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Article

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International Journal of Energy Economics and Policy

Reference: Mohamed, Erna Farina/Abdullah, Azlina et. al. (2024). Energy efficiency in developing countries : a systematic review of current findings and directions towards a net zero economy. In: International Journal of Energy Economics and Policy 14 (5), S. 495 - 508.
https://www.econjournals.com/index.php/ijeep/article/download/15719/8198/39309.
doi:10.32479/ijeep.15719.

IJEEP
INTERNATIONAL JOURNAL OF ENERGY ECONOMICS AND POLICY
EJ EconJournals
ISSN: 2146-4553

International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2024, 14(5), 495-508.

EJ EconJournals

Energy Efficiency in Developing Countries: A Systematic Review of Current Findings and Directions towards a Net Zero Economy

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Received: 18 January 2024 **Accepted:** 15 July 2024 **DOI:** https://doi.org/10.32479/ijeep.15719

ABSTRACT

In an era marked by growing concerns about climate change and sustainable development, the interconnection between energy efficiency, economic growth and environmental sustainability has emerged as a critical area of inquiry. This systematic literature review (SLR) examines a number of studies published between 2013 and 2023, concentrating on the multifaceted impact of energy efficiency on both economic growth and the environment. The primary objective of this review is to synthesize the existing literature to provide insights into the complex connections between energy efficiency and its impact both on the economy and the environment. In addition, this study investigates potential trade-offs and decoupling, particularly within the framework of developing nations. The PRISMA method was used in conducting the study which covered only journal articles published in Scopus and the Web of Science (WOS). As a result, 75 articles were reviewed - 23 articles for the growth impact, 37 articles for the environmental impact, and the remaining 15 articles, for both impacts and decoupling results. By critically analyzing research from the past decade, this review provides valuable insights for policymakers, researchers and practitioners working towards a sustainable and low-carbon economy.

Keywords: Energy Efficiency, Developing Countries, Systematic Literature Review, Net Zero Economy, Decoupling, Impact
JEL Classification: O44; Q43, Q48; Q56

1. INTRODUCTION

Since early industrialization, a persistent inquiry has revolved around the prioritization of either environmental concerns or economic growth. This predicament is continuously confronted by many developing nations around the world, as they navigate their paths towards a low-carbon economy while simultaneously striving for sustained economic progress. When a nation opts to embrace environmental protection policies at the expense of economic growth, it demands substantial efforts to find other suitable undertakings. However, research indicates that energy efficiency measures can, in fact, have the potential to bolster a country's GDP, stimulate economic activity, while improving energy intensity (Chen et al., 2023). Indeed, this might help mitigate the perceived trade-off between these two objectives, thus, attaining decoupling. Decoupling refers to a situation where a country can either reduce its total emissions as the economy grows (absolute decoupling) or experience slower emissions growth compared to economic development (relative decoupling) (Das and Roy, 2020). In other words, it means the economy can grow without harming the environment.

The fundamental principle of energy efficiency is grounded in the optimization of finite energy resources, ensuring the attainment of desired outcomes with minimal energy consumption. In practical terms, it involves the strategic implementation of technologies, policies, and practices that facilitate reduced energy usage in the processes of distribution, production, and consumption, thereby promoting energy saving and environmental sustainability. Furthermore, at its essence, the concept of energy efficiency aims to sever the traditional connection between economic growth and upsurge energy demand. It promotes the idea of decoupling;

wherein economic progress can be pursued without a proportional raise in energy consumption.

Hence, energy efficiency has become an imperative in this modern world as nations grapple with the dual challenges of sustainable development and climate change mitigation. The efficient utilization of energy resources not only reduces CO_2 emissions, but also enhances economic productivity and improves the quality of life for people. It is evident that energy efficiency is also a significant factor for all three dimensions of sustainability, namely the environment, society and the economy (Uddin et al., 2023). In an era marked by growing energy demands and mounting environmental concerns, understanding the influence of energy efficiency in achieving decoupling is paramount. The importance of energy efficiency in mitigating climate change and securing a sustainable energy future has been accentuated in recent years. It has been a focal point of scholarly discourse in many energy economic studies as a cost-effective measure to decarbonize the economy and a key policy strategy to lessen the predicament inherent in energy security and energy-saving (Javid and Khan, 2020; Rajbhandari and Zhang, 2018; Zulkifli, 2021). Moreover, international climate agreements, such as the Paris Agreement, emphasize the pivotal role of energy efficiency in reducing greenhouse gas emissions (GHG). It has been named "the first fuel" for a sustainable economic and environmental goal by the International Energy Agency (IEA). Therefore, achieving this goal requires a deep understanding of energy efficiency relationships within the environment and economy as a whole.

This paper is structured into three parts: It begins by outlining the methodology employed, followed by a presentation of findings of a systematic literature review. This section is divided into two sub-sections which are: (i) the impact of energy efficiency on the economic growth and environment and (ii) energy efficiency and decoupling. The last section concludes the paper.

2. METHODOLOGY

The primary objective of this SLR is to comprehensively investigate and synthesize the journal publications regarding the impact of energy efficiency both on the economy and the environment. In addition, this study also aims to review the role of energy efficiency in achieving decoupling by ensuring economic growth can be achieved without environmental degradation.

Generally, Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) is used in many sustainability and energy efficiency SLR studies (Arshad et al., 2023; Batwara et al., 2023; Rehman et al., 2023; Saraji and Streimikiene, 2023). Similarly, this study also utilizes PRISMA as the main methodology in ensuring a comprehensive examination of literature reviews with its specific protocols of a 27-item checklist (PRISMA). The study has formulated a number of research inquiries and below are the specific research questions identified for this SLR:

RQ1: What are the impacts of energy efficiency on the economic growth in both developed and developing countries?

RQ2: What are the impacts of energy efficiency on the environment in both developed and developing countries?

RQ3: Can energy efficiency help achieve decoupling, especially in developing countries?

This SLR was conducted in four main phases of (i) searching, (ii) synthesizing, (iii) analyzing and (iv) reporting.

2.1. Phase 1: Search

The searching phase is a meticulous and vital stage in the synthesis of existing research. This phase is pivotal in identifying, retrieving, and screening relevant literature to ensure the comprehensiveness and reliability of the SLR.

Table 1 indicates the detail of research queries relating to energy efficiency impact. 2,701 articles were selected in this phase. It is also worth noting that the search queries also included "energy intensity". This is because it is one of most common indicators used in energy macroeconomic studies that have investigated energy efficiency impact (Abban et al., 2020; Akdag and Yıldırım, 2020; Akram et al., 2021; Bashir et al., 2020; Cantore et al., 2016; Go et al., 2019; Mahapatra and Irfan, 2021; Nam and Jin, 2021; Su, 2023). This indicator is employed as an inverse proxy to energy efficiency in their analyses.

2.2. Phase 2: Synthesize

Any journal publications encountered during the search phase that were deemed irrelevant or duplicative were subsequently eliminated. The selection process adhered to several specific criteria. Firstly, articles written in the English language were exclusively chosen for inclusion. Secondly, a meticulous examination of abstracts and keywords was conducted, with a focus on identifying articles directly pertinent to the central themes of "energy efficiency" or "energy intensity." Articles with vague or unclear abstracts were further excluded after a detailed review of their full content. Thirdly, journal articles lacking relevance to the macroeconomic level impact were also excluded from the selection. Figure 1 shows the flow of this research information. As a result, 75 papers were found to be relevant and retained for

Table 1: Searching mechanisms employed

Input	Content
Databases	Scopus and WOS
Keyword search within	"Titles", "Abstracts", "Keywords"
Subject area	"Energy", "Environmental Science", "Social Sciences", "Economics, Econometrics, and Finance" (for Scopus) "Agriculture, Biology, & Environmental Sciences", "Arts & Humanities", "Social & Behavioural Sciences" (for WOS)
Main research queries	("energy efficiency AND "economic growth") OR ("energy intensity AND "economic growth") OR ("energy efficiency" AND "environment") OR ("energy intensity"AND "environment") AND ("impact")
Time period	2013-2023
Source type	Research and review articles

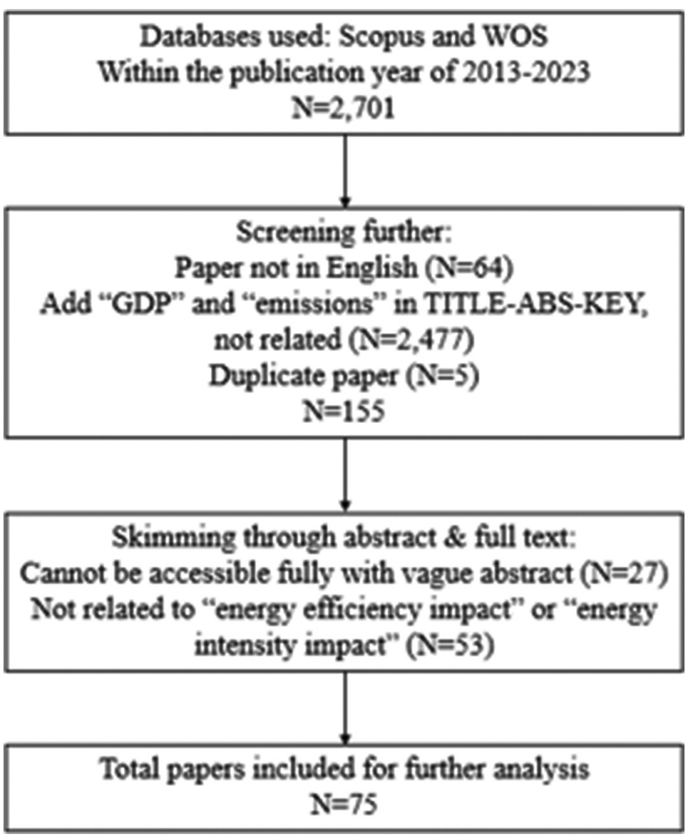
WOS: Web of sciences

the next stage. Four papers that could not be accessed fully were included due to clear and comprehensive abstracts covering the countries studied, the study period, method used and relevant findings. A number of papers that were removed mainly focused on the energy consumption impact, renewable energy, carbon intensity tax, and/or the relationship between CO_2 emissions and economic growth (Environmental Kuznet Curve (EKC) study). However, some papers that were EKC-related were included if they were augmented energy efficiency-EKC investigations. Table 2 illustrates the detailed criteria considered when choosing the related articles.

Table 2: Criteria for selected articles

Relevant criteria	Irrelevant criteria
("energy efficiency AND "economic growth") OR ("energy intensity AND "economic growth") OR ("energy efficiency" AND "environment") OR ("energy intensity" AND "environment") AND ("impact")	Papers not written in English
"energy efficiency" "energy intensity" "growth" "GDP" "environment" "emissions" "impact" in the titles, abstracts, and keywords	Duplicate papers in all databases
"econometrics" "input-output" "regression" "macroeconomic"	Papers that are not related to "energy efficiency" or "energy intensity" Papers that are not related to the macroeconomic level of analysis

Figure 1: Flow of research information



Then, the main information in articles was synthesized and classified into several categories. These included the journal, publication year, countries studied, study period, methods, and the main results of analyses. The distribution of journals is presented in Figure 2. Based on the 75 papers selected, *Journal of Cleaner Production* was found to be the most significant contributor to the energy efficiency impacts study with 12 published papers, followed by *Energy* with 6, while *Environmental Science and Pollution Research* and *Energy Policy* tied with 5 papers each. Furthermore, it is evident that the volume of research dedicated to investigating the impact of energy efficiency has shown a notable uptrend over the past decade. Of the 75 papers, the year 2021 stands out as the peak in terms of publication frequency, boasting a total of 16 publications, as shown in Figure 3.

2.3. Phase 3: Analysis

All selected articles were synthesized based on both the impacts of growth and the environment, as well as decoupling. All results also took into consideration and highlighted the countries' studied status - either developed, developing, high income or low income countries. The results of this phase are presented in the next section.

2.4. Phase 4: Report

This phase is crucial in ensuring all PRISMA checklist items were covered in the paper (Saraji and Streimikiene, 2023).

3. FINDINGS

This section discusses the findings on both energy efficiency impacts on economy and environmental in the first subsection, followed by its findings related to decoupling in both developed and developing countries, in the subsequent subsection.

Figure 2: Distribution of journal

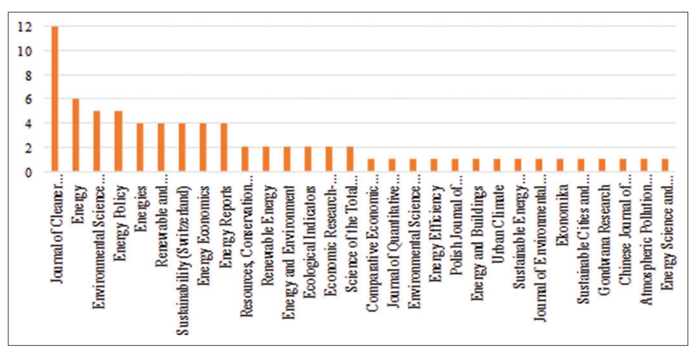
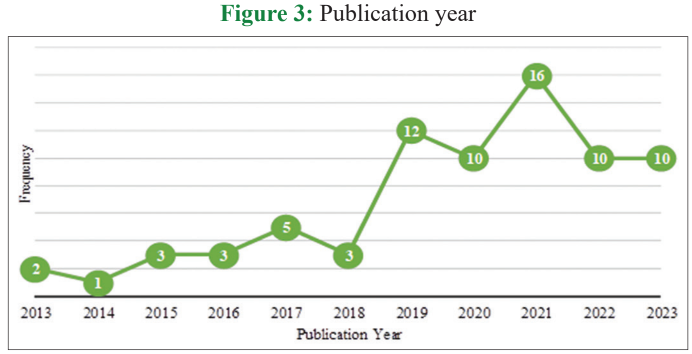


Figure 3: Publication year



3.1. Energy Efficiency Impact on Economy and Environment

3.1.1. Energy efficiency and economic growth and development

A substantial number of studies have explored the relationship between energy efficiency and economic growth. Consequently, the scholarly landscape has witnessed a burgeoning array of empirical inquiries delving into the relationship between economic growth and energy efficiency over the past decade. Nonetheless, concerns have arisen about the potential trade-offs between growth-oriented initiatives and environmental policies, concerns that are particularly pronounced in developing nations. Table 3 presents a summary of some relevant literature on the connection between energy efficiency and economic growth.

In the context of developing countries, pursuing both environmental goals and economic growth often presents a challenging trade-off. Many of these nations face the dilemma of prioritizing environmental sustainability while still striving for robust economic development. However, despite the "trade-off sceptics" in pursing both environmental and growth objectives, numerous studies have shown otherwise. Specifically, research conducted by Akram et al. (2021), Cantore et al. (2016), Go et al. (2019), Kadir et al. (2023), and Zhang et al. (2020), with a specific focus only on developing countries, demonstrate the positive influence of energy efficiency on economic growth and overall development. However, it is essential to note that the role of income inequality in these countries is pivotal to ensuring this positive impact. As emphasized by Sehrawat and Singh (2021) high income inequality may exert lower energy efficiency, hence, slower economic growth. This notion finds further support in Adom et al.'s (2021) work which identifies a significant positive impact of energy efficiency on economic growth, particularly in countries with low income inequality.

Furthermore, the heterogeneous effects of energy efficiency within various income groups were highlighted. As depicted in Table 3, the majority of studies have demonstrated the positive impact of energy efficiency in both developed/high income and developing/middle income countries. Notably, many studies have also unveiled a positive correlation between energy efficiency and high economic development. This trend is particularly evident among OECD countries, with studies by Sueyoshi and Goto (2023) and Ziolo et al. (2020), revealing that the most developed/high income nations exhibit higher levels of efficiency compared to many developing/middle or low income economies. Similarly, Bataille and Melton (2017), Hartwig et al. (2017), Zhang et al. (2021) presented the same results in Canada, Germany and 29 developed European countries, respectively.

In addition to this, economic growth is also regarded as a pathway to achieving improved energy efficiency status. Marques et al. (2019) and Rajbhandari and Zhang (2018) exemplify the bidirectional Granger causality between energy efficiency and economic growth, especially in high and middle income nations. Likewise, Irfan (2021) finds that growth encourages more energy efficiency in developing countries. Despite countless positive findings, in the same research, Irfan (2021) posits that the pursuit of growth might hinder energy efficiency in developed nations, thus revealing a contradictory relationship. In a similar vein, Ziolo et al. (2020) reports that energy efficiency may not have a full effect on sustainable economic growth. This situation primarily arises from the prevalent reliance on fossil fuels for energy consumption in most countries which significantly elevates energy intensity levels, consequently diminishing energy efficiency.

3.1.2. Energy efficiency and environment

In today's dynamic global landscape, the critical nexus between energy consumption and environment highlights the importance of energy efficiency. This reflects the substantial impact of energy efficiency, not only on the economy, but on the environment, emphasizing its role in mitigating environmental degradation. Table 4 provides an overview of 37 studies on energy efficiency and its environmental implication.

Drawing upon a comprehensive analysis of these 37 scholarly studies, a substantial body of evidence consistently supports the notion that energy efficiency measures can effectively mitigate environmental degradation. A majority of these investigations, encompassing approximately 60% of the studies, specifically concentrated on developing, middle income, and low income countries, reveal a positive relationship between energy efficiency and environmental well-being, with an exception to this trend being in a study conducted in Siberia, Russia, which noted insufficient data. However, it is worth noting that some studies in China have yielded differing results. While most studies have found positive (negative) correlation between energy efficiency (energy intensity) and environmental quality in China, Miao et al. (2019) highlights that energy intensity had no substantial impact on CO_2 emissions in two provincial areas due to rebound effects. Similarly, Lin and Benjamin (2019) conclude that in Shanghai, energy efficiency had a negative impact on CO_2 emissions in the short run but gradually improved in the long run.

However, these positive findings are supported in many developed countries -concentrated studies as shown in Table 4 above. In fact, the impact is more prevalent in developed or high-income nations, as validated by Mahapatra and Irfan (2021) in their study. Huo et al. (2015) also highlights that as China was reforming its economy and slowly developing, the energy intensity impacts on CO_2 emissions also significantly reduced. This indicates that, although energy efficiency is crucial for emissions abatement, it is necessary to have comprehensive efficiency policies that extend beyond the energy sector. Policies addressing broader aspects such as urbanization and industry are imperative to achieve more substantial emissions reductions.

3.2. Energy Efficiency and Decoupling

Khan et al. (2021) contend that the policy challenge facing many developing nations lies in reconciling environmental preservation and economic growth, creating a trilemma. Mahapatra and Irfan (2021) similarly note that energy efficiency initiatives lead to heterogenous emissions outcomes in developed and developing countries. While developed nations can decouple CO_2 emissions through substantial efforts, developing countries grapple with trade-offs. Table 5 shows some findings on decoupling and studies that investigated the impact of energy efficiency on both the economy and environment.

Table 3: Literature findings on energy efficiency and growth

Country	Author (s)	Studied period	Journal	Method (s)	Main result (s)
29 developing countries	Cantore et al. (2016)	2000-2005	Energy policy	Panel regression	Energy efficiency positively affects firm productivity and economic growth at both micro and macro level, respectively
15 developing Asian countries	Zhang et al. (2020)	1990-2013	Sustainability (Switzerland)	Panel ARDL, DEA application	Energy efficiency positively affects economic growth
7 developing countries	Kadir et al. (2023)	1990-2019	Energy efficiency	ALS-EG cointegration test and QARDL technique	Energy efficiency positively affects GDP
BRICS (Brazil, Russia, India, China, South Africa) countries (developing)	Sehrawat and Singh (2021)	1996-2015	Journal of Quantitative Economics	Co-integration test, econometric modelling	Long-term co-integrating relationship between economic growth, energy efficiency, income inequality, and corruption
BRIC (Brazil, Russia, India, China, South Africa) countries (developing)	Akram et al. (2021)	1990-2014	Energy	Fixed-effect quantile regression	Energy efficiency positively affects economic growth across all quantile mainly at 50th and 60th
51 African countries (high-middle and lower-income)	Adom et al. (2021)	1991-2017	Journal of cleaner production	Stochastic frontier analysis GMM	Energy efficiency positively affects economic growth, most significantly in lower income inequality countries
56 countries (high income, middle-income, low income)	Rajbhandari and Zhang (2018)	1978-2012	Energy economics	Panel vector auto regression	(i) Long run Granger causality of economic growth to lower energy intensity across all economies (ii) Bidirectional Granger causality between economic growth and lower energy intensity across high and middle income
62 countries (28 developed and 34 developing)	Irfan (2021)	1990-2017	Environmental science and pollution research	Panel Granger causality test, panel ARDL	(i) Energy efficiency positively affects GDP in long run for both developed and developing (ii) Growth discourages (encourages) energy efficiency for developed (developing) countries
44 countries (31 high income, 13 middle income)	Azhgaliyeva et al. (2020)	1990-2016	Energy policy	Cross-sectional regression	Energy intensity negatively associated with GDP
37 OECD countries (developed and developing)	Sueyoshi and Goto (2023)	2000-2019	Energies	DEA application	(i) Improvement in energy intensity positively affects economic growth (ii) Six most developed countries (France, Iceland, Japan, Switzerland, the UK, and the USA) presented the most stable status of full efficiency
OECD countries	Ziolo et al. (2020)	2000-2018	Energies	DEA application, regression	(i) Developed countries had higher TFEE than developing countries (ii) GDP has a positive long term impact on TFEE (iii) TFEE has no full effect on sustainable economic growth
11 EU countries (developed and developing)	Marques et al. (2019)	1997-2015	Journal of cleaner production	Non-liner ARDL	Bidirectional causality between energy efficiency and economic growth
35 European countries (developed and developing)	Pan et al. (2020)	1990-2013	Environmental science and pollution research	Cross-sectional regression	Energy efficiency positively affects economic development
19 European countries (mostly developed)	Kėdaitienė and Klyvienė (2020)	2000-2016	Ekonomika	PVAR	Short-term (long-term) negative (positive) effect of environmental policy (energy efficiency) on economic growth
29 Europe countries (all developed)	Zhang et al. (2021)	2010-2014	Journal of environmental management	DEA application	Most highly developed countries had the highest level of energy efficiency score

(Contd...)

Table 3: *(Continued)*

Country	Author (s)	Studied period	Journal	Method (s)	Main result (s)
127 countries	Napolitano et al. (2023)	1990-2014	Energy economics	Nonparametric DEA application, Hansen threshold model, regression	Energy efficiency positively affects countries' productivity performance mainly in high energy-efficient economies
46 countries	Su (2023)	2000-2020	Energy policy	Panel regression	GDP positively affects energy efficiency improvement
China (developing)	Zhao et al. (2022)	2003-2018	Renewable energy	Metafrontier-global-SBM super-efficient DEA model, spatial regression	U-shaped non-linear effect of energy efficiency-related environmental regulation on green economic growth
China (developing)	Sheng et al. (2021)	2005-2017	Energy reports	Tapio framework, nonparametric input-output	Productive efficiency in economic growth showed downward trend
China (Yangtze River urban agglomeration)	Zhong et al. (2020)	2008-2017	Sustainable energy technologies and assessments	SBM, Tobit regression model	Economic development positively affects energy efficiency
Malaysia (developing)	Go et al. (2019)	1971-2013	Energy and environment	ARDL	Energy efficiency Granger causes growth at the aggregate level not at disaggregate level
Canada (developed)	Bataille and Melton (2017)	2002-2012	Energy economics	Retrospective CGE	Energy efficiency positively affects economic growth
Germany (developed)	Hartwig et al. (2017)	Energy efficiency policy until 2012	Energy	Dynamic input-output model	Energy efficiency initiatives positively affect GDP

SBM: Slack-based model, CGE: Computable general equilibrium, PVAR: Panel vector auto regression, TFEE: Total factor energy efficiency, ARDL: Autoregressive-distributed lag, GMM: Generalized method of moments

Table 4: Summary of literature findings on energy efficiency and environment

Country	Author (s)	Studied period	Journal	Method (s)	Main result (s)
12 African countries (developing and low income)	Shahbaz et al. (2015)	1980-2012	Ecological Indicators	VECM Granger	Energy intensity positively affects CO_2 emissions
50 African countries (developing and low income)	Namahoro et al. (2021)	1980-2018	Renewable and Sustainable Energy Reviews	CS-DL and CCEMG	(i) Energy intensity positively affects CO_2 emissions (ii) Bidirectional causality between energy efficiency and CO_2 emissions
47 African countries (developing and low income)	Ibrahim et al. (2021)	2000-2014	Polish Journal of Environmental Studies	GMM	Energy intensity positively affects CO_2 emissions
Iran, Iraq, and Turkey (developing)	Shokoohi et al. (2022)	1971-2015	Energy	ARDL	Energy intensity positively affects CO_2 emissions in all three countries
10 industrialized countries (Brazil, China, India, Indonesia, Malaysia, Mexico, Philippines, South Africa, Thailand, and Turkey) (all developing)	Ghazali and Ali (2019)	1991-2013	Energy Reports	DCCE regression, STIRPAT	Energy intensity positively affects CO_2 emissions
BRIC countries (developing)	Qing et al. (2023)	2000-2019	Economic Research-Ekonomska Istrazivanja	MMQ	Energy efficiency negatively affects GHG emissions

(Contd...)

Table 4: ***(Continued)***

Country	Author (s)	Studied period	Journal	Method (s)	Main result (s)
66 developing countries	Akram et al. (2020)	1990-2014	Journal of Cleaner Production	Panel OLS, panel quantile regression	Energy efficiency negatively affect CO_2 emissions across all quantiles
MINT countries (developing)	Akram et al. (2022)	1990-2014	Energy Reports	Panel co-integration, nonlinear panel ARDL	(i) Asymmetric impact of energy efficiency on CO_2 emissions (ii) Energy efficiency negatively affects CO_2 emissions
MENA countries (mostly developing)	Ibrahim and Alola (2020)	2006-2016	Science of the Total Environment	DEA application, ARDL, PMG	Energy efficiency and economic growth negatively affects environment quality in the long run
South, South-East, and East Asian countries (mostly developing)	Hashmi et al. (2021)	1971-2014	Urban Climate	DSUR, DOLS, and FMOLS	(i) Energy intensity positively affects CO_2 emissions (ii) Bidirectional causality between energy efficiency and CO_2 emissions
APEC countries (developed and developing)	Zaidi et al. (2019)	1990-2016	Journal of Cleaner Production	Panel regression, CUP-BC, and CUP-FM	Energy intensity positively affects CO_2 emissions
147 countries (47 high income, 45 upper-middle income, 41 low-middle income, and 14 low income)	Liobikienė and Butkus (2018)	1990-2013	Science of the Total Environment	Dynamic panel regression	Energy efficiency negatively affects GHG emissions in all income countries
147 countries (47 high, 45 upper-middle income, 41 low-middle income, and 14 low income)	Liobikienė and Butkus (2019)	1990-2012	Renewable Energy	GMM	GDP, urbanization, and trade negatively affect CO_2 emissions at the technique effect mainly via energy efficiency
65 BRI countries	Liu et al. (2023)	2008-2020	Environmental Science and Pollution Research	Panel ARDL regression	Energy efficiency negatively affects CO_2 emissions in all countries
10 countries (developed and developing)	Arango-Miranda et al. (2018)	1971-2014	Energies	OLS regression	Energy intensity negatively affects CO_2 emissions
EU countries (developed and developing)	Deka et al. (2023)	1990-2020	Environmental Science and Pollution Research	CS-ARDL	Energy efficiency negatively affects CO_2 emissions
EU countries (developed and developing)	Nepal et al. (2021)	1980-2018	Energy Policy	Panel quantile ARDL	Energy efficiency negatively affects CO_2 emissions across all quantile
62 countries (28 developed and 34 developing)	Mahapatra and Irfan (2021)	1990-2017	Energy	Nonlinear panel ARDL	(i) Asymmetric long-term impact of energy efficiency on CO_2 emissions in both developed and developing countries (ii) Asymmetric impact of energy efficiency is more prevalent in developed than developing countries.
BRI countries	Abban et al. (2020)	1995-2015	Environmental Science and Pollution Research	Panel regression	Energy intensity has bidirectional relationship with CO_2 emissions in low, upper-middle, high income but one way

(Contd...)

Table 4: ***(Continued)***

Country	Author (s)	Studied period	Journal	Method (s)	Main result (s)
					in low-middle income countries
109 countries	Nam and Jin (2021)	2010-2017	Journal of Cleaner Production	Fixed-effect estimation model, quantile regression	Energy intensity positively affects CO_2 emissions
129 countries	Niu et al.(2017)	2002-2012	Energy and Environment	Panel co-integration, panel-based error correction models	(i) Long term co-integration between energy efficiency and environmental performance (ii) Energy efficiency positively affects environmental performance
China (developing)	Wang et al. (2021)	2004-2016	Energy Economics	Panel regression, Dynamic spatial econometric model (STIRPAT framework)	FDI through energy intensity positively affects CO_2 emissions
China (developing)	Bao et al. (2022)	1990-2014	Economic Research-Ekonomska Istrazivanja	Quantile-on-quantile regression, DEA application	Energy efficiency negatively affects CO_2 emissions
China (developing)	Cai and Fan (2019)	2012-2016	Sustainability (Switzerland)	DEA application	(i) Provinces with lowest energy efficiency had the worst air quality (ii) Provinces with high energy efficiency measurement had the highest emissions reduction
China (developing)	Du et al. (2022)	2000-2017	Chinese Journal of Population Resources and Environment	Decomposition model (Kaya specification), Decoupling model (Tapio framework)	Energy intensity positively affects CO_2 emissions from primary industry
China (developing)	Lin and Benjamin (2017)	1980-2010	Journal of Cleaner Production	Quantile regression	Energy intensity positively affects CO_2 emissions from the transportation sector
China, Beijing (developing)	Mi et al.(2015)	2010-2020	Journal of Cleaner Production	Input-Output	(i) Energy efficiency negatively affects energy intensity and CO_2emissions (ii) Energy intensity can be reduced with better energy efficiency adjustment and positively affect economic growth
China, Xinjiang (developing)	Huo et al. (2015)	1958-2010	Environmental Science and Policy	STIRPAT	(i) Energy intensity positively affected CO_2 emissions especially before the reform policy (ii) Energy intensity impact on CO_2 emissions lessened as the country reform and slowly developed
China, 3 regional areas) (developing)	Miao et al. (2019)	2000-2016	Journal of Cleaner Production	STIRPAT	(i) Energy intensity positively affects CO_2 emissions especially in central area

(Contd...)

Table 4: ***(Continued)***

Country	Author (s)	Studied period	Journal	Method (s)	Main result (s)
					(ii) Energy intensity has no impact on CO_2 emissions in eastern and western regions due to rebound effect
China, Xinjiang) (developing)	Dong et al. (2017)	1989-2012	Sustainability (Switzerland)	STIRPAT, Rigid regression model	Energy intensity positively affects CO_2 emissions (but not too significantly)
China, Shanghai) (developing)	Lin and Benjamin (2019)	1990-2015	Journal of Cleaner Production	Quantile regression	Energy efficiency positively affects CO_2 emissions from the industrial sector in the long run (negative impact in short run)
China, 30 provinces (developing)	Li et al. (2022)	2005-2019	Sustainable Cities and Society	Tapio framework, panel threshold model	(i) Worst decoupling happened in four periods mainly due to recessions and higher growth of CO_2 emissions (ii) Higher energy efficiency level indicates better reduction of CO_2 emissions
Portugal (developing)	Sowah et al. (2023)	1990-2020	Sustainability (Switzerland)	Non-liner ARDL	Energy efficiency negatively affects CO_2 emissions
Russia, Siberia (developing)	Pyzheva et al. (2021)	N.A	Energies	STIRPAT	Energy efficiency has no significant impact on emissions (air pollutant)
Türkiye (developing)	Shahbaz et al. (2013)	1970-2010	Renewable and Sustainable Energy Reviews	VECM Granger	Energy intensity positively affects CO_2 emissions
Czech Republic, Hungary, Poland, and Slovakia (developed)	Wawrzyniak (2020)	1993-2016	Comparative Economic Research	LMDI decomposition, Kaya specification	(i) Energy intensity positively affects CO_2 emissions in all four countries (ii) Energy efficiency policy in all countries could negatively affect CO_2 emissions
G7 countries (developed)	Bampatsou and Halkos (2019)	1993-2016	Energy Policy	DEA application, regression	Energy inefficiency positively related with GHG

OLS: Ordinary least squares, CUP-BC: Continuously updated bias-corrected, CS-DL: Cross-sectional augmented distributed lags, GMM: Generalized method of moment, ARDL: Auto-regressive distributed lag, DCCE: Dynamic common correlated estimator, MMQ: Moment quantile regression, PMG: Pooled mean group, DSUR: Dynamic seemingly unrelated regression, DOLS: Dynamic OLS, FMOLS: Fully modified OLS, CUP-FM: Continuously updated fully modified, LMDI: Logarithmic mean divisia index, NA: Not available, BRIC: Brazil, Russia, India, China

Compared to studies that mainly concentrated on one implication (either the economy or environment), studies that focus on both impacts found interesting findings and the heterogeneity across different income levels were pronounced. Unlike developing countries, decoupled has been mainly achieved in developed nations as illustrate by Juknys et al. (2014) in the EU, Zhao et al. (2022) in 29 developed countries, as well as Razzaq et al. (2021) and Wang et al. (2019) in the United States. Nevertheless, it is intriguing to observe that countries, primarily developed nations, with comparatively high energy efficiency levels also exhibit high CO_2 emissions (Chen et al., 2023; Lu et al., 2019).

It is also interesting to note that most developing countries in the above studies have shown negative decoupled from emissions. While energy efficiency initiatives may contribute to environmental improvements, they seem to yield a divergent impact on economic growth. A study in China by Pan et al. (2022) indicates that energy intensity policies would only negatively affect their growth in the long run. Likewise, Zhang et al. (2013) finds that energy efficiency policies had no significant impact on their growth despite its positive contribution to reduced emissions. Similar findings were also found in Iran (Zanjani et al., 2022). This scenario can be largely attributed to the rebound effect. Dong et al. (2021) investigates factors influencing the decoupling index and

Table 5: Summary of literature findings on both energy efficiency impacts and decoupling

Country	Author(s)	Studied period	Journal	Method(s)	Main result(s)
27 OECD countries (developed and developing)	Pata et al. (2023)	2000-2019	Energy and buildings	Panel regression	Negative long term correlation between economic growth and CO_2 emissions with energy efficiency
10 most energy-efficient countries (Germany, Ireland, Denmark, the UK, Norway, France, Austria, Italy, Mexico, and Australia)	Chen et al. (2023)	1990-2019	Gondwana Research	IPAT framework, panel regression	Energy intensity positively affects economic growth and CO_2 emissions
Estonia, Latvia, Lithuania (Baltic countries, developing), Bulgaria (upper-middle income), Luxembourg (developed/high income)	Štreimikiene and Balezentis (2016)	2004-2012	Renewable and Sustainable Energy Reviews	Kaya specification, Decomposition analysis (Shapley value)	(i) Decrease in energy intensity positively affects GHG in all studied countries (ii) Most noticeably in Bulgaria & Lithuania (less developed compared to others) (iii) No decoupling found in Baltic countries
EU countries (developed and developing)	Juknys et al. (2014)	N.A	Journal of Cleaner Production	Review paper	Decoupling was achieved as energy efficiency initiatives improved in most EU countries (year 1991-2007)
29 countries (mostly developed)	Zhao et al. (2022)	2000-2018	Journal of Cleaner Production	LMDI, Tapio framework	(i) Energy intensity positively affects CO_2 emissions (ii) Decoupling achieved and mostly maintained in the US, France, the UK, Hungary, New Zealand
48 high-income countries and China (developing)	Lu et al. (2019)	2010-2014	Energy Science and Engineering	Dynamic SBM model, DEA application	Countries with high energy efficiency produce more CO_2 emissions
China (developing)	Shi et al. (2022)	N.A	Energy	Bayesian network and scenario analysis	(i) Energy intensity positively affects CO_2 emissions (ii) Energy efficiency positively affects economic growth
China (developing)	Pan et al. (2022)	2017-2050 (simulation)	Energy	Multi-regional EDCGE	(i) Better energy intensity constraint target would negatively affect CO_2emissions (ii) More stringent energy intensity constraint target would also negatively affect economy
China (developing)	Zhang et al. (2013)	2000-2007	Renewable and Sustainable Energy Reviews	Econometric modelling	(i) Energy efficiency negatively affects emissions (ii) Energy efficiency improvement does not significantly affect GDP
China (developing)	Dong et al. (2021)	2000-2014	Ecological Indicators	Decoupling, decomposition model	Energy intensity positively affects decoupling index then negative at a later stage in some areas (mainly due to rebound effect)
China (developing)	Hu et al.(2019)	2002-2015	Journal of Cleaner Production	Stochastic frontier analysis, panel regression	(i) Energy efficiency negatively affects SO_2 emissions in the long run (ii) GDP positively affects SO_2 emissions in the short run
India (developing)	Sinha (2016)	2001-2013	Atmospheric Pollution Research	Panel regression	i) Bidirectional causality between SO_2/NO_2 emissions and energy intensity

(Contd...)

Table 5: ***(Continued)***

Country	Author(s)	Studied period	Journal	Method(s)	Main result(s)
					((ii) Bidirectional causality between SO_2/NO_2 emissions and economic growth (iii) Bidirectional causality between economic growth and inequality in energy intensity
Iran (developing)	Zanjani et al. (2022)	1995-2015	Energy Reports	Complete maximum entropy approach	(i) Energy intensity positively affects CO_2 emissions (ii) Energy intensity has no impact on GDP
United States (developed)	Wang et al. (2019)	2007-2016	Resources, Conservation and Recycling	LMDI, Kaya specification	(i) Energy intensity effect accelerated the decoupling process (ii) Energy intensity negatively affects CO_2 emissions
United States (developed)	Razzaq et al. (2021)	1990-2017	Resources, Conservation and Recycling	Boot-strapping ARDL	(i) Energy efficiency positively affects economic growth (ii) Energy efficiency negatively affects CO_2 emissions

LMDI: Logarithmic mean divisia index, ARDL: Auto-regressive distributed lag, NA: Not available

found that energy intensity negatively affects the decoupling index mainly due to the rebound effect. This situation was also named by Brookes (1990) as the "efficiency fallacy" phenomenon. Although emphasizing and enhancing energy efficiency is crucial, it does not necessarily result in reduced energy consumption and emissions. Thus, a comprehensive approach incorporating multifaceted strategies and initiatives must be considered in conjunction with energy efficiency enhancements to ensure sustainable economic growth.

4. DISCUSSION AND CONCLUSION

This paper conducted a comprehensive review of 75 scholarly studies examining the impact of energy efficiency and its role in achieving decoupling. The majority of these studies affirm a positive correlation between energy efficiency, economic growth, and environmental improvement. Nevertheless, the magnitude of this impact is more significant in developed countries compared to their developing counterparts. Decoupling, in particular, is predominantly observed in developed nations, while many upper-middle-income countries are transitioning slowly towards a state of weak decoupling (Apeaning, 2021). This notion was supported in a comparison study by Wu et al. (2018), in which they found that strong decoupling was mainly observed in developed countries rather than developing countries.

One of the pivotal factors in achieving strong decoupling is the enhancement of energy efficiency (Kulionis and Wood, 2020). Developed nations like the United States, Germany, the United Kingdom, France, and Japan, were actively pursuing energy-saving goals by adopting energy-efficient technologies across various sectors. In contrast, developing countries encounter barriers stemming from technological and knowledge gaps that impede the adoption of green technologies and sustainable practices. Many developing nations struggle to transition towards cleaner and more efficient production processes due to limited access to green technologies and financial constraints. Many energy efficiency policies, both in developed and developing economies, tend to overlook the trade-offs in societal and environmental aspects, including an unjust economic burden on consumers and business as a result of adopting energy-efficient technologies (Dunlop, 2022). For developing countries, particularly, economic constraint is the main issue. Shifting away towards more sustainable alternatives can be economically challenging, as it may require significant investments and restructuring the economy. In addition, Abban et al. (2020) assert that the weak enforcement of environmental standards in developing countries serves to explain these challenges, despite international collaboration on environmental issues.

Nevertheless, the attainment of absolute decoupling remains a subject of ongoing academic discourse, even in the context of developed nations. The world has experienced relative decoupling as emissions per unit of GDP have slowly decreased over the past 60 years. However, only a few countries have achieved absolute decoupling, that too for only a short period of time, eg the UK and Denmark (Brockway et al., 2021). One of the main critiques regarding the ineffectiveness of energy efficiency policy is the narrow focus on techno-economic aspects, leading to a bias in favour of economic interests (Dunlop, 2022). This may result in overlooking of other crucial elements such as human behaviour, societal norms, and institutional structures. This narrow focus may lead to a limited perspective on the complex nature of energy efficiency challenges, which are integral to a holistic energy efficiency strategy.

The challenge of arriving at a conclusive understanding of the impact of energy efficiency on both the economy and the environment arises from variations in the methodologies employed, the use of different independent variables related to energy efficiency, and the sensitivity of study results. Moreover, some studies tend to overlook the rebound effect in their analyses which can lead to an overestimation of potential energy savings and an underestimation of actual energy consumption. Various studies offer differing interpretations of energy efficiency, with some assuming it as a direct improvement in energy productivity without associated costs, while concurrently showing a decrease in energy intensity (Brockway et al., 2021). However, the effect of energy efficiency can vary depending on the magnitude of the rebound effect. This is significant because the rebound effect can counteract the efficacy of energy efficiency, especially at the macroeconomic level, where economy-wide rebound effects may occur. Furthermore, there are critiques regarding the quantitative assessment of energy efficiency, often measured as a ratio. This measurement is considered problematic as it tends to overlook the rebound effect and may not accurately reflect the actual measurement of total energy consumption. This is because an improvement in efficiency in specific technologies does not necessarily translate to an overall reduction in total energy consumption. The deterministic narratives promoting the economic development through energy efficiency may limit the exploration of comprehensive sustainable pathways (Dunlop, 2022).

Efforts aimed at enhancing energy efficiency remain crucial in the transition to sustainable economic growth and the realization of absolute decoupling. Nonetheless, it is imperative to recognize that relying solely on energy efficiency measures may not be sufficient. A holistic approach, involving multifaceted policies, is required to advance the state of decoupling. This challenge persists, not only for developed nations, but is particularly significant for developing countries due to factors like resource scarcity, technological gaps, socio-economic inequalities, and policy barriers. Developing nations should prioritize the enhancement of their industrial structure through the adoption of sustainable and environmentally friendly production policies. This approach will help optimize resource utilization, minimize waste generation, and ensure the implementation of circular economy principles. The imperative of reinforcing sustainable policies and governance cannot be overstated, particularly in the context of most developing countries. Key areas of focus and improvement include the establishment of robust environmental regulations, the strengthening of institutional capacity, and the development of effective financing mechanisms. Additionally, fostering international collaboration is essential for bridging technological and knowledge gaps by facilitating technology transfer and capacity building. This collaborative effort is vital, not only at the national level, but also on a global scale to expedite the process of decoupling economic growth from environmental degradation.

5. FUNDING

This study was funded by Dato' Low Tuck Kwong International Energy Transition Grant (202204002ETG).

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