Academic Contributions

This research will fill the knowledge gap as previous studies investigate artificial intelligence (AI) or blockchain in isolation when applied to renewable energy, and , on the other hand, there exists a few studies that discover the impact of combination of these technologies to support cross-border collaboration, especially in a complex economy like China(Al Shareef et al., 2024a). We proceed by undertaking empirical evaluation of these technologies by Chinese renewable energy companies in overseas projects. Furthermore, we adopt two theories related to this topic such as Diffusion of Innovation (Roger, 2003) and Socio-Technical System (Geels, 2011) to clarify the mechanisms behind disruptive technologies' success or failure in heavily regulated energy systems. Methodologically, we draw on primary data from semi structured interview with technology and green energy practitioners to reinforce the studies trustworthiness by applying thematic analysis and triangulation to ensure that we reflect the breadth of stakeholder perspectives (Braun & Clarke, 2006; Creswell & Creswell, 2018).

1.6.2 Practical Contributions

Chinese renewable energy companies are trying to digitalize so fast, yet there are some difficulties, the systems do not always respond, and cyber security is also an authentic concern as the initial price might be prohibitive(Otoum & Mouftah, 2021). We propose a practical pathway for the future such as leveraging AI to forecast production and streamline plant operations and to make energy trading transparent and fair utilizing blockchain smart contracts. These approaches support transnational scaling and maintain efficiency, trust and compliance. We also demonstrate that it is not an issue of one company for a single time; the entire ecosystem can be transformed by decentralized

platforms. Supply chain systems will also be well manageable with the help of AI and blockchain, peer-to-peer trading will become more rationalized and distributed energy systems are coordinated across the borders (Li et al., 2025; Q. Wang & Su, 2020). This paper simply provides effective manuals on how multinationals can have a more robust, trustworthy partnership experience with renewable energy. It also shows how AI and blockchain can develop Chinese green energy companies more successfully in the cross border market. Digital technologies through transparency and openness make the deals more attractive to global partners, especially where trustworthiness and responsibility are matters of great deal.

1.6.3 Policy Relevance

Another important feature that the study offers is the demonstration of the significance of the alignment of governance structures among the countries. IRENA (2024) states that the nations have to permit these digital energy platforms to transmit the information, be secure, and adopt blockchain-based green energy certificates to upgrade them to global standards. The Chinese law and the foreign law are disparate, and this complicates the efforts of other countries in trading energy with China. This is among the significant issues that this paper identifies. The other reason as to why rules should be more in sync is to ensure the market does not disintegrate. Moreover, the findings of the study can assist the government to provide an atmosphere where the application of AI and blockchain can be facilitated. This is being done through establishing regulatory sandboxes in order to test digital energy. These steps may facilitate entry by individuals into countries as the study indicates in order to establish trust and teamwork among countries.Such measures are necessary to create trust and cooperation between trade partners, and they will be effective when states are united in reducing the entry barrier, which can be sociotechnical and organizational characteristics and policy, discussed in the study (Q. Zhao et al., 2024). As shown in this paper, institutions also serve as a major contributor to digital adoption

where regulatory bodies and governments do not merely make a rule; they also promote institutional learning, skill acquisition, and cross-border policy discussions that can keep digital energy transitions on track.

1.6.4 Global Significance

This paper is addressing not only China but also the rest of the world: with the 2024 outlook published by IRENA, we are reminded that the key to achieving net-zero by 2050 is technology, and China, as the largest emitter but also the largest investor in renewables, can teach the world a lesson. We demonstrate how the combination of AI and blockchain in China can be used as a viable example of emerging markets in Africa, South Asia and Latin America, which have to overcome the same challenges (poor regulations, poorer infrastructure, tight budgets), by pointing out what works and does not. The results also inform international systems such as the Paris Agreement and the UN SDGs because they demonstrate how digital solutions can enhance efficiency, decentralization, and transparency in transnational renewable initiatives, and provide specific means of how to increase collaboration in a way that is just and safe. To put it in a short sentence, the article is worth discussing in the academic environment as it informs the businesses, makes a difference in the policy and adds to the environmental discourse across the globe. To illustrate, the way in which the integration of AI and blockchain can expedite, fairly, and technologically improve the worldwide energy transformation is proof of this.

2. Literature Review

2.1 AI and Blockchain in China's Renewable Energy Sector

China's renewable energy (RE) industry faces many issues like fixing inefficiencies, reliability which are changed gradually by digital technologies such as Blockchain and Artificial Intelligence (AI) as well as these technologies also encourage people from different countries to work together. Ai technologies like machine learning and deep learning algorithms are being used to enhance grid management, predictive maintenance, and energy forecasts. On the other hand, blockchain serves decentralized, open, and safe systems when it comes to selling energy, managing contracts, building trustworthy stakeholder relationships. Although China owns the most patents in AI and blockchain, it still has operating issues and lack of skilled workforce. Despite these issues, China shifts gradually to a digital, collaborative, and sustainable future based on green energy by combining AI and blockchain technology.

2.1.1 AI Applications in Renewable Energy

Based on advanced technologies, artificial intelligence (AI) has gradually worked as an impactful force that solving the long term issues related to inefficiency and reliability in Chinese renewable energy sector.Furthermore, by utilizing AI technologies like deep learning and machine learning which is used in power and energy production(Ahmad et al., 2021) China is developing its operational effectiveness in significant areas such as grid control,energy forecasting and planned maintenance. China has plan to be world leader in AI by 2030 (Khanal et al., 2025) and following this the country has made strategic goal such as " New Generation Artificial Intelligence Development Plan" and the milestone of this plan is becoming a carbon-neutral nation by 2060 (Zhao et al., 2024). By connecting AI with renewable energy projects, China removes the hurdles of cross border integration

through improved production efficiency and distribution of energy that speeds up the move to a sustainable, low-carbon future.

Artificial intelligence has helped to develop China's renewable energy sector a lot especially, it improves forecasting, efficiency, and energy management.A group of researchers discuss the role of AI in improving investments in green energy by making energy prediction, grid optimization, and smart energy management better (W. Li et al., 2025).They also claim that AI enhances investment by streamlining operations , but their discussion found some difficulties where they mentioned that high capital costs and limitation of resources can affect the effectiveness in the renewable energy sector in the long term (W. Li et al., 2025).Similarly, Zhang et al. (2024) portray AI's part in developing energy system, most importantly when it is about fixing problems with renewable energy sources such as solar and wind power that go out at odd times.Their study reflects that AI can make accurate prediction, which make renewable energy to add into the grid easily and ensure best use of energy storage (X. Zhang et al., 2024).In addition they also say that, as the technology improves AI can flourish its good effects (X. Zhang et al., 2024). Tian et al. (2024) also agree with them as they looked into the different paths of growth in renewable energy that are affected by AI. In the long term, AI is better for green energy, but climate uncertainty and short-term issues such as financial downturns or, technological obstruction can slow-up the effectiveness (Tian et al., 2024).

Most of the researchers are agreed on the point that utilization of AI in renewable energy sector is challenging. Li et al. (2025) concerns about regulatory uncertainty and the huge startup investment that is essential for AI deployment. Qin et al. (2024) also support this thought. They say that, there exist high cost in implementing AI as well as it is difficult to integrate AI with ongoing energy systems (Qin et al., 2024). Both studies indicate that, even though AI can develop energy systems better, financial and legal issues make it difficult for AI to be utilized in a greater extent. Additionally, another group of researchers found that, in the short term AI's sophisticated integration process can weaken renewable

energy, benefiting non-renewable areas more than the renewables (Zhao et al., 2024). On the contrary, some experts talk about the potentiality of AI that can develop energy systems in rural areas by providing customized alternatives for distributed energy management (Peng et al., 2024). While Zhao et al. (2024) discuss about AI technology's potentiality in renewable energy in the long run, they also realize that the result of short term energy transition can be worse if non-renewable energy sectors get more facilities from it.

Another significant idea that most of the literatures discuss is about decentralization and transparency of green energy system that AI could help to make. Researchers Zhao et al. (2024) elaborate the importance of AI in forecasting energy production and ensuring the equilibrium between supply and demand.This is essential to ensure the energy flow to be clear enough and also decentralized energy trade systems.Similarly , Peng et al. (2024) give importance on rural energy planning where the utilization of AI is also necessary. They say that , to make data analysis and and prediction programs better decentralized energy management system is essential (Peng et al., 2024). On the other hand, Wang et al. (2024) discuss about the connection between AI and high-quality energy development (HED) in China. They argue that, without proper regulatory frameworks and digital economy infrastructure AI can not provide its full potentiality in green energy (B. Wang et al., 2024). This adds another level of complexity because it suggests that AI cannot be utilized fully until bigger economic and policy issues are dealt with fully. Furthermore, regulatory gaps and willingness of organizations to accept AI are most talked topic in energy sector. Li et al. (2024) and Tian et al. (2024) both experts group agree on the point that regulatory uncertainty can make hurdle in the way of AI development in renewable energy sector. It not only make difficulties in the installation of AI , but also it can create obstacles in cross border integration because for a smooth trade system regulatory systems need to be matched. Similarly, Wang et al. (2024) say that faster growth of AI in China's digital economy only can be possible if government, companies, and academic institutions work together. AI utilization in cross border green energy collaboration is still an area that hasn't

be explored that much in current literatures which need flexible national and international policies.

Most of the literature discussed above commonly agree on some points that high startup costs, unclear rules, and difficult integration make a hurdle in the way of broader use of AI. Previously published researches found It is essential to change the regulatory and organization policies in China for the greater use of AI in renewable energy that can help countries to work together to reach their carbon neutrality goals. While AI can develop China's green energy systems, the process of linking AI and blockchain to help people from various nations to work together is still not fully developed. The emerging renewable energy sector slowly started to apply blockchain in this sector which is discussed in following section.

2.1.2 Blockchain in China's Energy Sector

In China where the speedy improvement of green energy sources demand for more efficient and clear systems, could be changed a lot by blockchain technology. Moreover researchers also confirm that blockchain has a huge potential to make the energy industry operate better by developing things like data integrity, decentralization, and transactional openness instead of the regulatory and institutional issues (Zhu et al., 2020a). According to the writer, a crucial cause that makes the process of adopting blockchain difficult is the governmental policies and rules that don't support it. In their opinion, the ongoing advancement of blockchain in the area of energy requires policymaker's willingness and clear sight. This led Hou, Wang. And Luo (2020) to look into how blockchain could be used to manage distributed energy sources in China. They evaluate Porter's Five Forces model to investigate how blockchain technology can make the energy market more competitive. Their research portrays that blockchain works well with distributed energy systems because it supports decentralization and lets people trade energy with each other, and make good use of resources (Hou et al., 2020).

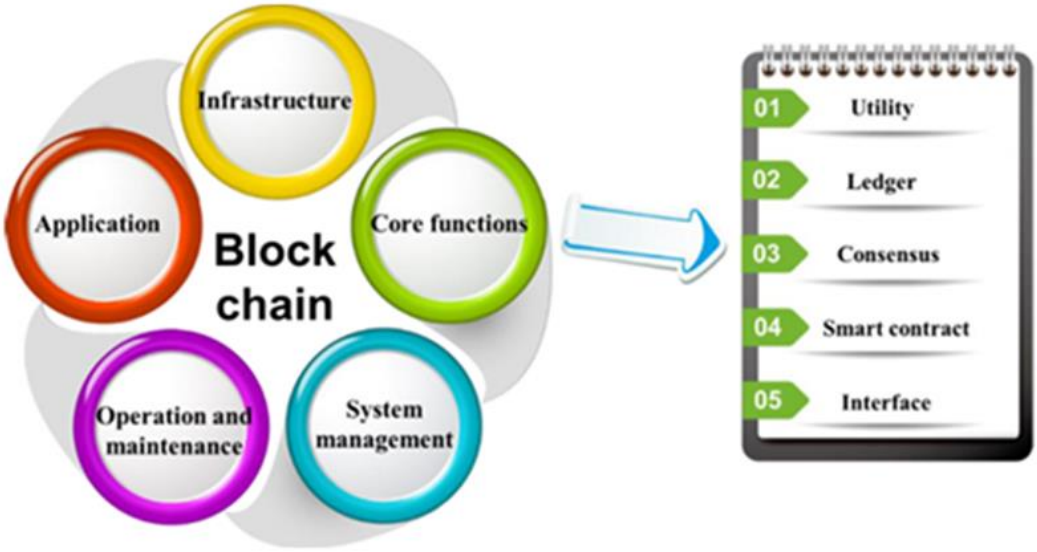

Fig: 5 Technical architecture of blockchain (Q. Wang & Su, 2020)

A huge number of studies portray the potentiality and benefits of blockchain in Chinese renewable energy sector but they also critically examine the issues that can hinder the deployment of it. Researchers gradually started to think about the benefits of blockchain to improve grid management, trading systems for energy and transparent tracking system in energy sector. Despite this, they stress significant problems such as strict legal policies , institutional resistance to accept new technologies and the updated technological knowledge that are essential to support this kind of breakthroughs. These analyses give us a big picture of blockchain's role in the Chinese renewable energy business and help us to learn more about the gaps that exist in the systems.

A group of experts introduced a new real-time consensus method called "Proof of Task" that makes better management of blockchain technologies in energy systems (Yu et al., 2024). To make it different, they concentrate on developing cybersecurity, dealing with probable cyber security threats and ensuring reliable renewable energy systems which is vital because China's growing renewable energy sector builds up on these facilities (Yu et al., 2024). In contrast to other studies, Yu's article mostly focuses on the procedures of

blockchain technology and its security, that is significant for real-time operation in power systems. However, this study doesn't elaborately discuss about China's regulatory policies and its backdraws that make hurdle for the proper application of blockchain technologies. While other researchers group find out the decentralization potentiality of blockchain and they explain that blockchain can modify China's monopolized energy market by establishing distributed energy trade (Zhu et al., 2020a). As the researchers point out that China's regulatory structure is so strict, that can create obstacle in the installation process of blockchain technologies in green energy sector that could facilitate decentralization of energy trade (Zhu et al., 2020a). Compared to Yu's article, Zhu's study gives more priority on China's market and policies, even though both the researchers agreed on the point that blockchain is one of the greatest helping technologies that can manage energy better. But Zhu's study ensures that blockchain cannot be utilized fully in China until the country modifies it regulations (Zhu et al., 2020a).

In a bigger picture, Wang and Su (2020) apply a bibliometric study that shows the progress of blockchain technologies in the energy sector all over the world. According to them and other researchers, China has become a major player in blockchain research compared with other developed countries (Green & HSU, 2021; Q. Wang & Su, 2020). Wang and Su (2020) discuss blockchain's growing significance as a whole without going into details about China's regulatory problems, which Zhu and other researchers point out as a bigger issue in this case. Wang and Su's work covers many important issues relevant to blockchain but completely ignores the regulatory issues that are significant for blockchain adoption in the Chinese energy industry. Conversely, Zhu et al. (2020) talk about the regulatory environment, which is the biggest obstacle in the transformation process of China's energy sector, while blockchain has the full ability to develop the green energy and financial systems. According to their work, existing Chinese rules don't appropriately cope with the upgraded characteristics of blockchain which are more specific policy suggestions and they suggest moving toward a more relaxed regulatory environment (Zhu et al., 2020b). Therefore, Zhu's study combines the technological potential of blockchain with the most

needed change in regulation policy (Zhu et al., 2020b). Lastly, Taherdoost (2024) states blockchain from a financial viewpoint, focusing on smart contracts that facilitates the decentralized energy trade make more efficient energy markets. The researcher is curious in the monetary uses of blockchain in the renewable energy that can develop energy management and cheap production (Taherdoost, 2024). Taherdoost agrees with Zhu's study about regulatory problems but he emphasizes more on the significance of overcoming policy resistance and incorporating trust in blockchain systems for successful integration.

To sum up, all the literatures consent on one point that blockchain has the ability to transform China's renewable energy sector. But still there exists some significant gaps related to regulatory and legal policies. Few studies, including Zhu et al. (2020) discuss China's monopolized energy market issues that need to be solved to enhance the use of blockchain. While Yu et al. (2024) see this on technological viewpoint and focus on real-time control and hacking. Wang and Su (2020) on the other hand, focusing only on China's role in research from a global point of view without going into detail about the problems that still exist in Chinese regulatory system. Bringing up the financial side, Taherdoost (2024) prioritize green financing but explain a little about the need for regulatory help to deal the investment issues. Each of the studies provide significant knowledge about blockchain, but they all stick to one issue: that rules and regulations need to be streamlined to make blockchain technologies work well in the Chinese green energy sector. Moreover, to upgrade the Chinese renewable energy sector it is essential to combine the two technologies such as AI and blockchain together. This integration of technologies enhances the cyber security as well as transparency in energy trade.

2.2. Theoretical Frameworks

Building on the previous discussion about regulatory impediments, it is essential to apply theoretical foundation that can integrate AI and blockchain in China's renewable energy sector as well as guide its implementation. For this study we choose two theories that are aligned with our research objectives. The first one is the "Diffusion of Innovation" (DOI) theory that offers significant insights about how modern technologies such as AI and blockchain can be adopted and utilized across various sectors by emphasizing the role of communication, channels , social systems, and potential benefits of these technologies. On the contrary, another theory is the "Socio-Technical System " (STS) theory that considers both technological and social aspects of technological integration. These theories present valuable context to examine the feasible tracks for triumphing over barriers and aligning with the goal of an efficient energy system.

2.2.1 Diffusion of Innovation Theory

The Diffusion of Innovation (DOI) theory which provides an enlightening framework that explain how new ideas and innovations can spread within socities. This theory is developed by Everett Rogers where he categorizes adopters into innovators, early adopters, early majority, late majority, and laggards steps and emphasizes five core factors such as relative advantage, compatibility, complexity, trialability, and observability that influence the adoption. These attributes assist to know how and at what rate innovation can be adopted by the communities (Franceschinis et al., 2017). We find DOI theory relevant for our thesis as the paper discusses about new digital technological innovations such as AI and blockchain and how these combination of technology will operate in emerging energy markets like China where technological improvement, natural adversity and institutional diversity interact with each other and the cross- border trade of renewable energy.

In wind and solar sector China gained impressive growth, though there still exists uneven digital transformation. The overall absorption of AI and BC across the sector is hindered by structural and institutional barriers in spite of China's early adoption of smart technologies in large –scale firms and urban centers. Unstable institutional design, restricted external communication, and less developed knowledge infrastructure constrained China to diffuse the renewable energy technologies (Chen & Lin, 2020). DOI can solve these issues by its concepts of complexity and low compatibility. It works well when companies have less technical capacity to connect with modern systems into existing infrastructure. Conversely, by reinforcing observability and trialability in improving innovation diffusion, regions with stronger grid density and investment in human capital can experience quick upgradation.

AI and BC technologies are blessings for renewable energy sectors that can make possibilities for new avenues for collaboration. Data sharing, optimize forecasting and transparent operation all can be enhanced by utilizing these digital tools. The ability to operate in international border, knowledge flow about this is a critical factor that results innovation diffusion for the multinational enterprises and emerging markets (Rammal et al., 2023). Absorptive capacities and knowledge-sharing capabilities of the involved parties are core elements in DOI framework and here involving digital technologies not only depended on infrastructure and investment in international renewable energy collaboration. Countries can achieve relative benefits and compatibility of digital mechanisms by aligning incentives and governance technics through blockchain for more productive, distributed and, clear energy partnerships. However, effective diffusion depends on national innovation ecosystems as a bunch of researcher demonstrates that, to enable firms to innovative and adaptive knowledge-based dynamic capabilities such as knowledge creation, diffusion, absorption play a crucial role (Robertson et al., 2023). If these capabilities spread over the eastern region of China that will exhibit more flexible innovation ecosystems. For highlighting the spatial dimensions of innovation diffusion renewable energy technological innovation (RETI) encourages power generation both

directly within provinces and indirectly through interprovincial spillovers (Zheng et al., 2021).

Moreover, China positioned as a leader in renewable energy diffusion which is supported by Chinese policy, scale of deployment, and export-oriented technology strategy (Lacerda & Van Den Bergh, 2014). Chinese government's subsidies in wind and solar energy sector support its rapid growth in R&D investment, and favorable market framework which provides a strong relative advantage and develops the trialability of modern digital energy solutions for other emerging economy. Yet, there exists some barriers in adoption procedures as Liu and Zhang (2022) identify that, technological innovation in renewable energy is still uneven in various Chinese regions in spite of positive market integration impacts (X. Liu & Zhang, 2022). Central and western regions of China face greater hurdles in adopting complex technologies like AI and BC in comparison with eastern regions. The main reason behind the slow digital transformation of the energy sector of many developing countries are back dated legal frameworks, deficiency in private sectors engagement and technical illiteracy (Tabrizian, 2019). According to Jin et al. (2014), Proactive technology movement has make enormous change in Chinese industrial and global integration, especially in energy and environmental sector, but it still needed more modernization (Jing et al., 2014).

The DOI theory provides us coherent and multi-dimensional framework for realizing the benefits of adoption of AI and BC in Chinese renewable sector. Basically this theory gives a big picture that allows for a structured study of how innovation spread across borders and organizational networks. Additionally, it also portrays that how significant is communication network, learning ecosystems, regulatory alignment and institutional readiness for the developing nation like China by uncovering where and how these technologies are being used and what is lagging behind them for spreading. By applying this theory policymakers, energy companies and global technology partners can get the way for promoting fair and quick digital transformation.

2.2.2 Socio-Technical Systems (STS) Theory

The Socio-Technical Transitions (STS) theory developed by Frank W. Geels (2011), where he articulate Multi-Level Perspective (MLP) framework that portrays how enormous movement in systems, like shifting to green energy occur at various level of society that are all connected (Geels, 2011). This actually presents that technological alteration is affected by social, political, and economic situations, which opposes linear models of innovation. According to Rutherford and Coutard (2014), energy movement is critical as it depend on the situation where they occur. Socio-Technical Systems helps to evaluate how modern technologies shape social systems particularly when they are in complicated situations such as the integration of AI and blockchain that need to work with social factors like rules, government, and the needs of stakeholders . China invested a lot in green energy; that proves how AI and blockchain work together there to encourage the country to have more energy trade between countries (Zhai & Gao, 2024). Adding Chinese social and technical system and applying STS theory is essential for this policy (Xu, 2021).

China's infrastructure systems are linked by its sociotechnical and technological aspects where AI and energy production technologies as well as social aspects like policy and regulations are included. It is difficult for China to integrate old energy systems with modern technologies and it will be harder as China move forward to green energy which is mostly based on fossil fuels (Mah, 2020). Blockchain technologies can make it possible by ensuring safe and clear decentralized energy trade , but without aligning with international law this will not work properly (Xu, 2021). Similarly China cannot be able to utilize AI in grid system to distribute more energy until the country sets up data control and cooperative framework with its neighbors (Geels, 2019). Many developed countries take help of Socio-Technical Systems (STS) theory for efficient energy trade by using green technologies. In U.S. and Europe smart grid creation has played a major role where digital technology has made energy production more productive and companies have to follow the rule strictly for this purpose (Mah, 2020). Another example is Germany where use of

green energy and regulatory tool like feed-in-tariffs are encouraged to follow (Xu, 2021).For decentralized peer-to-peer energy trade which is significant for successful social structures and matching technology UK also utilizing blockchain (Mah, 2020). Furthermore, it can be said that STS theory helps to balance new technologies with social systems which leads to more sustainable energy future.

The Multi-Level Perspective (MLP) in STS theory is advantageous for altering Chinese energy transition, as it evaluates the current systems before adopting new technology. MLP consists of three levels, such as landscape forces, niche innovations, and sociotechnical regimes. New ideas like blockchain and AI can be applied in pilot projects before large-scale utilization at the niche level .China started to utilize its pilot projects, mostly in smart grids and energy swaps, though they are still not that well established (Mah, 2020). At the regime level, Chinese energy sectors are mostly fossil fuel-based, which are state-owned companies and that is why China has to alter its rules and market mechanisms to adopt new technologies for updating new energy systems. But the bigger social pressure resides at the landscape level, where policies for climate change and the need for energy are needed that push China to adopt green energy technologies. The Chinese energy system can go forward to adopt green energy integration by advanced technology like AI and blockchain (Xu, 2021).

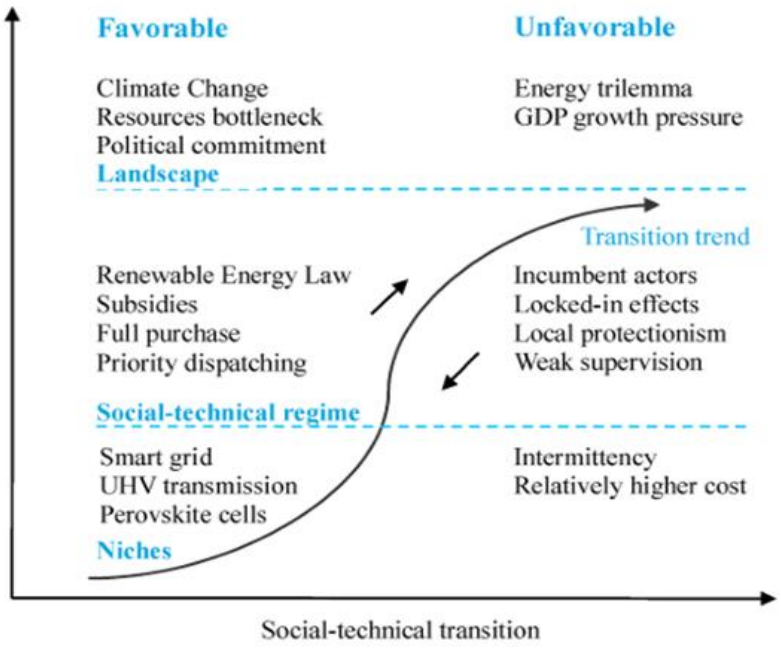

Fig: Factors affecting China's energy transition using the MLP analysis (Xu, 2021)

China must be aligning with both new technologies and current rules when it combines AI and blockchain technologies in the international energy market. Blockchain technologies are essential for cross-border integration but to use these technologies China has to be matched up with those of its partner country's laws (Geels, 2019). Similarly, if there exists agreed-upon infrastructure and data-sharing norms that go beyond China's borders ,AI can also apply successfully for managing decentralized systems and improving energy grids (Mah, 2020). Similarly technological progress and social structures are essential when countries are wanting to integrate for cross-border trade energy by following STS theory (Zhai & Gao, 2024). Policymakers and energy groups of China made it easier by creating rules that support digital technologies for successful sociotechnical transition toward cross-border renewable energy integration (Xu, 2021). For instance, China is going forward to set rules for sharing data and make rules that allow for decentralized energy trades by blockchain (Geels, 2019). Additionally, Chinese energy companies such as State Gris Corporation act significantly in overseeing the integration of AI and blockchain into current

grid systems. These groups need to make sure that involving these mechanisms meets the demand of all parties who are participating (Mah, 2020).

All the researchers also agree on this point that, more collaborative activities from policymakers and energy groups also play a major role that will support China's aim for renewable energy installation and technology enhancement. By adopting STS theory China's cross border energy process can work more smoothly because it gives solutions where complex technical and social systems interact with each other. Technological shift is an essential aspect for China to move forward to the energy market that is also required by Multi-Level Perspective (MLP), but it will only work when Chinese social and legal systems are compatible with other countries.

2.3 Integration of AI and Blockchain in China's Renewable Energy Sector

Combining AI and blockchain technologies is absolutely significant to overcome the barriers that currently exiting in the path of making green energy system that can be make it more efficient, scalable, and transparent and this section explores how the integration of digital technologies can be utilized in Chinese renewable energy systems by adopting the ideas of Diffusion of Innovation(DOI). China positioned as a leader in renewable energy diffusion which is supported by Chinese policy, scale of deployment, and export-oriented technology strategy (Lacerda & Van Den Bergh, 2014). The Chinese government's subsidies in the wind and solar energy sector support its rapid growth in R&D investment, and favorable market framework which provides a strong relative advantage and develops the reliability of modern digital energy solutions for other emerging economies. Yet, there exists some barriers in adoption procedures as Liu and Zhang (2022) identify that, technological innovation in renewable energy is still uneven in various Chinese regions in spite of positive market integration impacts (X. Liu & Zhang, 2022). China faces greater hurdles in adopting complex technologies like AI and BC in central and western regions in

comparison with eastern regions. The main reason behind the slow digital transformation of the energy sector of many developing countries are back dated legal frameworks, deficiency in private sectors engagement and technical illiteracy (Tabrizian, 2019). Proactive technology movement has made enormous change in Chinese industrial and global integration, especially in energy and environmental sector, but it still needed more modernization (Jing et al., 2014).

To change the country' energy system both the technologies such as AI and blockchain need to be aligned to the renewable energy industry. When discussing the potentiality of blockchain in China, researchers find out that this can support the much needed openness, security and distributed productivity, as China wants to shift from a carbon based system to renewable energy system (Q. Wang & Su, 2020). According to Wang And Su (2020), for safe and decentralized trading system blockchain is the best solution as China wants to adopt clean energy procedure. Also they point out some big issues like China's legal structure still not ready to adopt blockchain in energy system which make it difficult (Q. Wang & Su, 2020) as well as they also didn't give that much importance in the alignment of AI and blockchain in their article. On the other hand, another experts group, examine the issue in a more expansive way by including AI and also share the same concern about the integration of digital technologies (Al Shareef et al., 2024). According to them, blockchain ensures safe and decentralized trade energy and AI can help this process by supporting operations through correct prediction and real time decision making (Al Shareef et al., 2024). As China tries to add more renewable energy sources, integrating these technologies is essential to better manage its energy on a big scale. However, Al Shareef et al. (2024) also focus on the issues that combining these technologies in the Chinese energy sector is not still easy as it is technically complicated and there exist opacity in rules.

Unlike two previous researchers, Kumari et al. (2020) find out the potential benefits of modern technologies in energy systems such as cloud management in smart grids, which is also a significant area of China's energy infrastructure that is gradually growing. According

to them, the competence of both technologies can make the smart grid operation much better, as blockchain is able to endure safe data transfer, which can be enhanced by AI's ability to properly predict energy and optimize energy demand (Kumari et al., 2020). China eagerly adds more green energy sources like solar and wind, where smart grid procedure is more helpful to keep the grid stable and lessen the complexity of distributed energy sources (DERs). Still, Kumari et al.(2020) are concerned about the similar issues like system connectivity, security purposes, and the demand for solutions that exist in China's huge energy networks.

Additionally, Hua et al. (2022) give importance to the combination of modern technologies that can help prosumers, who use and also make it. Prosumers play a significant role in market-driven energy model, and China aims to adopt this model as well as to be more decentralized in energy trade. According to the researchers, blockchain is able to make decentralized energy trade platforms where, with the help of AI, prosumers can get the most out of energy scheduling and forecasting (Hua et al., 2022a). Meanwhile, they also find it difficult for China's existing energy market arrangements, as they are not fully prepared to handle the growing number of prosumers and two-way energy flows (Hua et al., 2022). In China, where cities are upgrading and renewable energy system are advancing, these issues must be taken into consideration as early as possible. Finally, Kumar et al. (2020) stress the focus on how AI could assume energy demand, while blockchain ensures clear transactions. Like the other studies, they also point out some big issues, like the inability to utilize technologies on a large scale, and that requires a full integration plan in order to spread on a national level as well as they suggest improving Chinese energy infrastructure so that this combination of digital technologies can enhance performance (Kumar et al., 2020).

All of the literature discussed above agrees on one point: that China's renewable energy sector which wants a more decentralized system to maintain itself can be improved by combining blockchain and AI in the operation. However, every study investigates this topic in its own way. Wang and Su (2020) focus on blockchain applications that can fully speed

up traditional systems. On the other hand, Al Shareef et al. (2024) focus on the integration of AI and blockchain that can operate together to improve energy systems. Another researchers group, such as Kumari et al. (2020) and Hua et al. (2022) , specifically choose cloud management and prosumer integration for energy operation efficiency. Both the studies are concerned about Chinese regulations and infrastructure that make the diffusion of technology hard in China. Additionally, Kumar et al. (2020) point out the hurdles of collaborating technologies in China's ever-changing smart grid system in the real world. Overall, all the studies suggest that strong rules, better infrastructure, and more research are essential to collaborate on AI and blockchain in the Chinese energy sector as well as explain the significance of this collaboration.

In light of the previous discussion, the Diffusion of Innovation (DOI) theory can be considered as a major path through which AI and blockchain technologies could be utilized in China's renewable energy industry. Though both the technologies are able to change the energy sector by enhancing efficiency, transparency and decentralization, but some regulatory and infrastructural issues still exist (Hua et al., 2022b; X. Liu & Zhang, 2022). Bypassing these problems can make it easier for China to figure out how well the technological innovation works with the current energy systems, rules, and beliefs, which are centralized and slow moving (Q. Chen et al., 2024). Conducting primary testing and observing can work well before the wide use of AI and blockchain in energy operation and running pilot projects that display how well distributed energy trade platforms and AI-driven grid management operate in the real world. This activity can prove the benefits of these technologies as well as reduce doubt (Zheng et al., 2021). It is also necessary to clear the relative benefits, like lower operation costs, better grid efficiency, and energy security, in order to get support from the stakeholders for adopting these new technologies (Kumar et al., 2020). Local groups in China , especially those who live in rural areas, are more valuable participants who can make major changes in smart grid systems and decentralized energy solutions. That's why social influence and community participation are needed for adoption to work in China, and partnerships between private and public

sectors are essential to get resources and data that will make innovations available for local people (Eitan et al., 2023). Another important issue is governmental support with clear policies and rules, and it should be ensured that the energy market is flexible to adopt these technologies with proper security and control (Tabrizian, 2019). China can take advantages from these technologies easily if the country strategically aligns regulatory frameworks with observing technical challenges and upholding social acceptance through pilot projects and community involvement. Such measures will enhance China's energy transition goals and contribute to global efforts to make the world sustainable (Zheng et al., 2021).

2.4 Digital Transformation in Emerging Markets: The Chinese Context

China's economy is one of the fastest-growing in the world, and it has become a leader in investing in green energy in developing countries. Digital technologies like AI, blockchain, big data, and the Internet of Things (IoT) have been used more and more in China's energy industry over the past few years to make it more efficient, open, and decentralized. Not only are these technologies speeding up China's energy transition, they are also changing the country's ability to work with other countries on green energy projects. China's institutional, legislative, and infrastructure rules for digital tools are difficult and vary from region to region, which can be both a benefit and a drawback. These paragraphs carefully look at the main things that are causing a digital revolution in China's green energy industry.

2.4.1 Technological, Regulatory, and Economic Influences

Majority of scholars attribute various factors as the primary drivers as they expect the digital transformation to alter the Chinese green energy market. Nazari and Musilek (2023) also mention new technologies such as AI, IoT, cloud computing, and blockchain that are

able to optimise the performance of the system and foster its sustainability. Other people emphasize the importance of regulatory policies, such as China Emissions Trading System (ETS) and the China Certified Emission Reduction (CCER) regulator that create financial opportunities to make environmentally friendly investments (Paraschiv et al., 2024). A third group of researchers labels economic growth and efficiency targets as key factors that have led to the use of digital technologies arguing that the GDP growth in China has helped to reduce carbon intensity as well as support investment in renewable energy (W. Wang et al., 2023).

Moreover, the strength of these effects is disputable in regard to various studies. Nazari and Musilek (2023) provide evidence that digital technologies render everything more efficient and reduce the costs. But, according to Zhao et al. (2022), these advantages will require that structural issues in the Chinese grid, including the divide between the generation and demand and the necessity of smart dispatch systems, are addressed. Moreover, Yang et al. (2024) reveal that such an organizational issue as the ability to be innovative, capital, and the way people are informed are equally significant as technology and the law. This implies that technology does not have the capacity to change without the help of the society and institutions. Unlike the previous tests, such as those carried out by Ekonomou and Menegaki (2023), which had an expansive national perspective and indicated that the emphasis was to be placed on long-term policy consistency and the long-term research and development instead of immediate use of technology.

Despite these good factors, most authors claim that there are issues that halt development. The significant issues are frequently referred to as big start-up expenses, merger issues, and safety risks (El Zein & Gebresenbet, 202440). Moreover, despite the high-quality governing instruments, such as ETS and CCER, which China has, Paraschiv et al. (2024) indicate that little practical evidence supports the idea that these instruments directly assist the digital transformation of renewable energy. According to Sung et al.

(2024), the discussion on energy policy in China has shifted towards more stakeholders (including privates) and international issues. Nevertheless, the similar argument can also be made that the revolutionary capacity of the digital technologies can be missed due to divided regulations and unequal application.

Despite the fact that most of the studies concur that the renewable energy sector in China is taking a digital direction due to the improved technology, incentive by the government and economic considerations, significant disparities in the same remain. Very little research has been conducted to establish the precise impact of AI on such aspects as reduced constraint, enhanced anticipation, or decentralized collaboration. There is not a lot of information about the way the digital policies of China are connected to the collaboration across the international energy boundaries, and in particular, to the realization of certificates, data sharing, and cooperation with the systems of other countries. These gaps are directly connected to the primary research question of this thesis determined to understand whether AI and blockchain can indeed simplify the task of countries cooperating in green energy projects.

2.4.2 Chinese Renewable Energy Superpower and Its Role

By undertaking colossal execution, government dedication and conquest of the world energy market, China has assumed its position as powerhouse regarding renewable energy systematically. Numerous literary sources shed light on the issue of the paradoxical nature of the current situation in China as the world leader in carbon emissions and the most significant investor in renewable energy. Auffhammer et al. (2021) state that the watershed occurred when China enacted its Renewable Energy Law in 2006. This legislation preconditioned the enormous development of wind and solar industries and took China to the first place in the world rating in terms of installed renewable capacity. Nevertheless, their study indicates that even today, such leadership is not sustainable yet

since it has issues like arrears on subsidies and high curtailment rates in some areas. Other pundits have mentioned that China is experiencing a paradigm shift. Renewable energy is one of the pillars of the smart grid and the development of low-carbon in China (Jia et al., 2015). That is because the electricity consumption in the country is on the rise and the legislation in the Five-Year Plans. Ekonomou and Menegaki (2023) argue that other developing countries can emulate the example of China in the development of renewable energies due to the fact that the country has been able to achieve high economic growth and, at the same time, make large investments in renewable energy sources such as wind, solar, and hydro. To them, China needs to allocate more resources towards R&D and institute more efficient policies in case it wishes to remain a powerhouse despite its impressive accomplishments.

Wang and Liu (2024) note that photovoltaic (PV) business is king when it concerns specialized technologies. They elaborate on how China has enhanced its dominance on world supply chains and become more energetically secure by becoming the biggest power producer of solar and the highest number of installed photovoltaic units in the world. Wind generating is already growing at a rapid pace with the most significant government subsidies and expansion of the system as Sun and Huang (2014) also elaborate. Based on these findings, the competitiveness in the global clean technology markets and local market demand are two aspects that will define China as a powerhouse in the renewable energy markets.

Nevertheless, a great number of difficulties are still there. Zhao et al. (2022) argue that it is still unmatched between the resource-intensive western provinces and the demand-intensive eastern regions even when there is a significant expansion in capacity resulting in inefficiencies and curtailment. Their focus will be on better dispatch systems, ultra-high-voltage transmission, and huge storage to achieve carbon neutrality by 2060. According to Auffhammer et al. (2021), the financial feasibility of the Chinese renewable energy boom

is questioned because of the unpaid subsidy liabilities. Comparative assessments also raise disparities with other emerging economies. Sawhney (2013) draws a juxtaposition and contrast between the Chinese and Indian policies, stating that the state-centered and well-coordinated policy allowed the former to grow its renewable energy industry faster. This comparison analysis proves the idea of China as a renewable superpower and demonstrates that the governance systems and not only the availability of the resources influence this position.

The literature has shown that China has taken the lead in renewable energy in the world. Experts however differ on whether this leadership can be sustained without systemic changes in terms of sweeps. Though a majority of the experts say that wind and photovoltaic energy have come a long way it is also true that there are numerous hurdles to jump through including subsidy liabilities, regulatory fragmentation and curtailment. There is little research examining how the leadership of renewable energy in China is encouraging the collaboration at the international level, particularly on the front of digital technologies such as blockchain and artificial intelligence. This represents a great knowledge deficit. A significant connection to the objectives of this thesis is that, though China has a reputation as the provider of renewable energy, the potential of the country to apply the digital revolution to enhance international cooperation has not been explored completely.

2.4.3 The latest digital energy systems in China and other emerging markets

The digital energy tools have recently gained significant importance to China and other developing states in order to regulate their renewable energy systems. The systems are built using smart technologies such as artificial intelligence (AI), the Internet of Things (IoT), Big Data, and blockchain. Numerous researches have been conducted regarding the manner in which they assist in enhancing the accuracy of forecasts, ease tracking in real-

time, facilitate peer-to-peer (P2P) energy trading, and generally open the system. Li et al. (2023) believe that AI and IoT-based tools have already been applied to predict the generation of renewable energy, organize the maintenance of assets, and enhance demand response. They emphasize that cloud and edge computing are emerging as the foundation of data-based tools which are forming the foundation of energy management systems. Kuefeoglu et al. (2019) consider the impact of digitalization on the development of new business models such as virtual power plants (VPPs), distributed energy resource (DER) aggregators, and local trade platforms. Also, they find that through these platforms, small players and prosumers find it easier to enter the energy market. This underscores the importance of having clear market rules and connectivity to be extensively accepted. Studies on blockchain-based platforms indicate that they would render the energy industry decentralized and open.

Otoum and Mouftah (2021) state that blockchain combined with AI can also ensure that energy data streams become more trustworthy and enable the execution of transactions safely and detection of issues in real-time. They studied blockchain, which is perceived as a decentralized and immutable layer and can enable individuals to trust trade and settlement systems more. China stands even better in terms of patent proof position. According to the findings of Chinese researchers Mao and Fujii (2023), China has the majority of patents of blockchain-energy in the world. These patents are digital grid platforms, energy exchange systems, and data processing mostly. This demonstrates the deliberate attempt by China to develop blockchain research and development despite the fact that there is still a wide gap between patent application and utilization. Energy technologies supply chain, as well as grid operations and trade are also areas where blockchain is being considered. Talla (2022) proposes that the combination of AI and blockchain can be used to trace renewable energy elements and ensure the clarity of green purchases. These platforms may result in increased confidence of consumers and investors in the sustainability of energy systems over the long-term.

In other emerging economies beyond China, there is an increasing number of emerging economies testing out digital energy systems. In Asia, Africa and Latin America some pilot projects have also researched P2P energy sharing, smart meters and VPP aggregation to make energy easier and more flexible in those locations (Kuefeoglu et al., 2019). Some of these are positive indications that these platforms are simplifying the autonomous management of energy, yet the majority of them are just starting out and are struggling with regulation and finances. Li et al. (2023) examine microgrids and urban platforms in developing areas in their study. They conclude that technical solutions such as AI predictions and IoT integration are improving, but most countries lack the appropriate institutional structures to ensure the large-scale implementation of platforms. Scholars are largely of the opinion that digital platforms can enhance efficiency, independence, and openness, albeit still a few large issues to address. Issues such as high cost of applications, scalability and security have been raised by researchers whenever discussing new systems. Regulatory uncertainty is another major problem. This is more so when trading and certificate systems are based on blockchain as not all locations have the laws that acknowledge digital contracts and attributes.

Although China makes huge investments and owns the most patents, academic research has yet to provide sufficient tangible evidence of how these platforms are being applied nationally or what quantifiable outcomes they yield in terms of higher productivity or reduced limitations. Nor is there a lot of literature regarding the relevance of digital platforms being cross-border willing to work. These are such items as data sharing standards, acceptance of renewable certificates, and smart-contract templates, without which it is impossible to collaborate across the borders.

The studies that were examined indicated that AI and IoT-based platforms are the most developed and used at the moment. Conversely, blockchain solutions are at a stage of testing and are exploited in pilot projects or at the level of patents. China leads in research and development especially in relation to blockchain patents. Not many large-scale, real-

world examples have been made to date, however. Similar systems have also been implemented in other developing countries though in lesser scale. This demonstrates that digital technologies are going global but they all have the sameness in terms of cost, scalability and governance. Through these holes, it is apparent that we must do more practical research into how digital energy platforms can expand beyond small pilot projects to large-scale systems that do not only make the US more efficient and open but also allow nations to collaborate on renewable energy projects.

2.5 Challenges and Role of Cross- Border Integration

2.5.1 Role of Digital Technologies in Enabling Integration

Raising economies such as China are finding digital technologies such as AI and blockchain to have a large impact on the delivery of renewable energy.To boost efficiency, support decentralized energy systems and cross-border energy trade needs digital platforms. This section of the study discusses the significance of integrated digital technologies and how it can help Chinese green energy companies to go global and run their businesses more efficiently.

Tan and Mathews (2015) discuss in their article about the internationalization that Chinese wind turbine companies have sped up by using their existing resources and capabilities to enhance rapidly all over the world.They found that, companies like Goldwind and SInovel utilized their strategic resource leverage to speedily enter foreign markets (Tan & Mathews, 2015). Application of integrated digital technologies into these sectors prove that how well thay can forecast market and take decisions, which make faster global expansion possible. When compared, Ahi et al.'s (2022) study focus on global value chains (GVCs) which is developed by new technologies like AI, blockchain, and big data. Their main concern is converting the global operations, especially by coordinating information and accumulate parterns from different places to work together (Ahi et al., 2022). From their study it is clear that, Chinese green energy can also grow fasterby using digital

technologies that help them to manage global value chains more productively. However, this expert group focus on digital technologies that can convert foreign trade in a bigger range of areas (Ahi et al., 2022), while the previous experts only talk about wind energy sector (Tan & Mathews, 2015).

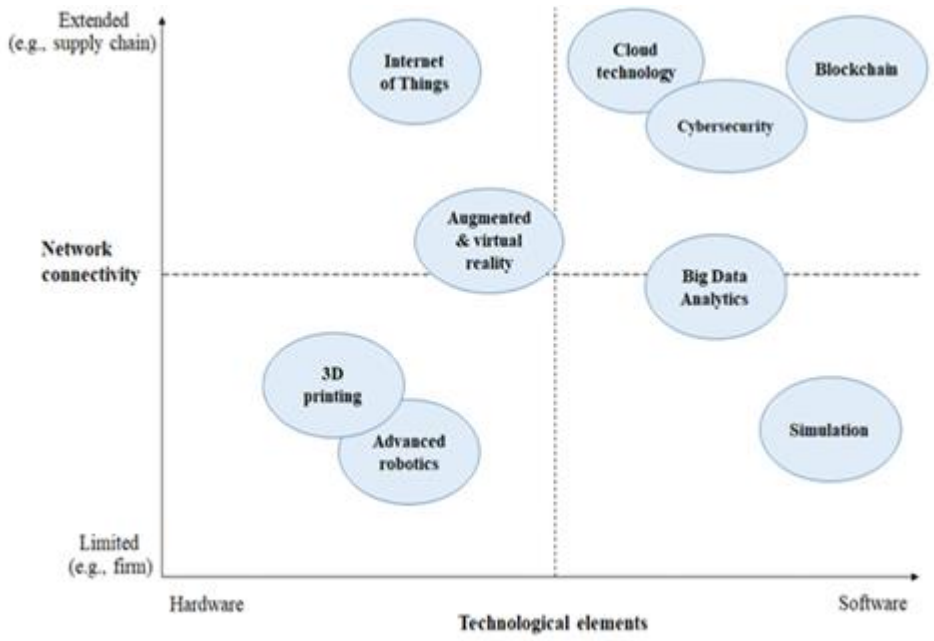

Fig: Categorization of advance technologies based on technological elements(hardware v. software) and network connectivity (limited v. extended) (Ahi et al., 2022)

In 2025, Liu et al. delve into the cross-border digital platforms that support exporter to eneter into the foreign emerging market and change their market approach.Their results show that, these platforms make outreach plan simpler, which is essential for the companies that want to expand their operation in foreign markets (F. Liu et al., 2025).Like Alibaba and other energy based digital platforms facilitate Chienese companies to explore

market options and trade energy with each other because digital technologies support trustworthiness and openness. Meanwhile, Grosse et al. (2021), who study China's rise in multinational business dynamics, confirm that globalization still holds its strong position even though there exists political conflicts . In spite of trade disputes between US and China, they portray how essential digital platforms are for lower transaction costs and establish infrastructural set up for cross-border transactions in trading green energy (Grosse et al., 2021). But instead of looking at how these platforms connect with emerging markets and make decisions in real time , this article focuses solely on the geopolitical effects of China (Grosse et al., 2021).

Digital platforms enhance the collaboration between foreign entities and Chinese renewable energy sectors as it allows sharing data in real time, analyses hazards and integrate energy movements. Chinese companies often face problems when it comes to working together on green energy projects as there exist institutional and geographical distances (Lee et al., 2023). But digital platforms linked the energy stakeholders, such as producers, customers, and regulatory bodies with each other when it comes to cross-border e-commerce. Chinese small and medium sized energy businesses now can access global markets and meet with international partners through the use of online tools (F. Liu et al., 2025b). Moreover, to reduce technological gap between nations, Chinese infrastructural investment in the sector 5G network and cloud software installment is huge and this will make it simpler for energy producers and consumers to work in a collaborative way (Zhu et al., 2020b). Furthermore, these mechanical advancements supports to link green energy systems with fewer technical issues as well as make sure that different nations can work together in energy systems (F. Liu et al., 2025b).Overall, China is more efficient in cross-border energy integration through the better utilization of big data and cloud computing (Yan et al., 2025).

2.5.2 Challenges in Cross-Border Energy Integration

China has upgraded itself as a world leader in the new alteration of renewable energy sector, but still cross-border integration of renewable energy projects is complicated for various causes. Issues are worsen because of regulatory, technical and institutional barriers that not only make it difficult for people to work together but also make it harder for global integration of digital platforms.

Fortunately,AI, IoT, and blockchain are some digital tools that improve the general perform ance of energy sharing networks and they do this by making it easier to track down proble ms and by making smart grid services more reliable, available, resilient, stable, secure, and good for the environment (Kumar et al., 2020).

Complex regulatory system that exists in different countries makes it tough to integrate green enrgy between nations. Strong intellectual property protection, contract enforcement, and well-functioning institutions all lower transaction costs and make it easier for businesses to work together by stopping people from taking advantage of situations (Alexander, 2012). The ever-changing Chinese green energy policies sometimes don't even align with international rules and it makes complications among companies who work on projects that span borders (Yan et al., 2025). There are some nations that impose tariffs or, other trade limits on each other which makes it costly to do business in energy sector across borders (Zahoor et al., 2023). However, the government of China subsidize renewable energy sector to quickly expand , but this sector still faces difficulties because of trade barriers, like anti-dumping and anti-subsidy movement of some countries like USA and EU hat is good enough for smooth energy trade in emerging markets at all (Conklin, 2005).

Another major issue in the way of combining renewable energy sources is the scarcity of common technology. China has already developing it green technology sharply but some

countries are not developed enough technologically to integrate in energy systems and failed to standardized it's infrastructure across regions (Verbeke et al., 2025).For instance, high tech system that synchronize the power grid of different countries and facilitate the flow of energy across borders. However, many countries cannot adopt with this systems because of the lacking of their infrastructural frameworks and unable to work together. Emerging economy, especially China, took the challenge by doing rush to develop their energy sector and entering into the global energy market. This attempt taken by Chinese wind turbine makers Goldwind and Sinovel who are quickening up their global operation by utilizing smart partnerships, technology licensing, and joint ventures and successfully able overcome the hurdles and making progress across international borders (Tan & Mathews, 2015). Though, It needs a common data infrastructure to forecast and operate energy demand correctly which is still not available in many countries (Golgeci et al., 2021).

Unfavorable geopolitical situation makes it harder for Chinese businesses to create partnerships with other countries to use renewable energy as entities from other countries are suspicious about their political issues. Unmatched cultural views is another hurdle for combining businesses from different nations (Choksy et al., 2025). Institutional distance such as " liability of origin" is another big issue for Chinese companies when they eager to work with foreign partners as companies from growing economy are more legitimate and trustworthy that the entities from China and this maki it complicated for another nations companies to go forward (Yan et al., 2025).Because political instability and weak institutional framework in many developing nations make worse situation where investment in long-term green energy projects is risky (Ahi et al., 2022). For widening global economic deviation systematic struggle for economic power support in trade protection policies is essential (Zahoor et al., 2023).

Blockchain and AI technologies are solution to solve these problems by safe cross-border energy trades and transparency. Such technology facilitate smooth partnership with

foreign countries by tracking clear and unchangeable records of transactions of renewable energy (Tan & Mathews, 2015). Digital tools like AI, IoT, and blockchain improve the overall performance of energy sharing networks by effective problem monitoring and dependable, available , and resilient smart grid services that create secure and sustainable environment (Kumar et al., 2020). This will make easier for countries especially emerging country like China to work together and integrate energy sector more smoothly.

2.6. Impacts on International Renewable Energy Collaboration

In recent literature, the impact of digital technologies, primarily AI and blockchain, on the global sustainable energy collaboration is also discussed more and more. These technologies provide avenues and measures of enhancing transparency, operating coordination, and cross-border governance. But they can be only limited in the context of international use due to technological incompatibility, regulatory incompatibility and institutional incompatibility, especially in the emerging economies like China. The paper will review the current research in three critical areas of impact.

2.6.1 Enhancing International Coordination through Digital Tools

AI and blockchain are commonly cited as the means of enhancing the coordination and the performance of the international energy systems. Research indicates that AI could be used to improve forecasting, grid balancing, and prediction of energy demand, which are essential functions that help to perform more dependable energy exchange regionally and across nations (Wang et al., 2024; Etukudoh et al., 2024). In the same way, smart contract functionality affords blockchain to conduct automated, auditable transactions of energy, as

it minimizes the costs of cross-border transactions and enhances trust between trade partners (Barcelo et al., 2023; Bao et al., 2021).

Even though these advantages are widely reported, a number of researchers indicate that technological interoperability may continue to be a hindering factor particularly when there is a disparity in the maturity of digital infrastructure across nations (Zhang et al., 2024). This is surprisingly apposite to China specifically where attempts at blockchain and AI energy programs are block pilot in the state so the question of scalability as well as standardization across international systems rises with respect to international systems. The literature also identifies absence of empirical studies that evaluate the real world effectiveness of these technologies within the cross border environment- an issue which this thesis hopes to fill.

2.6.2 Decentralization and the Shifting Role of National Energy Systems

A growing body of literature presents the decentralization feature of the AI/blockchain application in energy systems, as one of the strategic advantages. Blockchain provides a peer-to peer market, and microgrids, whereas AI helps to manage the decentralization and optimization of the system in real-time (Hou et al., 2018; Tao et al., 2024). By contrast, in China, the technologies are regarded as the means of modernizing the historically centralized energy industry and making the system more flexible (Gawusu et al., 2022; Bao et al., 2021).

Yet there is less discussion of the consequences in regards to intercontinental cooperation. Although theoretically, decentralization contributes to building resilience and local control, very little research is available on the impact of national decentralization processes on the capacity of China to participate in cross- border renewable energy projects. Also, studies tend to neglect the conflict between the decentralized nature of the blockchain and the centralized policy in China, which introduces doubts concerning the sustainability of the given models in the international context.

2.6.3 Transparency and Trust in Cross-Border Energy Exchange

International energy cooperation literature has given more emphasis on the themes of trust and transparency. The use of immutable data systems through blockchain to enhance transparency in both carbon monitoring, certification of renewable energies, trade processes related to energy has often been alluded to (Barcelo et al, 2023; Bhavana et al, 2024). AI supplements this, by allowing the real time observation of the system, and further allowing data consistency among stakeholders (Durmus Senyapar et al., 2025).

Although these are the strengths, researchers warn that a positive attitude toward the technologies, in particular, AI algorithms, is not universal, and issues related to data privacy, algorithmic transparency, and cybersecurity issues are raised (Zhang et al., 2022). In addition, there is institutional trust between states that is a constant affair. The latest literature in the field of international business indicates that the matters of institutional transparency, harmonization of laws, and governance systems in digital media are essential to provide trust among international digital energy systems (Meyer et al., 2020; Li et al., 2016). However, little research on energy explicitly examines what happens when these institutional aspects of collaboration negotiate with digital tools in order to support collaboration (or not) thus, indicating an essential niche that the current thesis is intended to address.

Overall, the literature on the empowering possibilities of AI and blockchain technology in the context of the development of international renewable energy cooperation indicates the relevance of these technologies in terms of better coordination, decentralization, and transparency. Yet, there are still notable gaps about a pragmatic application of these technologies in cross-border situation, particularly in centralized systems, such as it is the case in China. The interaction between digital tools and the institutional dynamics (i.e. trust, compatibility of governance and regulatory alignment) are understudied. This paper

fills these gaps by trying to empirically evaluate the impact of AI and blockchain on the outcomes of cross-border collaboration with respect to efficiency of operations, decentralized decision-making, and transparency. By so doing, it also seeks to provide realistic, situational policies that can be followed by the policymakers and the firms about what they can do to use digital technologies to build international partnerships in renewable energy.

Table: Findings from the literatures

AI in renewable energy in China

Article	Objectives	Methods	Theory	Findings	Gaps Identified
Li, W., Li, J., Wang, Y., Stan, S. E. (2024). *Is artificial intelligence an impediment or an impetus to renewable energy investment? Evidence from China*. Energy Economics, 147, 108550.	Exploring AI's role in green energy investment.	Bootstrap subsample rolling-window Granger causality	Sustainable development & low-carbon transition theory	AI makes grid optimization energy forecasts and smart energy managemen t better than before and upgrades system efficiency. Even though there have resource scarcity and high cost of capital related to long run operation.	The challenge of poorly organized regulatory systems and the high cost associated with AI management is overlooked by this article.

Zhang, X., Khan, K., Shao, X., Oprean-Stan, C., Zhang, Q. (2024). *The rising role of artificial intelligence in renewable energy development in China*. Energy Economics, 132, 107489.	Investigating the impacts of AI integration in the development of China's green energy systems.	Time-varying co-movement and phase relationships.	Techno-economic paradigm (TEP) theory Co-movement & feedback theory	As technology gets better day by day better predictions of solar and wind energy are made possible by AI which connect renewable energy sources to the grid and uses energy storage more efficiently.	Does not address the fact that AI systems are difficult to adopt and use because of its complicated nature and high initial expenses.
Tian, L., Li, X., Lee, C.-W., Spulbăr, C. (2024). *Investigating the asymmetric impact of artificial intelligence on renewable energy under climate policy uncertainty*. Energy Economics, 137, 107809.	Examining how AI influences renewable energy in various ways under conditions of unclear climate policy.	Nonlinear Autoregressive Distributed Lag (NARDL) model	Asymmetry theory in econometrics	Policy uncertainty and short-term problems makes the application of deep learning less useful .Though it has a good long-term effect on the growth of renewable energy.	Short term policy disruptions and technological implementation that lead to slower adoption AI applications is not properly addressed in this article.

Meng, Q., Hu, W., Qi, X., Chang, T. (2024). *Do the benefits outweigh the disadvantages? Exploring the role of artificial intelligence in renewable energy*. Energy Economics, 131, 107403.	Delving into how AI contributes to investments in green energy and problems related to it.	Full-sample and sub-sample econometric models	Digital technology adoption theory Technological revolution & industrial transformation theory	AI develops renewable energy investments by organizing energy management and forecasting and this development and widespread adoption hindered by high initial costs and regulatory uncertainty.	Experts didn't mention about AI's short-term negative effects on the renewable energy business compared to the benefits that could be gain by non-renewable sectors.
Zhao, Q., Wang, L., Stan, S.-E., Mirza, N. (2024). *Can artificial intelligence help accelerate the transition to renewable energy?*. Energy Economics, 134, 107584.	Exploring the different paths by which AI might facilitate China to move quicker toward using green energy.	Quantile-on-Quantile (QQ) method Nonlinear and heterogeneous impacts	Technological innovation and transition theory	AI applications works better in energy systems that make it more efficient and managing storage system far better. Instead of the fact that, AI adoption mostly helps nonrenewable sectors in the short run.	This article didn't discuss in details about AI's high costs and complexity that make it harder to utilize in renewable energy, while it is more beneficial for nonrenewable energy sectors.

Peng, X., Guan, X., Zeng, Y., Zhang, J. (2024). *Artificial Intelligence-Driven Multi-Energy Optimization: Promoting Green Transition of Rural Energy Planning and Sustainable Energy Economy*. Sustainability, 16, 4111.	Look into how AI contributes in multi-energy planning for China's rural areas.	Simulation and optimization framework	Green transition theory & Porter Hypothesis	Decentralized energy system is considered as most appropriate solution by this article, especially in rural areas and AI can improve this system for more sustainable and efficient operation.	This study doesn't address the limited use of AI in rural areas and existing knowledge gap for using AI-based management tools.
Wang, B., Wang, J., Dong, K., Nepal, R. (2024). *How does artificial intelligence affect high-quality energy development ? Achieving a clean energy transition society*. Energy Policy, 186, 114010.	Investigating AI's role in China's high-quality energy development (HED) and clean energy movement.	High-Quality Energy Development (HED) index and System GMM	Endogenous growth & innovation theory Threshold theory	Through optimizing energy system and by increasing energy economy AI facilitates clean energy transition. However, the benefits are minimum without strict regulatory frameworks and infrastructure for the digital economy.	Experts don't go into detail about how developments in the digital economy and insufficient alignment with business models can hamper AI's operation on high-quality energy development. This omission represents a gap because these are essential for AI application.

Zhang, L., Ling, J., Lin, M. (2022). ***Artificial intelligence in renewable energy: A comprehensive bibliometric analysis*****. Energy Reports, 8, 14072–14088.**	To examine AI's contribution in switching to green energy when it comes to dealing with power outages.	VOSviewer, CiteSpace, Bibliometrix	Bibliometric/ scientometric theory	The article finds the proper balance between supply and demand which improves the green energy system to fix issues related with solar and wind power occur at different times.	This study doesn't highlight the fact that AI can speed up the changes but large scale development may be delayed because of high maintenance cost. This study gap leaves out significant practical issues that make it difficult to use AI for energy growth.

Blockchain in renewable energy in China

Article	Objective	Methods	Theory	Findings	Study Gaps
Yu, Y., Liu, G.-P., Huang, Y., Chung, C. Y., & Li, Y.-Z. (2024). A blockchain consensus mechanism for real-time regulation of renewable energy power systems. *Nature Communications*, *15*(1), 10620.	Design a blockchain based real time consensus system for effectively managing renewable energy systems.	Proof of Task (PoT) consensus mechanism	Cybersecurity & control theory Decentralized consensus theory	By using Proof of Task consensus method safer and easier renewable energy systems can be improve to control in real time which provide protection against cyber threats and making the system more stable.	Not enough research has been done on Chinese legal hurdles and China's recent energy policy structure where blockchain system hove to fit.

Zhu, S., Song, M., Lim, M. K., Wang, J., & Zhao, J. (2020a). The development of energy blockchain and its implications for China's energy sector. *Resources Policy*, *66*, 101595.	To investigate how blockchain technology facilitates the deployment of energy and motivates citizens to use clean energy. See how blockchain can	Qualitative analysis Case studies	Energy transition & circular economy theory Decentralizatin theory	Blockchain can promote green energy, develop distributed energy trade and make the transaction cost lower. Even though there have regulatory problems in China which create hurdles for the blockchain operation.	This study gives unclear technical answers or examples about the utilization of blockchain system in China.The main topic that the article discusses mostly is about problems related to regulations and market structure.
Wang & Su (2020) *Integrating blockchain technology in the energy sector*. Computer Science Review, 37, 100275.	Evaluate China's role in energy blockchain technology as well as investigate how this technology used in energy industry around the world.	Systematic Literature Review Bibliometric analysis	Blockchain as a theory of decentralizatio n & trust Energy Internet & distributed energy theory	Blockchain is making more developmen t in energy sector to make it more stable and China is one of the active participants in this developmen t.	This study gives more focus on global research trends and China's growing output, rather than policy and legal issues that create barriers in the way of blockchain establishmen t.

Taherdoost, H. (2024). Blockchain Integration and Its Impact on Renewable Energy. ***Computers*****,** ***13*****(4), 107.**	To find out how blockchain can work in independent energy systems and improve energy management as well as lower transaction costs.	Systematic review	Decentralized power dispatching models Permissioned blockchain theory Sustainability & energy optimization frameworks	Blockchain can develop market openness and improve energy management with smart contracts that allows the technology for decentralized energy control wit lowest expense.	The article mostly talks about the probable benefits of blockchain, but it doesn't give enough focus on the rules that might make it harder to take over the blockchain in Chinese energy market.

Integration of AI and BC

Article	Objective	Methods	Theory	Findings	Study Gaps
Al Shareef et al. (2024)	To evaluate the role of AI and blockchain integration which can develop energy trading and improve efficient energy control?	Systematic review methodology Case study analysis	Decentralizatio n theory Automation and intelligent decision-making theory Energy transition & sustainability frameworks Consensus & smart contract theory	Integration of AI and blockchain can improve the speed and transparenc y of energy transition. Because AI enhance operational control, predicitive analysis and system optimizatio n which ensured by Blockchain technology.	Real-world application of AI combine with blockchain in energy system is missing in this study, especially for large-scale uses.

Kumari et al. (2020)	With a focus on smart grids and energy systems this study look into how digital technologies such as AI and blockchain can be utilized together in managing energy clouds.	Comprehensive survey Bibliometric analysis	Energy cloud theory AI-based prediction and optimization theory	Connecting AI and blockchain technology can make smart grids more stable and effective where Ai improve the demand forecasting and blockchain makes sure clear data transaction.	Writers highlight the potential benefits of Blockchain and AI in big decentralized energy systems but not significantly address the challenge related to interoperability, security, and scalability that still create barriers in effective implementatio.

Hua et al. (2022)	With the focus on decentralized energy trade and whole system in China, the goal of this study is to find out the role of AI and blockchain to help prosumers in smart grids.	Literature review of blockchain and AI applications in smart grids	Smart grid & prosumer theory Decentralization theory Intelligent control theory	The article highlights two key findings that upgrade China's green energy movement. First of all, blockchain technology which is prosumer friendly that support them share energy directly instead of going through a central authority and another one is AI that improves energy operations efficiency and stability by proper planning and scheduling.	The article emphasizes the fact about how prosumers can help China's up gradation to green energy, while it doesn't focus more on the issues that come with letting them into the energy market. Particularly, the market structure which is still not preferable for prosumers and controlling two-way energy flows.

Kumar et al. (2020)	To investigate the contribution of blockchain and AI in the developmet of China's smart grids by safe and optimized energy movement.	Critical literature review	Smart Grid theory Energy Internet vision Intelligent control theory Decentralizatin theory	With help of AI and blockchain smart grid operation is possible where blockchain secure energy transfer and AI makes this process reliable by proper forecasting.	Lack of proper plan for integrating the systems is a major gap of this article. This issue isn't solved, so there is a significant knowledge gap in how AI and blockchain collaboration used in smart grid infrastructure.

China's Role as a Renewable Energy Superpower:

Study	Objectives	Methods	Theory/Framework	Key Findings	Identified Gaps
Auffhammer et al. (2021)	Assess performance of China's renewable policies since 2006	Policy review & performance analysis	Policy evaluation	China became global leader in wind/solar due to Renewable Energy Law; issues remain (subsidy debts, curtailment)	Does not explore digital transformation (AI/blockchain) or international collaboration
Jia et al. (2015)	Review current status & trends of China's renewable industry	Review of policies & demo projects	Smart grid & low-carbon transition	Renewables central to smart grid development; strategic choice for sustainable growth	Outdated (2015); limited on recent AI/digitalization; no cross-border perspective
Ekonomou & Menegaki (2023)	Review China's role in global renewable energy transition	Integrative review (empirical & non-empirical)	Economic & environmental interface	China combines rapid growth with RE leadership; stresses need for R&D and efficient policies	Focuses on macro sustainability; no empirical link to digital technologies or collaboration
Wang & Liu (2024)	Analyze status, challenges & future of PV industry	Systematic literature review	Energy transition & industry outlook	China leads globally in PV capacity and manufacturing; PV central to "dual carbon" goals	Limited discussion of AI/blockchain in PV; little on cross-border implications

Sun & Huang (2014)	Track wind power growth in China	Historical overview	Energy transition theory	Explosive growth of wind power due to subsidies; government commitment central	Early study; does not address digital transformation; limited relevance to cross-border integration
Zhao et al. (2022)	Review renewable energy under carbon neutrality target	Systematic review	Policy/technology transition framework	Capacity expansion impressive; challenges = curtailment, mismatch, storage & UHV needs	Focuses on policy/tech; little discussion of AI/blockchain role in addressing challenges
Sawhney (2013)	Compare renewable energy policy in India & China	Policy comparison	Comparative policy framework	China's success due to stronger state-led coordination vs. India's fragmented approach	Comparative, but not digital-specific; does not address AI/blockchain or collaboration

Digital Energy Platforms in China and Other Emerging Markets:

Study	Objectives	Methods	Theory/Framework	Key Findings	Identified Gaps
Li et al. (2023)	To review methods and applications of AI, Big Data, IoT, and Blockchain in smart energy management	Systematic literature review	Smart Energy Management framework	AI/IoT platforms are already applied in forecasting, predictive maintenance, and demand response; cloud–edge computing is the backbone	Lack of China-specific case studies; no quantified evidence of AI's incremental efficiency or curtailment reduction

Küfeoglu et al. (2019)	To explore the role of digitalisation in shaping new business models in the energy sector	Conceptual review and case surveys (working paper)	Digitalisation and business model innovation	Digitalisation enables DER aggregators, VPPs, and P2P markets; opens participation for small actors	Evidence mainly from pilots; limited focus on China; no discussion of cross-border platform interoperability
Otoum & Mouftah (2021)	To examine blockchain and AI for trustworthiness in sustainable energy infrastructure	Conceptual/technical review	Trustworthiness framework in digital energy systems	Blockchain + AI can improve decentralization, transparency, fraud detection, and secure data exchange	Lacks empirical deployment studies; scalability and latency barriers remain unresolved
Mao & Fujii (2023)	To analyze blockchain-related patents in the energy sector	Patent decomposition analysis	Innovation and patent analysis framework	China holds the majority of blockchain-energy patents, focused on data processing and digital grid platforms	Gap between patent innovation and real-world operational deployment; lack of evidence on effectiveness
Talla (2022)	To propose integration of AI and blockchain for energy supply-chain transparency	Conceptual study	Transparency and provenance in supply chains	Combining AI and blockchain can enhance traceability, green procurement, and transparency in energy supply chains	Lacks empirical validation; unresolved regulatory and data-integrity challenges

Zhao et al. (2022)	To review renewable energy transition under China's carbon neutrality target	Systematic literature review	Policy and technology transition framework	AI and intelligent dispatch platforms are essential to solve curtailment and grid mismatch in China; UHV and storage needed	No quantified incremental impact of AI platforms; little attention to international collaboration or cross-border data exchange

3. Research Methodology

Research is an investigative technique or, a journey of adventure that allow individuals to discover the truth to proof that the phenomenon is actual or, not, or, it gives a deep observation into something that has been believed as a presumed idea in the form of a proposition, assumption, hypothesis which isn't limpid in its description (Sakyi et al., 2020). Furthermore, researcher's exploration ideology is their aspect of thinking on truth, practice, and understanding (Ryan, 2018). The process of data collection, analyze and design with philosophical ideas is affected by this view. In this thesis, the "Research Methodology" chapter discusses the research methods, data collection and analysis process as well as the reliability and validity of data where we try to find out how AI and blockchain can help countries to work together in China's renewable energy sector. Uncovering the top method for reaching out research goals and collect necessary data is the aim of research methodology (Bryman & Bell, 2015; Saunders et al., 2019).This study's aim also to find out what are the difficulties and benefits of AI and BC integrated utilization in cross border energy projects and how they affect productivity , decentralization, and openness to work in collaborative way around the world.

3.1 Research Philosophy

This study utilizes interpretivist research philosophy, where the aim is to observe how individuals feel and response to their surroundings and actions by looking into social phenomena. Interpretivism mainly focuses on people's actions and the causes behind the social process (Ryan, 2018).This also fits the study's objectives. This view has been chosen because it allows researchers to go deeper into the complicated, situational factors that affect the utilization and adoption of new technologies in the renewable energy industry (Creswell & Creswell, 2018). Although this method helps researchers to find out how digital technologies affect international collaboration by analyzing organizational technological barriers and enablers.

3.2 Research Process

We applied the qualitative research process for our study as it is a naturalistic way of research to figure out phenomena that occur in natural environments (Creswell & Creswell, 2018). We find this process more useful, as it produces information by using individuals own experiences and thoughts that they apply to improve or test the system. We chose a qualitative approach because we needed open-ended information and experiences to address our research questions, and such answers enable us to develop new ideas (Creswell & Creswell, 2018). Fourteen (for managerial staff) and twelve (for technical staff) most significant and relevant interview questions were developed that align with our research questions and goal. With the chosen six interviewees, who are all connected with the digital technologies specially with AI and Blockchain in energy sector, also experience in different cross border collaboration project, we conducted semi-structured interviews. Among 8 of the interviewees, 7 of them are from China and one of the from India but working with Chinese company, and the authors connected with those people through networking. The interviews are conducted by using Zoom application and the interview transcripts are taped thoroughly. The authors took the permission of all the participants, but most of them preferred to appear as anonymous .Every interview took one 30-40 minutes on average.

3.3 Data Collection

This paper utilizes the primary data collection method, as the researchers are well connected with the people who are knowledgeable enough about digital technologies and the renewable energy sector of China. In this study, we collected data through semi-structured interviews, as this interview method allows interviewees to be more flexible while still staying with the topic and research question (Bryman & Bell, 2015).Semi-structured interviews are conducted with a list of questions that are based on the study

aim and objectives that are necessary to collect primary data (Lindlof & Taylor, 2017; Saunders et al., 2019). Additionally, this method supports detailing and managing information, which makes the paper more reliable. For authentic research, researchers need enough data from different sources to ignore biases (Creswell & Creswell, 2018).However, semi-structured interviews let the researchers continue the conversation with the freedom to ask more in-depth questions if they can convince interviewees that the topic is relevant and interesting (Bryman & Bell, 2015; Creswell & Creswell, 2018).As a consequence, this method is preferred as the best one for discovering the personal experience of professionals from the Chinese renewable energy sector who can give detailed information about how AI and BC are utilized in green projects of China and how this collaboration can span the international border. Furthermore, for the purpose of diversity and varied points of view we also applied snowball sampling. Snowball sampling is a data collection method where experts from relevant sectors suggest other experts who can give more detailed information in the data collection process. This works well when researchers have good communication with a network of people, which can upgrade the depth of insights (Bryman & Bell, 2015).

No	Firm	Interviewee position	Company HQ	Interview length
R1	Huawei Digital Power Technologies Co., Ltd.	Senior Technical Engineer	China	30
R2	Envision Energy Co., Ltd.	Engineer	India	40
R3	Huawei Digital Power Technologies Co., Ltd.	Solutions Engineer	China	35
R4	State Grid Corporation of China (SGCC)	Senior Technical Engineer	China	35
R5	Shenzhen Center Power Tech. Co,. LTD. (Vision Group)	Senior Manager – Digital Energy Solutions	China	25
R6	Shenzhen Center Power Tech. Co,. LTD. (Vision Group)	Senior Mechanical	China	30

		Engineer & Project Manager		
R7	State Power Investment Corporation (SPIC)	Electrical engineer & Project Coordinator	China	35

3.4 Data Analysis

For this research, researchers collect primary data from the people who have related knowledge and experience in the digital technology based renewable energy sector in China as the nature of the topic demands authentic information. Moreover, this study needs purposeful sample which depends on the researcher's networking and ability to convince the participants (Saunders et al., 2019).For this purpose, the research sample is made up of professionals who are directly engaged with AI and BC based energy sectors such as multinational ones, research-led ones, and the Chinese blockchain based industries which provide good source of data as they provide information from experience. The conversations were done by Zoom application and the zoom recording taped the interview transcript that favors the researchers to analyze the authenticity. Most of the interviews take 30-40 minutes.

After successfully collecting the data, researchers analyze it thematically to find the patterns and describe the correlation between them. This study applies thematic analysis which best is for closely observe how the use of AI and BC impacts the green energy industry (Braun & Clarke, 2006).

The interview transcript was coded after collecting to investigate the significant issues. Furthermore, the codes will then put together into theme to find out how AI and BC can be utilized in cross-border energy projects that results efficiency, decentralization and transparency as well as it will compared with the study goals .Finally, to make the result more reliable triangulation and member checking will be conducted thoroughly. Triangulation is a process that compares data from different sources to prove the

consistency and member checking is the way of giving feedback to the participants and asking for their confirmation (Creswell & Creswell, 2018).

3.5 Reliability and Validity

In qualitative research, maintaining reliability and validity is essential as the data gathered from the sources must be trustworthy and credible because they rely on the research method chosen (Bryman & Bell, 2015; Saunders et al., 2019). Reliability considered as a context that refers to consistency and reproductivity of the data. On the other hand validity measures the truthfulness of the data as it measures the findings of what it intends to measure. To enhance the reliability this study applied semi-structure interview process and hematic analysis to ensure that the research process is transparent and consistent (Creswell & Creswell, 2018).Additionally, to ensure the validity of the data which prove that the data is comprehensive this study employed member checking and triangulation process. Individuals who are being interviewed in this research process are experts in digital technologies and renewable energy industries in China. Also, the candidates haven't any direct relationship with the researchers as we got all the participants from networking as well as most of them wanted to participate anonymously which meant that there would be less bias at all. Furthermore, to enhance the fairness and objectivity of the interviews researchers heard the opinion of interviewees and not implied their own view into it (Kara, 2018). By applying these strategies this study aims to improve its comprehensiveness and draw conclusions that are grounded in authentic and reliable data.

4.Empirical Results

The chapter presents the empirical findings from eight semi-structured interviews with professionals and specialists in the fields of digitalization, renewable energy, and organizations involved in policy. The interviews covered information on how blockchain technology and artificial intelligence (AI) are transforming sustainable energy and international cooperation in emerging markets. Analysis was undertaken in a reflexive thematic way to come up with six key themes that represent shared and varied experiences of the participants. To facilitate interpretation, these topics are presented below with a few quotes that reflect the opinions of the participants.

4.1 Theme 1 – Artificial Intelligence for Operational Efficiency

All the respondents agrees upon one fact that AI plays significant role for the efficient use of renewable energy systems. For the accurate energy forecasting and make production schedules appropriate AI can be used as a main tool suggested by all the participants. Most of the respondents expressed the necessity of AI base predictive maintenance and fault detection process to lower the operation cost as well as make the system more reliable. One of the interviewees revealed some media, such as:

"*AI optimizes energy production, reduces downtime, and increases the efficiency of renewable assets*" (R1).

Other participant equally emphasized that AI has already important tool for modern control and monitoring system:

"*AI is already embedded in our SCADA systems and monitoring dashboards, so I use it regularly*" (R2).

Although all the participants undoubtedly support the benefits of AI and also expected to leverage the potentiality of it. Quality data and competent human resources as well as advanced digital infrastructure were always cited as prerequisites. Inaccurate models may also be caused by poor data governance or lack of technical literacy and may result in

biased decision-making. Respondents emphasized that the success of AI will be determined by human skill in interpreting the data and managing the ethical aspect.

Consistent with the Diffusion of Innovation (DOI) model, the results indicate that the AI has a definite relative advantage in enhancing efficiency and cost-effectiveness. Nonetheless, it remains incompatible with current energy systems and fairly complicated to implement, making the scale of diffusion challenging. According to a Socio-Technical Systems (STS), AI integration is more of a technological upgrade than an organizational change that needs human, institutional, and infrastructural coordination.

4.2 Theme 2 – Blockchain for Trust and Transparency

The second theme is associated with using blockchain technology to increase transparency and promote trust in worldwide partnerships in renewable energy. The respondents noted that blockchain is an essential instrument to data integrity and accountability, especially in checking the renewable energy certifications, carbon credit tracking, and settlement of international partners. As one of the respondents indicated,

"*Blockchain ensures trust among international partners by providing immutable records of energy generation, consumption, and carbon credits*" (R1).

Similarly, another interviwee expressed the blockchain's ability to develop shared confidence among stakeholders

"*The benefit is trust—everyone can see the same record, so there are fewer arguments*" (R4).

For minimizing the gap between institutional voids and dependency on intermediaries blockchain act as a bridge. The participants delivered that the information inequality could be lessened with the active utilizaion differentiated ledger technology, especially in energy-trading situtaions where openness to situation is essential.On the other hand,

some respondents also mentioned the difficulties of existing blockchain mechanisms such as, costliness and inability to scale.

In this perspective one respondent explained,

"*In some countries, blockchain-based certificates are still not legally recognized, which limits cross-border trading*" (R8).

This theme reveals that enhancing trust by blockchain is a more institutional than technical problem. Blockchain has to be practiced in line with legal, regulatory and governance systems to be effective in the diffusion. The use of blockchain is a new socio-technical exchange of technology, trust, and institutional legitimacy as established by STS theory.

4.3 Theme 3 – Regulatory and Institutional Friction

Regulatory fragmentation and institutional rigidity were presented by all respondents as significant obstacles to digital transformation in the energy sector. The various national standards, control over the market on a centralized basis, and the lethargy in adapting to the policies were regarded as being a critical barrier to scaling AI and blockchain projects. One of the participants summed up the problem to the point:

"*Regulatory fragmentation across countries, especially differing grid standards and data-security policies, creates major obstacles*" (R1).

Another mentioned,

"*Different countries interpret data privacy and certificate validation differently, and that slows everything down*" (R6).

Those who had the experience working with state-owned organizations showed concerns especially in regards to the repressive character of the hierarchical governance structures which are not easy to decentralize in terms of technology. This lowers the innovation and taking a risk in business. According to some of the interviewees, although pilot initiatives

are often promoted, long-term regulatory change does not align with technological advances.

The results indicate that policy transformation is directly related to the diffusion of innovation. This theme will be crucial in the light of the DOI, where the incompatibility of new digital solutions and the current regulation systems is observed. Regarding the STS approach, it proves that institutional inertia may serve as a regime barrier that restricting niche innovation and to ensure collaboration across nations , state leaders must have to standardize legal frameworks that ensure the applicability of the digital certificates and smart contracts.

4.4 Theme 4 – Interoperability and Data Governance

The challenges of data interoperability and data governance were raised by the respondents multiple times as the obstacle to expanding AI and blockchain systems internationally. Major technological and operational issues were found such as inability to have consistent data formats, privacy policies, and incompatible data sharing infrastructures. A participant observed,

"*Data standardization is the biggest issue—different countries use different data formats and protocols*" (R3).

Another noted,

"*Different privacy and data-governance rules mean we often share aggregated or anonymized data, which limits what AI can do*" (R4).

The results indicate that interoperability of data is a technological, political and ethical issue. Even though most of the respondents concurred that blockchain can ensure and standardise data, the issue of cybersecurity and intellectual property was raised. The interviwee expressed that the scalable digital energy solutions needs the application of general data mechanisms supported byglobal standards and reliable connections.

Furthermore, from the viewpoint of STS theory, data governance is a opinion-based interface that maintain contact between technology, legal framework and ethical issues.The uninterrupted attendance of piecemeal data systems, most needed collaborative systems and worlwide recognized governance has supported the significance of cleanness without questioning the problems of security and sovereignity.

4.5 Theme 5 – Organizational Capacity and Skills Gaps

Fifth theme of our findings is about human capital and readiness of the organization. Individuals who shared their thought regarding this discussed about both the new technologies as well as the way any organization maintain culture, skills, and resources for making digital operation smoother. One common issue signified by the respondents was the lack of professionalism to set up AI and blockchain system.

One person interviewed said,

"*AI needs a lot of good data and skilled workers to work well*" (R6).

Another participant stressed the necessity of developing internal skills instead of solely relying on outside vendors:

"*Develop internal skills in AI and blockchain, don't just rely on vendors*" (R1).

Furthermore, interviewees the main hindrances in making and adopting new ideas are the reluctance of taking risk and rigid purchasing systems. Another thing is organizations tendency to keep cost low that create another barrier to faster acceptance. This scenario completely aligns with the idea of absorptive capacity (Robertson et al., 2023) that explains the significance of learning and adopting new technology know-how. In particular, this data clearly prove that adaptive leadership and creating human capital are not only necessary element for technological change but also backbone of it.

4.6 Theme 6 – Pilot Projects and Incremental Scaling

All the respondents acknowledged that pilot projects and regulatory sandboxes are critical tools that can be used to test and legitimize AI and blockchain solutions. Pilot programs have been defined as safe environments where both technical feasibility and regulatory compliance could be tested at the same time. One of the participants indicated that,

"*Start with pilot projects before full-scale deployment*" (R1).

Another shared an example from their organization:

"*We ran a pilot using smart contracts to validate renewable energy certificates; the contract executed automatically when validation was complete*" (R7).

Pilot projects were perceived to be valuable learning objectives, trust-building and confidence of the investors. Nonetheless, some of the respondents cautioned that pilot projects may also end up being comfort zones that postpone the total implementation. The understanding gained by pilots has to be used in creating lasting policy frameworks and scalable architectures in order to bring systemic change.

DOI model pilots contribute to the increase of trialability and observability, so the potential adopters can witness the tangible results. In terms of STS, they can be considered as a sort of niches where new socio-technical arrangements are tried out which over time have an overall impact on larger institutional regimes.

4.7 Cross-Respondent Variations and Comparative Insights

Although all the six themes shared similar views, some distinct differences were observed in the different types of organizations and in the professions. The answer of AI and blockchain as a strategic facilitator of innovation and competitiveness was also consistent across respondents of the private technology companies like Huawei Digital Power and Vision Group. They talked about experimentation, the implementation of digital analytics

into business modelings, and the possibility of growing the markets based on data. Conversely, those who work in state-owned or policy-related institutions, including SGCC, prioritized the reliability of processes and compliance, including digital tools as the means to enhance stability within set regulatory frameworks and not to interfere with the current processes.

Likewise, the technical experts specialized in the practical issues of implementation namely; data quality, compatibility of infrastructures, and cybersecurity, and the managerial and policy level experts emphasized coordination and readiness of the institutions as the decisive success factors. The respondents who had international project experience considered blockchain to be an intermediary of global trust, whereas domestically-based respondents were skeptical and referred to regulatory restrictions on the flow of data. These differences indicate that the views on the digital transformation depend not only on the availability of technology but also on organizational mission and access to cross-border cooperation. Therefore, AI and blockchain adoption in the Chinese renewable energy industry is more of a plural than a homogenous process in which strategy, control and context dictate the speed and the intention of innovation.

4.8 Summary of Empirical Findings and Comparative Insights

Theme	**Core Findings**	**Illustrative Quotations (R1–R8)**	**Key Implications / Links to Theory**
1. AI for Operational Efficiency	AI improves forecasting, predictive maintenance, and asset optimization; benefits depend on data quality and staff expertise.	"AI optimizes energy production, reduces downtime, and increases efficiency" (R1).	Strong *relative advantage* (DOI); efficiency shaped by socio-technical alignment (STS).
2. Blockchain for Trust and Transparency	Blockchain ensures data immutability, cross-border traceability, and trust; but scalability and legal recognition remain challenges.	"Blockchain ensures trust among partners by providing immutable records" (R1).	Builds *trust* and *observability* (DOI); depends on institutional legitimacy (STS).

3. Regulatory and Institutional Friction	Fragmented regulations, slow policy updates, and centralized structures hinder innovation and cross-border collaboration.	"Different countries' policies create major obstacles" (R6).	Weak *compatibility* (DOI); regime resistance to decentralization (STS).
4. Interoperability and Data Governance	Lack of shared data standards, privacy laws, and cybersecurity frameworks limit integration of AI and blockchain.	"Data standardization is the biggest issue—different protocols everywhere" (R3).	Data governance as a socio-technical interface; need for shared standards.
5. Organizational Capacity and Skills Gaps	Shortages of digital talent, limited internal expertise, and rigid hierarchies slow adoption.	"Build internal expertise in AI and blockchain, not just rely on vendors" (R1).	*Complexity* and *trialability* limited (DOI); learning and absorptive capacity essential.
6. Pilot Projects and Incremental Scaling	Pilot programs promote experimentation and legitimacy but risk staying isolated if not scaled systematically.	"Start with pilot projects before full-scale deployment" (R1).	Enhances *trialability* (DOI); niches as STS transition pathways.

4.9 Summary of Empirical Results

The empirical data shows that the digital transformation of the renewable energy sector can be defined by the technological potential and the institutional limitation. AI increases the efficiency of operations by bringing about optimization of the process of generation and maintenance, whereas blockchain improves the transparency, traceability, and confidence in global cooperation. Nevertheless, organizational capacity constraints, regulatory friction and data fragmentation are major troubling issues. The students were unanimous on the fact that pilot projects and collaborative structures will help narrow the gap on the same between technological innovation and policy change.

Comprehensively, the findings from this paper indicates the sustainable digital movement in the energy area as it is not merely a technological determination, but also a socio-technological transition that prolong the renovation of technology, governance, and humanity. This speculative adventure provide as the root for the analytical ideas for the further discussions where the findings have been thoroughly checked within the framework of Diffusion of Innovation and Socio- Technical System theories.

5.Discussion and Conclusion

5.1 Discussion

This study mainly focused on the combine use of AI and blockchain which can speed up the transformation of sustainable energy that can bring together energy bouded countries to work collaborately.For the further knowledge gathering we took eght interviews form eight exeprt persons in this field who deliver some valuable insights about the digital movement in the energy sector. They give the detail idea about the digital shift in energy sector that is not just a innovative technology, but rather a new thought that change the work mehods when people work together with technology.They also discussed that the AI and blockchain are being used successfully in China's transformation to renewable energy and that can only be possible by the proper adaptation of efficient technology, regulatory frameworks, and strong organising capabilities.Here aso include the findings about literature, theoritical frameworks, and policy report in this section.All are explored critically, by nurturing practical follow-ups, and finally thoughts are given.

For the betterment of enegry infrastructure in China AI has become a significant tool ,that is founded by this study.Interviwees expressed their opinion in that case as they said, AI-based forecasting, optimization algorithms, and proper management can make enegry production more trustworthy and successful.The results from this study also allign with the aspect that the Inernational Energy Agency (IEA ,2023) acknowledges that AI facilitate grid balancing as well as incorporate intermittent renewables.Another interesting fact that is revealed by the interviwee is the contextual dependency of AI advantage that has not been thoroughly examined in AI policy argument. They also expressed the contribution of talented employees,quality of data , and algorithms that enable AI to achieve sustainability and efficiency.In this respect, it is also considerable fact that in China to get access to the data and share it is possibly limited to state rule on national security.Therefore, AI facilitate efficient operations,still in the presence in the presence of controlled environment with policy regulation instead of open market competition.

The purpose of blockchain, as it can be seen in the empirical results, is also transformative but institutionally constrained. Respondents were also in line with their views about blockchain relating to trust, transparency, and traceability whenever dealing with renewable energy transactions, especially with the credentialing of green energy and carbon credits. These observations are in line with the International Renewable Energy Agency (IRENA, 2024), which emphasizes on the potential of blockchain to facilitate transparent markets of renewable energy. However, this paper finds another contextual aspect: in China, blockchain is not implemented to decentralize the governance but to strengthen the accountability in centralized systems. The respondents presented blockchain-based pilot projects, which store the data about the renewable energy generation in distributed ledgers, and the control and validation mechanisms are controlled by the government or state-owned enterprises. Such a form of hybrid adoption, as technological decentralization in the institutional control of a decentralized policy, is a Chinese contribution to the discourse of a global digital energy transition. It questions Western discourse that equates the adoption of blockchain with democratization and indicates that the belief in China is institutional instead of being algorithmic.

In comparison to the global policy frameworks, including European Commission and Joint Research Centre (JRC, 2023), which promote open energy data platforms and peer-to-peer trading models, the Chinese model appears to be a state-centred model of interoperability. According to the interview data, the digital energy strategy that is popular in China is selective openness, where blockchain systems will permit verifiable transparency among authorized partners but limit the flow of data across borders. As one participant explained, "*Data can't always move freely between provinces or to foreign partners due to national security rules*" (R6). Such a strategy is an example of what may be termed as "sovereign interoperability" a logic of governance that aims to keep technological interconnection without relinquishing regulatory power. This kind of partial openness can be viewed as contradicting in light of a Western mindset but is aligned with the overall Digital Silk Road

policy in which the integration of cross-border infrastructure is sought under specific criteria and bilateral agreements as opposed to open multilateral models.

To explain these results, this paper combines the Diffusion of Innovation (DOI) theory and the Socio-Technical Systems (STS) theory and integrates them into a multi-level explanatory framework. DOI theory can be used to understand why the adoption of AI and blockchain in China is an incremental and not a disruptive process. The two technologies have a high relative advantage when it comes to enhancing efficiency, transparency, and data integrity, but are hampered by the incompatibility with the current regulatory frameworks and organizational processes, as well as complexity caused by the difficulties in integration. The STS theory, in its turn, explains the systemic interdependence of technology and institutions and human actors. In this perspective, the digital energy transformation in China can be viewed as a co-evolutionary system as opposed to a linear process of innovation- technological innovation will restructure institutional arrangements slowly, institutional structures will govern the innovation process that is allowed to flourish. This conceptual integration supports the fact that technological change is also socio-political in nature and successful diffusion must be coordinated at technological, institutional and societal levels.

Based on the integrative view, the argument is that Chinese digital energy transformation can be ideally represented as a three level model that includes technological, institutional, and societal systems. On the technological tier, the hybrid architecture introduced by the co-deployment of AI and blockchain facilitates the increase of the operational reliability, as well as the provision of trustful energy certification. At the institutional level, state-driven coordination and regulatory adaption offer stability but is associated with rigidity that slows down experimentation and integration between countries. Ultimately, on the societal level, the legitimacy of the transformation in the long term is predetermined by the public acceptance and the establishment of digital literacy. The tri-level interaction indicates that digital transformation is not a policy issue of innovation but also a societal

negotiation and learning processes.

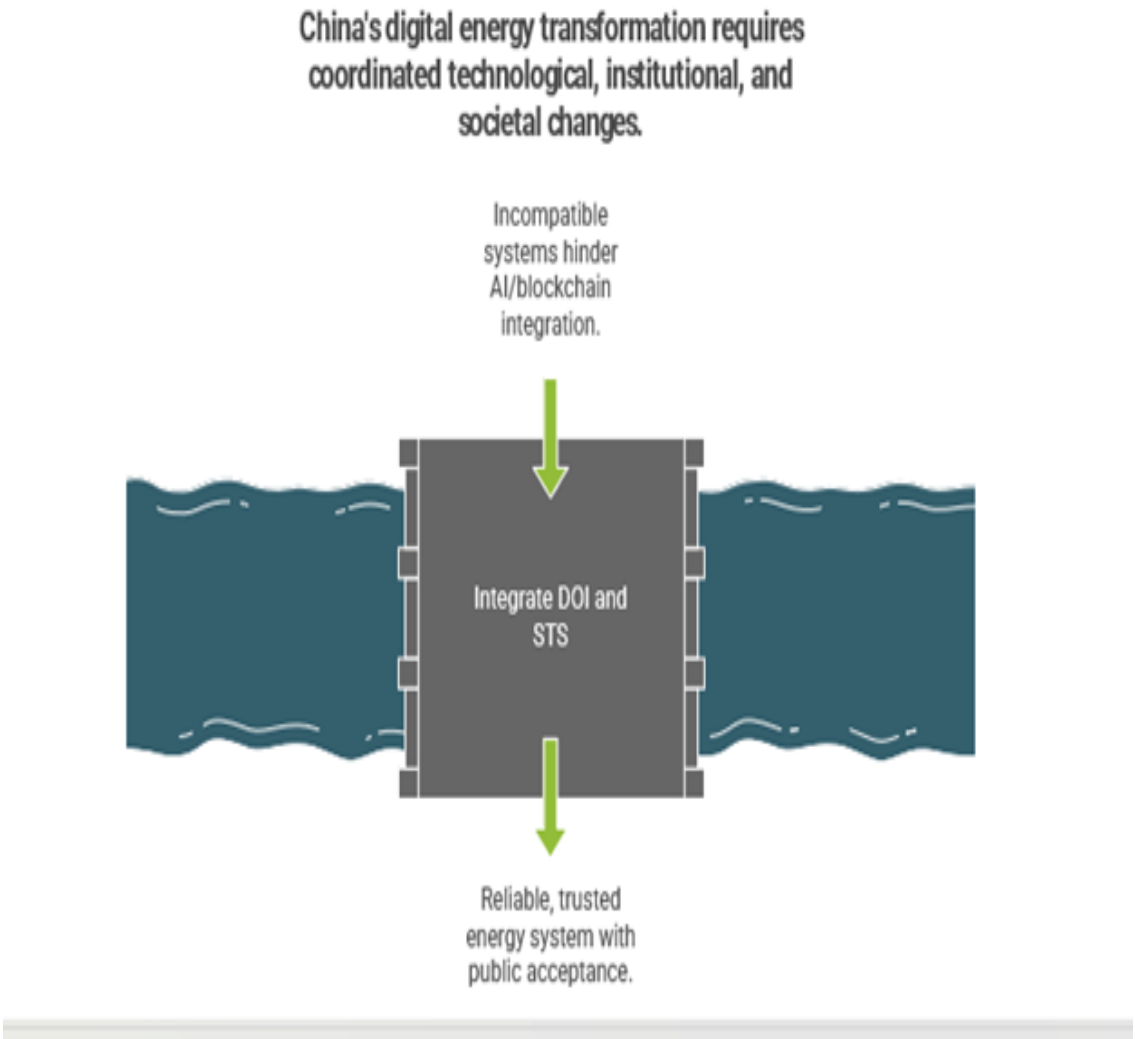

Figure 5.1: China’s digital energy transformation

The discovery of a hybrid form of governance in China that is digital energy transition a form which is both centralized in policy setting but decentralized in technological testing is one of the most innovative initial findings of this thesis. According to the respondents, pilot projects and regulatory sandboxes are essential in enabling controlled experimentation.One of the interviwees revealed, ”We start with small pilots before scaling up nationawide to ensure that risks are manageable” (R1). To make sure the consistent development of AI and blockchain under the acceptable limits,these pilot projects are operated by the safe laboratories.Instead of considering state-driven Chinese model is the resistance to change innovation,It can be more valuable to take into account another institutional logic of digitalization which prioritizes innovation and control as well as provide substantial implications on policymakers and international organigations.This findings express the western research policy which is decentralized is naturally optimal in technology diffusion where as Chinahave reversed thought where they belive powerful central coordination linked with selective flexibility can result scalable technology and regilatory coherence. Within the study, the increment of cross-border digital energy diplomacy is another aspect that is found. Programs like the Belt and Road Energy Cooperation, which use AI to keep an eye on things and blockchain to prove transparency for exporting equipment for renewable energy and digital government models. In this way, China affects trade partners all over the world in terms of both technological norms and political models as well as sets an example for how to operate digital energy. Because of these changes, sharing digital standards and investment in infrastructure are now part of the idea of energy relations. The obvious ending for discussions about international policy is that the digital innovative adaption of the energy industry is evolving it into a place where nations compete politically and work in collaborative way for technological advancement.

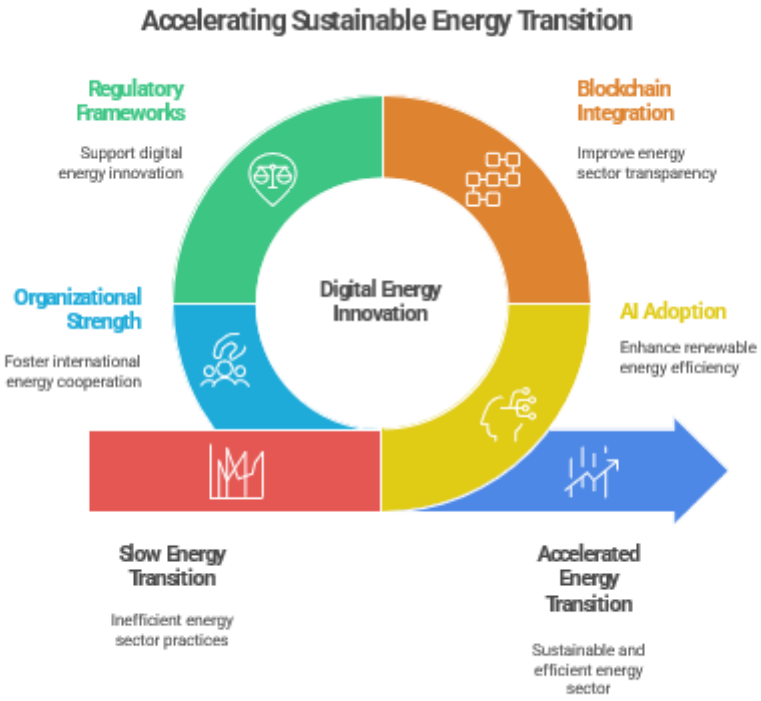

Figure: 5.2 Accelerating Sustainable energy transition

On the basis of the synthesis presented in Figure 5.2, this study can be described as complementary and as a prolonged version of previous researches on the aspect of digital transformation in energy. Other previous researches, including Wang and Su (2020) and Zhu et al. (2020) were more focused on the efficiency benefits of AI and blockchain or the regulatory barriers to their implementation. Nonetheless, the current results show that the effectiveness of digital transformation is not merely based on the technological potential or policy alignment but on the connection between organizational culture, institutional flexibility, and strategic intent. To give an example, although previous studies tend to adopt regulation as a homogenous obstacle, the interviews reveal the two-sided truth: domestic regulation in China is empowering, but cross-border regulatory divergence is the primary impediment to international cooperation. This observation modulates prior assumptions by showing how a given national ecosystem can at once be the source of

innovation and a limitation to international integration. Besides, in contrast to previous research, where blockchain is seen more as a decentralizing tool (IRENA, 2024; JRC, 2023), this study presents a hybrid model of centralized transparency in China where digital accountability is ensured by permissioned blockchain controlled in state institutions. In a similar manner, when Yu et al. (2024) and Otoum and Mouftah (2021) associated AI adoption with cost-efficiency and the spread of innovation, contextual dependency appeared in the interviews in this study, stating that the value of AI depends on data governance and human ability.

Based on such differences, the current study contributes to the discussion by establishing a hybrid regime of digital transformation a technologically decentralized but institutionally centralized system. The paper coined the new terms of sovereign interoperability and centralized transparency showing how China manages to gain trust and accountability with permissioned blockchain and AI deployment coordinated by policy. In contrast to the previous literature that has equated the concept of digitalization and the concept of liberalization, this study offers empirical data that innovation and control can exist in a fruitful relationship. It also indicates the three-tier co-evolution of technological, institutional, and societal systems, and the model of China is presented as a different alternative of digital transformation towards sustainability. Such reframing, as an efficiency prism of the West to an institutional hybridity paradigm, is the main theoretical and empirical contribution of this thesis, developing a context-based approach to digital transformation in developing economies.

5.2 Recommendation to policy and Business practice

There are various implications to policy and business practice in these findings. To policymakers, the findings demonstrate that institutional interoperability, to allow secure and trusted international energy cooperation, is the synchronization of standards, certificate recognition systems and data governance models. To energy businesses and

startup, the paper demonstrates the strategic value of hybrid digital architectures designed to provide efficiencies and regulatory compliance interests through the integration of AI-driven analytics with a blockchain-based verifying system. Also, the findings indicate that the companies that conduct business in China or related settings must invest in capacity-building by creating multidisciplinary team assembling technical, legal, along with policy knowledge to overcome the complicated regulatory framework of digital energy systems.

5.3 Study Limitations and areas of future research

Although this research is rich in insights, it faces limitations as it ought to be. The sample of eight experts is qualitative and is rich with context sensitivity but lacks generalizability. Moreover, digital technologies change rapidly, which implies that pilot projects mentioned in this section can become outdated quite soon due to the emergence of new regulatory or technical frameworks. Future studies should thus take a cross-country comparative design to investigate the role of various systems of governance in influencing digital transformation paths, namely; liberal, hybrid, and state-driven. Quantitative research would be able to supplement qualitative results with a quantitative evaluation of the quantifiable performance metrics of hybrid AI-blockchain solutions including cost-saving, carbon reduction, and energy efficiency improvements.

To conclude, this thesis illustrates that digital revolution in green energy which is not only technological, but also cultural and institutional one which can be added to bot academic and practical knowledge. Though there exist government pressure in the utilization of combine use of AI and blockchain, but still it is a terrific sample of a new path to digitize things that is transparent, effective, and ever-lasting. They takes into account the varied contexts as well as highlights that western thoughts about this innovation don’t applicable for every aspect and expand the necessity for global electrification. Lastly, the paper try to

explain that advanced digital technologies are the main tools for the further development of sustainable energy as well as the operating organisations are also responsible for that activities because their openness, flexibility and trustworthiness matters a lot for the sustainability of the green energy.

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Appendices

Appendix 1. Interview questionnaire for managerial staff

Participant Information Sheet and Consent Form

Participant Information Sheet

Project Title:

Digital Transformation in Energy Sector Sustainability: Accelerating Sustainable Energy Solutions through AI and Blockchain in Emerging Markets

Researchers:

Lotifa Chowdhury & Archy Majumder Master's Students, University of Vaasa

Purpose of the Study:

This research explores how artificial intelligence (AI) and blockchain technologies can support international collaboration in renewable energy projects. The study focuses on gathering insights from professionals involved in China's renewable energy sector, especially those engaged in international or cross-border initiatives.

What Participation Involves:

If you agree to participate, you will be asked to take part in a semi-structured interview lasting approximately 30–45 minutes. You will also be invited to complete a short pre- interview profile form. The interview will be audio-recorded with your permission and transcribed for analysis. You may skip any questions you do not wish to answer.

Confidentiality:

All information you provide will be kept strictly confidential. Your name, job title, and organizational details will be anonymized in the final thesis and any related publications. Data will be securely stored and used only for academic purposes.

Voluntary Participation:

Your participation is entirely voluntary. You may withdraw from the study at any point without providing a reason and without any negative consequences.

Contact Information:

If you have any questions or concerns about this study, feel free to contact us:

Lotifa Chowdhury: lotifa.chowdhury@student.uwasa.fi Archy Majumder: archy.majumder@student.uwasa.fi

Consent Form

Please read and confirm your agreement to the statements below:

1. I have read and understood the Participant Information Sheet.
2. I have had the opportunity to ask questions and received satisfactory answers.
3. I understand that participation is voluntary and I can withdraw at any time.
4. I agree to participate in this research project.
5. I agree to have the interview audio-recorded for transcription and analysis.
6. I understand that my responses will remain confidential and used only for academic purposes.

Participant's Name: _____

Organization:

Mailing Address:

Signature: __

Date: _

Researcher's Name: _____

Signature: __

Date: _

Pre-Interview Profile (to be completed before interview)

1. Your current role/title: _
2. Type of organization: □ State-owned □ Private □ Other: _
3. Have you worked on international renewable energy projects? □ Yes □ No
4. Familiarity with AI in energy projects: □ None □ Basic □ Moderate □ High
5. Familiarity with blockchain in energy projects: □ None □ Basic □ Moderate □ High
6. How supportive is the current institutional environment for adopting these technologies?

□ Very Unsupportive □ Unsupportive □ Neutral □ Supportive □ Very Supportive

7. In your opinion, what is the biggest challenge for cross-border energy collaboration?

Interview Guide – Managerial Staff

8. What is your role in your organization's digital or energy collaboration projects?

9. Has your firm been involved in international renewable energy initiatives? Please explain.

10. What prompted your organization to adopt AI or blockchain technologies?

I. Was the adoption proactive (strategic choice) or reactive (e.g., driven by regulations, market trends, or competitor actions)?

11. How do these technologies support your strategic or sustainability objectives?

12. What influence do AI and blockchain have on project planning and cross-border coordination?

13. Does your organization see value in combining AI and blockchain technologies for international energy collaboration? If yes, in what ways?

I. Is this synergy primarily operational (improving current workflows) or strategic (long- term positioning and innovation)?

7. What internal organizational factors help or hinder adoption?

8. How do government policies or regulations shape your digital strategies?

9. How do you address trust and transparency with international partners?

10. Have these tools helped overcome institutional or collaboration challenges?

11. What feedback have you received from stakeholders about these technologies?

12. What recommendations would you give to other firms considering these tools?

13. What are the three biggest risks you foresee in expanding AI and blockchain use in international energy collaboration?

Ⅰ. How do these risks differ in the short-term, medium-term, and long-term?

14. What are the biggest opportunities you foresee in expanding digital collaboration (e.g., AI and blockchain) in the renewable energy sector?

Ⅰ. How do these opportunities differ in the short-term**,** medium-term, and long-term?

Appendix 2. Interview questionnaire for technical staff

Participant Information Sheet and Consent Form

Participant Information Sheet

Project Title:

Digital Transformation in Energy Sector Sustainability: Accelerating Sustainable Energy Solutions through AI and Blockchain in Emerging Markets

Researchers:

Lotifa Chowdhury & Archy Majumder Master's Students, University of Vaasa

Purpose of the Study:

This research explores how artificial intelligence (AI) and blockchain technologies can support international collaboration in renewable energy projects. The study focuses on gathering insights from professionals involved in China's renewable energy sector,

especially those engaged in international or cross-border initiatives.

What Participation Involves:

If you agree to participate, you will be asked to take part in a semi-structured interview lasting approximately 30–45 minutes. You will also be invited to complete a short pre- interview profile form. The interview will be audio-recorded with your permission and transcribed for analysis. You may skip any questions you do not wish to answer.

Confidentiality:

All information you provide will be kept strictly confidential. Your name, job title, and organizational details will be anonymized in the final thesis and any related publications. Data will be securely stored and used only for academic purposes.

Voluntary Participation:

Your participation is entirely voluntary. You may withdraw from the study at any point without providing a reason and without any negative consequences.

Contact Information:

If you have any questions or concerns about this study, feel free to contact us:

Lotifa Chowdhury: lotifa.chowdhury@student.uwasa.fi Archy Majumder: archy.majumder@student.uwasa.fi

Consent Form

Please read and confirm your agreement to the statements below:

1. I have read and understood the Participant Information Sheet.
2. I have had the opportunity to ask questions and received satisfactory answers.
3. I understand that participation is voluntary and I can withdraw at any time.
4. I agree to participate in this research project.
5. I agree to have the interview audio-recorded for transcription and analysis.
6. I understand that my responses will remain confidential and used only for academic purposes.

Participant's Name: _

Organization:

Mailing Address:

Signature: ___

Date: _

Researcher's Name: _

Signature: ___

Date: _

A. Pre-Interview Profile (to be completed before interview)

1. Your current role/title: ___

2. Type of organization: □ State-owned □ Private □ Other: _____

3. Have you worked on international renewable energy projects? □ Yes □ No

4. Familiarity with AI in energy projects: □ None □ Basic □ Moderate □ High

5. Familiarity with blockchain in energy projects: □ None □ Basic □ Moderate □ High

6. How supportive is the current institutional environment for adopting these technologies?

□ Very Unsupportive □ Unsupportive □ Neutral □ Supportive □ Very Supportive

7. In your opinion, what is the biggest challenge for cross-border energy collaboration?

B. Interview Guide – Technical Staff

1. Can you describe your role and responsibilities in renewable energy projects?

2. Have you worked on any international or cross-border energy initiatives? Please describe.

3. What kinds of artificial intelligence tools have you worked with for international or cross- border energy initiatives?

I. Please give specific examples (e.g., predictive maintenance, demand forecasting, energy optimization).

4. What kinds of blockchain tools have you worked with for international or cross-border energy initiatives?

Please give specific examples (e.g., smart contracts, energy trading platforms, supply chain tracking).

4. What technical benefits or limitations have you observed?

5. How integrated are these technologies in your daily systems or workflows?

6. How do AI and blockchain technologies interact or complement each other in your projects? Are they integrated, or used separately?

7. What technical barriers have you encountered (e.g., data, compatibility)?

8. How are accuracy, reliability, or security maintained in these systems?

I. Can you give examples of protocols, processes, or case-specific measures used to ensure these qualities?

9. Have you experienced challenges related to data sharing in cross-border projects?

10. How have these technologies helped with communication or efficiency in international settings?

11. What improvements would make these tools more effective in global energy projects?

12. What do you see as the future role of these technologies in international energy cooperation?

Appendix 3 Acknowledgement of AI use

In the current writing of this thesis, we used ChatGPT (GPT-5, October 2025 edition) built by open AI to aid with specific writing and structuring operations. The AI helped to polish the wording, make it clearer, create first outlines, summarize background literature, and make the text simpler to read in general. Everything developed with the use of ChatGPT was carefully checked, investigated, and edited by us; therefore all of the content presented in this thesis is all our own ideas.

Appendix 4 Disclaimer

The presented thesis is the joint effort of both authors and is compliant with ethical, academic, and procedural measures of the University of Vaasa. The research and collaboration of intellectual efforts and conclusions are independent and are the results of research done by the authors themselves. Data gathering and processing principles were followed in the framework of GDPR and ethics principles of university research. Although all care has been adopted to provide the accuracy and reliability, the authors do not absolve themselves of making any other errors or omissions. The material is not necessarily the opinions or policies of the University of Vaasa and the institutions.