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Investigating Energy Efficiency Practices and Initiatives for Policy Development: Cross-Cultural and Sectoral Insights from the U.S. and China

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ABSTRACT

This paper examines energy efficiency developments and practices in the United States and China, two of the world's largest energy consumers, through a cross-cultural lens and with multi-sectoral evidence. By reviewing the findings of multiple studies, this research highlights the inefficiencies present in both nations, particularly persistent and transient inefficiencies in energy consumption, and explores sector-specific challenges in the residential energy use, the automotive industry, and the high-performance buildings. The paper draws on a variety of models and approaches, including stochastic frontier models, sectoral reforms, and regional energy strategies, to assess the effectiveness of energy efficiency interventions. The study finds that both countries can benefit from integrating energy efficiency policies with local economic priorities, advancing technological innovation, and adopting smart technologies for real-time feedback. While China should focus on expanding energy efficiency programs, enforcing stricter environmental regulations, and investing in renewable energy, the U.S. should enhance regional energy strategies, implement stricter regulations, and foster collaboration between the public and private sectors. This research emphasizes the need for a cross-cultural approach to policy-making that considers the unique challenges of each country in order to develop streamlined solutions with localised developments. It also looks at the potential of AI to improve energy efficiency, suggesting that future research should focus on this area for further progress.

Keywords: Artificial Intelligence, Climate policy interventions, Energy consumption, Energy efficiency, Energy intensity, Energy-saving technologies, Global energy sustainability, Renewable energy, Sustainable development.

1. Introduction

Energy efficiency is a crucial component in tackling global challenges, such as climate change and sustainable development. As two of the largest economies in the world, both China and the

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United States play significant roles in shaping global energy consumption and emissions patterns. However, their energy efficiency strategies differ considerably due to their distinct economic structures, development trajectories, and energy demands. China, for instance, has implemented top-down strategies such as the Energy Savings and Emissions Reduction (ESER) initiative and the National Energy Development and Conservation (NEDC) policy, which have driven progress in green technologies and low-carbon industries while addressing regional disparities through localized adaptation [1, 2]. In contrast, the U.S. employs market-driven and sector-specific approaches, such as gasoline pricing reforms that have improved vehicle fuel economy, and innovative energy practices in commercial buildings, which highlight the potential of decentralized policies and consumer incentives [3, 4]. Despite these differences, both nations share the challenge of addressing persistent inefficiencies while balancing economic growth with environmental sustainability, making the understanding of their strategies and outcomes crucial for informing global energy efficiency efforts, particularly in the context of the growing need for sustainable development.

In this study, we aim to explore energy efficiency in China and the United States, focusing on how each nation has approached and implemented policies and practices to improve energy use. Energy efficiency refers to the use of less energy to perform the same task and output, essentially minimising energy wastage [5]. While there is extensive literature on energy efficiency, much of the focus tends to be on individual technologies or country-specific measures. What sets China and the U.S. apart is their contrasting economic structures and developmental paths, which influence their energy consumption patterns [6], and hence differentiate their approach to energy efficiency. In addition, China's heavy reliance on manufacturing and infrastructure development has resulted in a higher energy intensity, while the U.S. focuses on domestic consumption and has seen slower improvements in energy efficiency [7, 8].

In 2017 Guo, Lu, Lee and Chiu reported that China exhibits a high inefficiency value of 81.73%. Additionally, China, amongst other countries, needs to decrease CO2 emissions, with a substantial cut of 184.19%. The authors investigated this with the purpose to evaluate the inter-temporal efficiency of various countries regarding their GDP growth and CO2 emissions from 2000 to 2010, including the case of China [9]. Their study aimed to identify which countries have underperformed economically while assessing their environmental impact by measuring inefficiency levels. In addition, their study explored the influence of international agreements, particularly the Kyoto Protocol, on the efficiency of CO2 emissions control. The Kyoto Protocol has positively influenced CO2 emissions and energy efficiency among 27 countries from 2000 to 2010. Although China's inefficiencies stayed significant, the study observed some improvement in efficiency linked to the Kyoto Protocol. In particular, the Protocol helped gradually improve energy efficiency and lower the carbon intensity of China's GDP starting in 2005, aligning with

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the country's commitments under the agreement. However, the scale of these improvements in relation to China's overall inefficiency is not clearly defined. While the study outlines a number of recommendations, it does not address the applicability of their findings to countries outside the sample nor any inaccuracies in measuring inefficiencies [9]. Economies like the US were not considered despite its size and importance in the global economic landscape.

The United States has made notable strides in energy efficiency and conservation through policies like the Energy Policy Act of 2005 and the Energy Independence and Security Act of 2007. These measures have driven progress across transportation, buildings, and electricity generation, with the potential to cut greenhouse gas emissions by an estimated 1,575 million metric tons of CO2 by 2030 [10]. At the same time, they have promoted economic growth by emphasizing energy efficiency and renewable energy development. However, in the case of the US the connection between energy efficiency and renewable energy is rather complex. Studies show that while energy efficiency can lower overall energy demand and inadvertently limit renewable energy use, higher retail electricity prices also reduce renewable adoption. On the other hand, increased household expenditure often drives renewable adoption as the US consumers seek sustainable and affordable alternatives [10]. Lessons from international practices suggest that integrating renewable energy and creating connections between public and private sectors can enhance the U.S.'s energy transition, lead global efforts toward sustainability.

Both China and the United States shape global energy consumption and greenhouse gas emissions due to their economic scale and development trajectories. While China's rapid industrial growth has led to high energy intensity and substantial inefficiencies, the U.S. has focused on energy efficiency policies that highlight both opportunities and challenges in renewable energy adoption. These contexts are contrasting and show the importance of examining how economic structures, policy frameworks, and international agreements influence energy efficiency in each country. This study aims to provide a comparative analysis of energy efficiency approaches in China and the United States, emphasizing their policy responses, technological advancements, and the resulting environmental impacts. The following sections will first detail the drivers of energy efficiency and the methodologies both countries used for this purpose, followed by an in-depth exploration of energy efficiency policies in China and the U.S., a discussion of international comparisons and best practices, and finally, recommendations and implications for policy making and sustainability in both nations.

2. The drivers of energy efficiency from a cross-cultural perspective

The first area to explore is, what drives energy efficiency. In a study conducted by Du, Matisoff, Wang and Liu in 2016 investigating energy efficiency across Chinese provinces, the factors driving the changes in energy efficiency were researched. In particular the study explored the

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influence of political, economic, and social factors on energy efficiency improvements. This provided insights into how provincial-level differences and policy interventions can impact energy efficiency. The particular research addresses a critical gap by analyzing the impact of R&D expenditures, economic openness, government expenditures, population density, and education levels on energy efficiency in the unique context of Chinese provinces, where diverse political and economic conditions may lead to different outcomes compared to other regions. It was found that higher R&D expenditures and greater openness lead to improvements in energy efficiency, although their combined effect is less beneficial. Government spending improves energy efficiency, but high growth rates driven by government intervention reduce these gains. Higher population density negatively impacts energy efficiency, while post-primary education positively influences it. Additionally, energy efficiency improvements in one province tend to spill over to neighboring provinces [11, 12].

Du, Matisoff, Wang and Liu [11] study utilizes data envelopment analysis (DEA) and panel data econometric methods to assess the relative efficiency of Chinese provinces over time and identify key factors driving efficiency improvements. However, the paper acknowledges the existence of potential biases from spatial weights matrices and the unique context of China, which might not be directly comparable to other regions. For example, another study by Su [13] that utilizes the same methodology with Du et al's [11] work, assesses energy efficiency across countries, identifying key factors influencing improvements. The study highlights drivers such as GDP growth, renewable energy adoption, and electrification, while noting barriers like climate conditions and industrial development stages. By applying DEA, Su compares the efficiency of countries, considering factors like economic structure, policies, and environmental challenges, providing a benchmark for each country's performance in energy efficiency [13]. However, the author acknowledges potential biases, particularly from spatial weights matrices that may skew results by not accounting for spatial dependencies between countries. Additionally, the unique political, economic, and environmental contexts of each country—such as China's rapid industrialization—mean the study's findings may not apply universally to other regions. The paper suggests that the methods used may need to be tailored for countries with different conditions [13].

While the aforementioned debate sheds light upon the drivers of energy efficiency and improvements, González-Torres, Pérez-Lombard, Coronel, and Maestre [14] introduce a pyramidal approach to analyze the factors influencing energy intensity across different countries, focusing on the supply side of the energy system. Their study finds that improvements in energy efficiency are mainly driven by demand-side changes, while shifts in the energy supply side—especially due to electrification—have led to less favorable structural changes, particularly in emerging economies. While their approach provides valuable insights into global trends, they

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suggest that more cross-country comparisons are needed to refine their analysis. The different contexts, such as varying energy policies, infrastructure, and economic structures, highlight the complexity of energy efficiency drivers across nations. The authors suggest that incorporating data from both developed and developing countries would offer a fuller picture of the factors impacting energy use [14].

Lastly, another study that investigates energy efficiency from a cross-cultural perspective is Reddy and Assenza's [15] paper, in which they create a framework that examines the complex factors influencing energy efficiency investments. They use an actor-oriented approach, categorizing barriers and drivers from the perspectives of three key levels: micro (individuals or end-users), meso (organizations), and macro (state, market, civil society). This classification aims to provide a more holistic view of the challenges and motivations for improving energy efficiency, highlighting how various actors, such as policymakers and investors, influence these factors. The study identifies barriers such as financial, legal, and informational constraints that hinder energy efficiency, and drivers like economic incentives, technological advancements, and policy support that facilitate it. The authors argue for targeted interventions at each level to overcome obstacles and stimulate energy efficiency investments. Finally, they stress on the importance of addressing market failures, government intervention, and the removal of technical and non-market barriers to fully realize the potential of energy efficiency technologies.

Considering the aforementioned studies, a large number of drivers of energy efficiency have been identified. Awareness of these drivers can assist countries, economies and governments to further promote and establish energy efficiency and adapt it according to their needs. A table outlining all the drivers of energy efficiency identified is presented below (Table 1).

Table 1: A summative table of the drivers of energy efficiency from the studies above; single country studies versus cross-cultural studies

Study	Study type	Drivers of energy efficiency
Du, Matisoff, Wang & Liu (2016)	Single Country (China)	- Higher R&D incentives - Greater economic openness - Government spending and funding - Post-primary education - Provincial spillover effect - Trends on energy prices - Level of technological and innovation openness (on a provincial level) - Interactions between regions (trade, technology diffusion, knowledge spillovers, and factor (e.g. capital, labor and energy) flows, may lead to greater geographically interdependent regions)

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		(p.1199)
Su (2023)	Cross-Cultural	- GDP growth - Renewable energy adoption - Electrification - Trade openness - Population and urbanization levels - Climate factors - Industrial expansion
González-Torres et al. (2021)	Cross-Cultural	- Demand-side changes - Policy - Infrastructure - Economic Development - Advances in energy efficiency in power plants - Renewable electrification - Access to natural resources - Coal phase out - Energy intensity improvements and requirements
Reddy & Assenza (2013)	Cross-Cultural	- Economic incentives - Technological advancements and relevant price levels - Policy support - Targeted interventions to to stimulate Energy Efficiency initiatives and practices -Removal of technical and non-market barriers. - Increase in energy prices - Environmental regulations

3. Energy efficiency, economic productivity and the impact of technology

To further explore the impact and importance of energy efficiency, the economic and technological implications have to be considered in further detail. A study from Laitner [16] investigates the relationship between energy efficiency and economic productivity in the United States, specifically examining how advancements in energy efficiency can not only bolster economic resilience but also facilitate significant reductions in greenhouse gas emissions. The study analyzes historical trends in energy efficiency since 1970 and its correlation with U.S. economic growth, while also evaluating the effectiveness of existing energy policies in fostering such efficiency. Analyzing historical trends in energy efficiency can show how past practices and policies have shaped current economic and environmental outcomes. The research uses literature review to identify gaps, followed by quantitative data collection on energy consumption, GDP,

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and energy efficiency from reliable sources. They conduct a trend analysis to find correlations between energy efficiency and economic indicators. Additionally, they model projections of future scenarios based on varying investments in energy efficiency and assess impacts on economic growth and emissions. They use qualitative case studies to provide context and illustrate successful policies and technological advancements. The U.S. economy has significantly underperformed in energy efficiency, achieving only 14% efficiency in converting high-quality energy into useful work. Historical data shows that improvements in energy efficiency have lagged over the past three decades, contributing to a weaker economy. The analysis suggests that focusing on energy efficiency rather than just energy supply can lead to substantial economic benefits and greenhouse gas emissions reductions, potentially achieving up to 60% of the needed reductions by 2050. The analysis effectively demonstrates how low exergy efficiency has impacted the U.S. economy and highlights the need for a shift in focus toward enhancing exergy efficiency. The U.S. economy is hindered by low energy efficiency (14%), leading to reduced resilience and growth. To improve this, the focus should shift from energy supply to enhancing exergy efficiency through better tracking and policy changes. This approach can address energy demands and reduce greenhouse gas emissions, potentially achieving up to 60% of needed reductions by 2050. Smart pricing and supportive policies and technologies are essential for boosting energy productivity and ensuring economic sustainability. The study interestingly mentions that energy efficiency remains a largely invisible resource and suggests the need for better tracking and policy focus by implicitly pointing to gaps in current approaches and infrastructure.

Following from the above points, a study by Ke Li and Boqiang Lin [17] investigates the impact of technological progress on energy productivity in China, focusing on how different types of advancements, such as Hicks-neutral and capital-embodied technologies, influence energy efficiency. The research examines data from 30 Chinese provinces between 1997 and 2012, analyzing both direct and indirect effects of technological progress on energy productivity. The study employs econometric models to assess these relationships, considering factors like energy price fluctuations and changes in manufacturing structures and processes. The results indicate that neutral technological progress and improvements in manufacturing structures positively impact energy productivity and efficiency, leading to greater economic opportunities. However, while direct technological advancements enhance energy efficiency, their indirect effects through manufacturing optimization are less beneficial. Technological catch-up, although not directly improving productivity, supports manufacturing optimization. Capital-embodied technological progress directly boosts energy productivity but is hindered by the rebound effect, which limits overall energy savings. The study emphasizes the need for advanced technologies and market reforms to optimize resource use. It suggests that energy price adjustments are crucial to maximizing energy efficiency benefits. In conclusion, the research highlights the complex

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interplay between technological progress and energy efficiency, underscoring the importance of comprehensive strategies to enhance energy productivity and reduce environmental impact.

Building on these findings, a more recent study by Aderibigbe, Ani, Ohenhen, Ohalete and Daraojimba [18] explores the role of Artificial Intelligence (AI) in enhancing energy efficiency. For both nations, prioritizing renewable energy and sharing innovative practices will be critical for reducing emissions and achieving sustainable energy use. For example, Aderibigbe et al. [18] have explored the use of AI in transforming energy efficiency. AI can be used especially in predicting electricity demand and supporting renewable energy. AI techniques such as machine learning (ML) and deep learning (DL) help improve accuracy, streamline operations, and lower emissions. Tools like Neutral Networks, Support Vector Machines, and AI models help balance energy supply and demand while also addressing climate risks. However, issues like poor data quality, complex integration, and challenges in adapting to changing conditions remain. Moving forward, the US and China can focus on considering improved AI tools for energy forecasting to boost renewable energy use and create cleaner, more efficient energy systems.

Despite recent advances, it is interesting to look at how shifts in energy use and technical change influences growth dynamics across different countries. For instance, Japan's post-oil crisis policies in the 1970s highlight how energy conservation efforts can initially drive energy-focused innovations, boosting growth as firms allocate research to high-return projects. However, as these energy technologies matured and became more efficient, the economy eventually faced diminishing returns. This led to a necessary shift toward labor-centric innovations, supporting continued growth when energy-related advancements reached saturation [19]. This example shows that while energy policies can drive growth at first, economies eventually need to diversify their research and innovation efforts to maintain long-term progress. This highlights the importance of adapting energy and research strategies over time to ensure balanced and sustainable growth.

It is helpful to look at how energy efficiency technologies (EST) and material saving technologies (MST) are adopted and their impact on firm performance in different countries and manufacturing contexts. In Germany, a study by Bunse, Vodicka, Schönsleben, Brülhart and Ernst [20], found that the adoption of ESTs significantly improved both operational efficiency and environmental performance, especially in industries like automotive and chemicals. This supports the focus of the current study, on the statement that more efficient firms tend to show better environmental performance. However, the economic benefits were not as immediate, as the initial investment in these technologies can be quite high. This suggests that while firms benefit environmentally, the financial payoff may take longer to achieve. In contrast, in developing countries like India, the adoption of energy-saving technologies (ESTs) has been slower, mainly due to financial challenges and a lack of awareness, particularly among smaller

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firms. While there is potential for significant improvements in resource efficiency, issues such as limited financial incentives and poor infrastructure prevent widespread adoption. However, some firms that successfully implemented ESTs experienced cost savings and reduced waste, even though the environmental benefits were not as significant as those seen in Europe. This shows that even in countries with fewer resources, energy-saving technologies can provide benefits, although these benefits might be less pronounced compared to more developed regions. The above examples demonstrate that the link between energy efficiency and company performance is influenced by several factors. While adopting ESTs and MSTs typically results in improved environmental outcomes, the economic impact varies across different regions. The success of these technologies depends on factors like government support, company size, and the specific industry.

More specifically, Wang and Wang [21] argue that in the European Union, countries like Germany and Denmark have successfully integrated renewable energy technologies into their industrial sectors, significantly improving energy efficiency while reducing carbon emissions. Germany's energy transition focuses on the promotion of green technologies and energy efficiency through innovation with measurable impacts on the country's energy productivity. Similarly, in Japan, technological advancements in energy-efficient manufacturing processes and smart grid technologies have led to considerable energy savings in both industrial and residential sectors. These international experiences highlight the importance of fostering innovation-driven development strategies and demonstrate the potential benefits of technological innovation for improving energy efficiency, offering useful lessons for China’s future policy development. By looking at these examples, China can identify best practices and use them in its economic and regional context to further advance energy efficiency goals.

Lastly, a study by Chen, Sinha, Hu, and Shah [22] shows that countries like Germany and Sweden have made significant strides in improving energy efficiency through technological innovation. Germany's "Energiewende" policy, which emphasizes the transition to renewable energy and improved energy efficiency, has played a major role in reducing carbon emissions and increasing the share of renewables in the energy mix. Similarly, Sweden has integrated smart technologies such as smart grids and energy storage systems to enhance energy distribution and consumption efficiency. These demonstrate how a combination of technological progress and strong policy frameworks can drive energy efficiency. For MENA countries, the experiences of these nations offer valuable insights for developing policies that promote innovation while also tackling the challenges posed by the shadow economy, which can hinder formal investments in energy efficiency.

The examples of Germany, Sweden, Denmark, Japan, and India show how the US and China can improve energy efficiency and reduce environmental impact. Both countries could benefit from

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adopting policies like Germany's *Energiewende*, which aligns innovation with energy goals and encourages green technology. They could also invest in smart systems, such as Sweden's smart grids or Japan's energy-efficient manufacturing processes, to optimize energy use. Addressing financial barriers, as India attempts to do, is another key lesson—offering subsidies or loans could help smaller firms adopt energy-saving technologies. Additionally, the slower financial returns seen in Germany highlight the need to focus on long-term benefits. By adapting these approaches to their unique challenges, the US and China can boost energy efficiency and address sustainability challenges through appropriate interventions, including energy conservation efforts.

4. Energy efficiency and conservation policies - challenges and opportunities from the US and China

In the landscape of energy efficiency, the next aspect to discuss is conservation policies. Conservation policies assist in addressing energy waste and promoting efficiency. Looking into a study from Dixon, McGowan, Onysko and Scheer [10] in order to assess the challenge and opportunities of energy efficiency and conservation policies, the impact and effectiveness of relevant policies has to be evaluated. Specifically, the study focuses on the case of the US, and they evaluate the Energy Policy Act of 2005 and the Energy Independence and Security Act of 2007 energy conservation and efficiency initiatives. The research aims to understand their role in shaping the country's energy policies, reducing greenhouse gas emissions, and promoting economic growth through energy efficiency and renewable energy development. The objective of Dixon, McGowan, Onysko and Scheer's [10] research is to provide a comprehensive analysis of technical, financial, and regulatory barriers, as well as the influence of market forces and political changes. The particular study offers insights and recommendations to improve the effectiveness of US energy policies and contribute to global energy sustainability efforts. What is particularly remarkable is a comparative analysis conducted with similar international policies to identify best practices and lessons learned.

In particular, the comparative analysis with international policies revealed that the U.S. could benefit from adopting best practices observed in other countries, particularly in terms of integrating renewable energy sources and fostering public-private partnerships. From their quantitative analysis they identified a notable reduction in greenhouse gas emissions, with estimates suggesting potential cumulative reductions of approximately 1,575 million metric tons of CO2 by 2030, attributable to advanced biofuel mandates and fuel economy standards. Through their qualitative analysis they identified significant improvements in energy efficiency in the transportation and buildings sectors, and challenges such as regulatory complexities and market fluctuations hindered progress. The study has documented that the aforementioned policies have led to significant improvements in energy efficiency in buildings, industry,

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transportation, and electricity generation through measures like integrated resource planning and efficiency standards. Recent legislation, including the Energy Policy Act of 2005 and the Energy Independence and Security Act, represents further advancements with the potential to impact oil imports and carbon emissions positively. While it is too early to assess the effectiveness of these laws, the expansion of clean energy initiatives is promising [10]. Ultimately, a focus on sharing successful practices and fostering communication is crucial for a sustainable energy future. The study acknowledges the complexity of measuring the overall impact of energy policies due to varying factors like market conditions and technological advancements and overall provides insights into the future prospects and ongoing challenges in the field [10].

In order to understand on a global scale, the challenges and opportunities of energy efficiency and conservation policies a further analysis of another country's case is discussed. China's case follows next. A study from Zhou, Levine and Price [23] has evaluated the effectiveness of China's energy efficiency policies implemented during the 11th Five-Year Plan, focusing on their impact on reducing energy intensity across various sectors. The study aims to understand the successes and challenges faced in policy implementation and to provide recommendations for enhancing future energy efficiency initiatives in the context of sustainable development and economic growth. The study utilized qualitative data from government reports and industry sources will be analyzed statistically to understand trends in energy use, GDP growth, and emissions, particularly focusing on the impact of the Top-1000 Energy-Consuming Enterprises Program. In addition, the authors provided qualitative insights gathered through interviews and focus groups with government officials and industry experts to explore challenges and perceptions of policy implementation. Case studies of successful energy initiatives were examined to extract lessons applicable to future sustainability efforts and improve policy. The research shows that China has made progress in energy efficiency through initiatives like the Top 1000 Program, which raises awareness among major industries. However, the goal of reducing energy use per unit of GDP by 20% is still difficult due to the growth of energy-heavy sectors like steel and cement. Challenges include weak enforcement, lack of financial incentives, and bureaucratic issues. Successful examples indicate that stronger enforcement and more financial support are needed for long-term success. Since 2006, China has developed a framework to enhance energy efficiency across its economy and key initiatives to do that include the Top 1000 enterprise program and a fund for energy efficiency investments. While it's uncertain if the goal of a 20% reduction in energy intensity will be fully met within five years, significant progress is anticipated. The success of the initiatives was stated to be dependent on how well these policies are integrated and sustained over time. The paper also acknowledges the ongoing nature of policy reforms and the challenges in fully achieving energy efficiency goals [24].

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In the U.S., market-driven solutions and partnerships between the public and private sectors are important, but the progress is often slowed by complex regulations and changing political priorities. Establishing a clear regulatory environment is essential for encouraging investment and innovation in sustainable practices. Simplifying regulations can facilitate the deployment of green technologies, while consistent political commitment creates a stable framework for progress. Additionally, effective communication and collaboration among stakeholders, including government agencies, businesses, and civil society, are crucial for aligning goals and objectives. Engaging communities in the decision-making process can enhance the legitimacy of policies, ensuring that diverse perspectives are considered [25]. China's strategy, on the other hand, is more centralized, with the government setting strict mandates, as seen in the Top 1000 Energy-Consuming Enterprises Program. However, enforcement can be inconsistent due to bureaucratic hurdles and the rapid expansion of heavy industries. This inconsistency leads to regional disparities, with cities like Beijing and Shanghai implementing stringent codes targeting up to 65% energy savings, while rural areas lag behind, affecting over 200 million households. The country's progress in enhancing building energy efficiency over the past two decades stems from careful planning, strong support from the central government, and a clear definition of stakeholders' responsibilities. Yet, challenges remain, including insufficient local support, financing difficulties for building retrofits, and regional disparities in implementation. As China continues to grow, achieving high energy efficiency standards in new buildings is vital to holding back overall energy consumption and greenhouse gas emissions. This will require a combination of regulatory measures, economic incentives, and public education on energy conservation [26].

Looking into both countries' cases, U.S. and China approach energy efficiency and conservation policies in ways that show their political and cultural contexts [10]; Zhou, Levine and Price [23], In a recent study by Young, Guttman, Qi, Bachus, Belis, Cheng, Lin, Schreifels, Eyndee, Wang, Wu, Yan, Yu, Zaelke, Zhang, Zhang, Zhao and Zhu [27] China addresses environmental issues through state planning and irregular criss responses outside of the Five-Year Plans, however, the U.S. relies on a law-centered approach that involves legislation, regulations, and court judgements as well as a federal systems that encourages policy innovation at different government levels both is national and sub-national levels. Both systems have strengths and weaknesses in tackling environmental challenges, however they demonstrate them under different conditions, and they are unlikely to align. Through the understanding of these two governance systems, we can see the importance of institutionalized governance processes in comparative politics research and the root causes of them that are both on political and cultural grounds. Both countries have seen successes and failures in their environmental governance. The U.S. has made progress in providing safe drinking water, reducing air pollutants like SO_2 and NOX, and cleaning up hazardous waste sites. Yet, it still faces challenges with agricultural

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fertilizers, algal blooms, and its high per capita greenhouse gas emissions. On the other hand, China has reduced sulfur dioxide emissions and improved energy intensity but faces severe environmental issues relating to air, water, and soil quality. Despite these challenges, however, both countries have worked together on environmental initiatives, such as phasing out ozone-depleting substances and working toward greenhouse gas emission reductions through joint agreements like the 2015 Paris Agreement. A significant milestone in their collaboration was the announcement during Obama's 2014 visit to China, where both countries agreed to coordinate efforts to reduce greenhouse gas emissions and work toward a successful outcome at the UNFCCC's COP 21 in Paris [27].

To conclude, both countries face the same challenge of balancing economic growth with sustainability when it comes to energy efficiency and conservation, but their approach differs. The U.S. could benefit from China's stronger enforcement, while China might learn from the U.S.'s collaborative, market-based approaches. By sharing these strengths, both nations could improve their energy efficiency efforts on a global scale. In the U.S., the environmental movement focuses on legal frameworks and public advocacy to promote sustainability. While grassroots initiatives have succeeded in areas like civil rights, environmental issues often struggle for attention. This leads to a sense of free riding, where individuals rely on others to address challenges like climate change. However, China's political culture limits effective social movements. Although the government responds to public crises, it hinders grassroots efforts. This results in a reliance on top-down regulations, which can enforce standards but may lack the adaptability seen in more collaborative approaches [27].

5. Policy making implications and interventions in energy efficiency from a cross-sectoral level

Policy making is a catalyst to promote energy efficiency. However, the nature, approach and purpose of energy inefficiencies need to be fully understood in order to ensure that the right approach is implemented. Transient energy inefficiency could be dealt through policies for short-term changes and solutions, while persistent energy inefficiency could be assisted through policies that address and deal with the structural issues. However, locations and sectors even in the same country can be facing both types of energy inefficiency at the same time and on the same scale. In a study by Filippini and Hunt [28] the authors defined and estimated energy efficiency for the 49 U.S. states through advanced econometric techniques. They provide evidence that suggests that relying solely on the type of energy inefficiency can mislead policymakers about the bigger picture of energy efficiency. Hence the authors analyzed energy demand through factors such as income, price, and weather conditions, and focused on the accuracy of traditional energy intensity measures compared to estimated energy efficiency. Their research used the Mundlak Random Effects Model and the Transient Random Effects Model to

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analyze panel data from 1995 to 2009. Data on various factors such as income, energy prices, population, household size, and weather conditions are included in the analysis in order to help them address unobserved differences between states, while to allow them estimate both persistent and transient energy efficiency. Also, statistical tests like the Hausman tests were used in their study to validate model specifications and assist in providing robust and reliable results for policymaking insights. The study found that weather impacts energy demand, with heating degree days being significant but cooling degree days not, while household size negatively affects energy consumption due to economies of scale. Notably, the rankings based on energy efficiency differ from those based on the intensity of energy inefficiency, with some states like California appearing inefficient despite their rankings of high energy efficiency as was previously observed by policymakers and other studies. Interestingly the study highlighted discrepancies between energy efficiency and energy intensity measures. While energy inefficiency may work as an indicator for some states, it can be misleading for others, such as California. Therefore, policymakers should use a more holistic analysis to guide funding for energy efficiency programs. Lastly the authors suggest stochastic frontier analysis as a valuable tool, though this needs further validation.

A more recent study by Alberini & Filippini [29] discusses the matter of energy inefficiency by evaluating residential energy efficiency among US households. The study compares the effectiveness of models in estimating energy inefficiencies and quantifies the levels of both persistent and transient inefficiency in household energy consumption. They use three stochastic frontier models (REM, TREM, and GTREM) to analyze energy consumption in US households, and incorporate variables like income, household size, heating and cooling degree days, and energy-efficient appliances. Each model captures different inefficiencies (persistent and transient) through distinct error term structures. They then use maximum likelihood estimation to compute efficiency scores and compare energy efficiency levels and insights into potential CO2 emissions reductions from efficiency improvements. Significant factors affecting energy efficiency are found to be the household characteristics, energy prices, and weather variables. Their research indicates that improvements in energy efficiency could lead to substantial CO2 emissions reductions, while they calculate the estimated energy efficiency levels across different models, identifying significant influencing factors, and noting the potential for CO2 emissions reductions. The study reveals a persistent efficiency average of 90% and a transient efficiency average of 83%. They then emphasize that modest improvements can significantly reduce energy use and CO2 emissions, while they recommend smart meters for real-time feedback, implement behavioral nudges, and establish stricter energy efficiency regulations. Educational programs and in-home energy audits can also guide households toward more efficient practices, highlighting the importance of well-designed policies to enhance energy efficiency.

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In the case of China, which is a Road and Belt country, the country is facing lower persistent inefficiencies than transient inefficiencies, indicating the need for more structural changes when we consider the type of inefficiency as the means to assess, design and implement interventions for policy making. In 2012 Kostka and Hobbs [1] examined the challenges of implementing China's Energy Savings and Emissions Reduction (ESER) policies at the local level, focusing on Shanxi province. Local officials struggled to balance national energy targets with regional economic needs. Officials used strategies such as reframing national goals to align with local growth objectives and leveraging formal and informal incentives to gain business cooperation. Shanxi used a relatively successful approach which involved "bundling" energy policies with local priorities. This approach was used in order to make sure of a smoother implementation through communication and a win-win situation. Later on, a study by Wu, Jiang and Hong [2] examined China's NEDC policy on Energy Utilization Efficiency (EUE) from 2007 to 2022 and found that the policy significantly improves EUE, particularly in non-traditional industrial bases and economically developed regions. The policy has also helped shift industries toward green, low carbon sectors and promoted technological innovations in energy management, production, and transportation. These changes have led to cleaner, more efficient production processes. Their research suggests expanding the policy to more cities, customizing it for different areas, and improving supervision to ensure ongoing process. Future studies should focus on spillover effects and how the policy affects sectors, businesses and individual behaviors.

One more element to consider particularly in the case of BRI (Belt and Road Initiative) countries (eg. China), is the effect that Foreign Direct Investment (FDI) has on energy efficiency. It has been observed that FDIs have had a minimal effect on improving energy efficiency convergence in BRI countries because of underdeveloped human capital and weak environmental policies. Many low-income nations lack the ability to fully utilize the advanced technologies that FDI brings, which prevents them from narrowing the technological gap and improving efficiency. In addition, weak environmental regulations in these countries often attract pollution-heavy industries from more developed regions. This reinforces the "pollution haven" phenomenon. To address these challenges, BRI countries, including China, need to prioritize human capital development, implement stricter environmental standards to discourage polluting industries, and foster regional cooperation to support cleaner energy and industrial advancements [30]. In addition, Gonzalez, Torres, Lombard, Coronel and Maestre [14] evaluate the impact of environmental policies on the efficiency of the energy systems, and they define the structural indicators that are important to explain the fluctuations in energy efficiency. They apply a pyramidal approach to their assessment and analyze the impact of energy intensity on energy inefficiencies. They suggest that such an approach could assist the guidance of further analyses and standardized energy efficiency interventions, while assisting with reporting. The scope of

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their study, however, aims at national level scale energy efficiency and climate policy making and interventions.

While understanding a country's context is important for national and international policy making, investigating the landscape of energy efficiency from a sectoral perspective aid to add a further level of analysis. A study by Sun, Xu and Yin [3] for example, examined the impact of China's 2009 gasoline-pricing reform on vehicle sales and fuel efficiency, highlighting energy efficiency advancements through pricing reforms in the automotive sector. Their research evaluated the effects of increased gasoline taxes and frequent price adjustments introduced in January 2009 on new vehicle sales and fuel economy in China. The authors analyzed gasoline price trends before and after the reform, measured consumer sensitivity to fuel costs, and simulated various pricing scenarios to inform future policies for enhancing automotive energy efficiency. Their quantitative study employs econometric models to assess the reform's influence on the Chinese automobile market by utilising monthly data from January 2008 to August 2013. The 2009 gasoline-pricing reform improved the average fuel economy of new vehicles in China by approximately 6.25% from January 2009 to August 2013. The gasoline tax increase accounted for a 3.43% improvement, while expedited price adjustments contributed an additional 2.82%. These results indicate a modest but significant impact of the reform on promoting energy efficiency in the automotive sector. Their study concludes that while the 2009 reform successfully improved fuel economy in the short to medium term, it fell short of achieving broader government energy efficiency targets. Hence it can be suggested that policymakers should implement additional measures to sustain long-term gains, such as incentivizing advanced vehicle technologies and influencing consumer behavior. Future research should examine extended impacts on market trends, including design innovations and shifts in purchasing patterns.

On a final note, an important study looked into the US and China's cases, by focusing on the commercial built environment, a sector that has attracted a lot of research interest for its contribution in energy consumption. Liu, Zhao, Liu and Wang [4] examined energy efficiency in high-performance office buildings in China and the U.S., focusing on discrepancies between actual and expected energy consumption and the factors driving these differences. Their study compared energy consumption across typical climate zones in both countries, identifying causes for these deviations and developing a correction model that accounts for climate conditions, indoor design temperatures, and architectural designs. Based on their data, this approach supports the creation of more effective energy efficiency strategies in the built environment. The researchers collected data from comparable office buildings, employing a correction model to adjust for regional differences, then measured and simulated energy consumption records were analyzed, with simulations conducted using DesignBuilder software. The findings revealed

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significant disparities in energy use, driven by factors such as U.S. buildings maintaining more comfortable indoor temperatures, leading to higher energy consumption, and differences in operational practices influenced by cultural and management norms. The correction model successfully clarified energy consumption trends, providing actionable insights. Their findings emphasize the importance of region-specific strategies to optimize energy efficiency in high-performance buildings. Considering their study, it can be suggested that it is important to consider intra-sectoral parameters within regional scales when it comes to policy making strategies in the specific sector. Therefore, recommendations could include China adopting advanced sector-specific technologies like automatic controls and heat recovery systems, while the U.S. could benefit from incorporating China's energy management practices on a regionalised grid.

6. Conclusions and Recommendations

In recent years, how to reduce energy wastage and establish efficiency of usage has become a popular international topic of discussion and of paramount importance in environmental protection. When looking at the two largest energy consumers on the planet, China and the United States account for the 21.9% and 17.7% respectively, of the total global primary energy consumption as documented in 2012 by BP's Statistical Review of World Energy [31], with this same trend continuing until this point [32]. With policies that predominantly focus on reducing the domestic consumption of fossil fuels, both regions could benefit from a series of recommendations for interventions and policy development. Both countries could utilize smart technology to provide real-time feedback to households and businesses. They can Integrate energy efficiency with local priorities by a "bundling" approach to align national energy goals with local economic and developmental priorities.

Considering the findings from the studies reviewed above, more holistic policy development and making approaches would benefit both countries. This would ensure that energy efficiency policies consider not only the type of inefficiency (persistent vs transient), but also factors like income, household size, energy prices, and weather conditions to improve effectiveness of policy implementation. While legislation has driven improvements in energy efficiency in the case of both countries, fostering collaboration and sharing best practices in a more proactive manner is critical to achieving long-term sustainability. Moreover, in order to enhance productivity and reduce CO2 emissions, countries should prioritize energy efficiency measures and adopt policies that support sustainable practices from a holistic perspective. And lastly, cities/regions with high carry-over inefficiencies within the countries should be prioritised by optimizing their energy stocks to align with best practices on a national level.

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Despite the common areas that both countries can consider for policy development, there are country-level recommendations that have been identified in this study that should be considered. In the case of China, the policymakers should consider:

1. Expanding energy efficiency policies to more cities
2. Prioritizing human capital development
3. Implementing stricter environmental standards
4. Adopting advanced sector-specific technologies
5. Increasing investments in renewable energy
6. Optimizing energy stocks and fostering innovation in energy technologies

While in the case of the USA, policy making and development should further:

1. Incorporate energy management practices from on a regional energy management approach
2. Promote stricter energy efficiency regulations
3. Expand clean energy initiatives and integrate renewable sources
4. Enhance public-private partnerships to effectively address evolving energy challenges.

Improving energy efficiency is an important global priority, especially for leading energy consumers like the United States and China. Both countries must adopt a more comprehensive approach to policymaking. Strategies like integrating national energy goals with local needs and using advanced technologies can drive significant improvements. China should focus on expanding its energy efficiency programs, enforcing stricter environmental rules, and adopting cutting-edge technologies. Whilst the U.S. can enhance its approach by implementing region-specific energy strategies, stricter regulations, and stronger collaborations between public and private sectors.

For both nations, prioritizing renewable energy and sharing innovative practices will be critical for reducing emissions and achieving sustainable energy use. For example, the recent advances in AI shed light to the transformative potential of AI in improving energy efficiency. By predicting electricity demand and supporting renewable energy integration, AI tools such as machine learning (ML) and deep learning (DL) can enhance accuracy, optimize operations, and reduce emissions. However, challenges like poor data quality and complex system integration must be addressed. Moving forward, both the U.S. and China should prioritize the adoption of AI tools for energy forecasting to accelerate the transition to cleaner, more efficient energy systems. This is an area that further research needs to be conducted and advanced.

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