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Integrating Renewable Energy and NZEB Standards in the EU: A Multi-Factor Analysis

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Abstract

Buildings account for approximately 40% of total global energy consumption, making them a significant contributor to energy demand. Net Zero Energy Buildings (NZEBs) have emerged as a critical area of interest due to the depletion of conventional energy resources. However, the lack of a universally accepted definition of NZEBs presents challenges in fully understanding the concept. This paper aims to provide a comprehensive perspective on the development of NZEBs in the European Union (EU), along with an overview of the relevant guidelines. Additionally, the study examines the influence of climatic conditions on the development of NZEBs across different EU regions. The paper defines various NZEB concepts outlined by the Energy Performance of Buildings Directive (EPBD) to assess their implementation across EU Member States. Furthermore, it presents an analysis of renewable energy technologies and their benchmarks in different EU countries. A detailed quantitative assessment of renewable energy technology installations in the Member States is also provided to support the development of NZEBs in the EU. The study compares different strategies for reducing energy demand while offering valuable insights into the strategic development of NZEBs across Member States. The findings contribute essential knowledge for policymakers and stakeholders seeking to understand the economic landscape of transitioning to NZEBs and optimizing the use of renewable energy resources.

Keywords

NZEBs; Renewable resources; EU; Cost analysis

1. Introduction

The demand for energy continues to increase annually due to population growth and technological advancements. This is primarily because energy is a fundamental human necessity. According to the International Energy Agency (IEA) report, in 2018, global energy consumption was double that of 2010. Due to this rising demand, carbon dioxide emissions have significantly increased, ranging from 1.7 Gt to 33.1 Gt (IEA, 2019). It is now imperative to conserve more energy, particularly given the rise in indoor activities (Yi et al., 2020; Dong et al., 2020; Li et al., 2020). Additionally, buildings account for 40% of total energy consumption and one-third of primary energy use (Directive 2002/91/EC of the European Parliament and of the Council on the Energy Performance of Buildings, 2002; Shaikh et al., 2014; Janda, 2011). The rapid depletion of the ozone layer is one of the key drivers of climate change, a topic frequently emphasized in climate discussions (Elsaid et al., 2020a, 2020b; Shehata et al., 2020; Wilberforce, 2020).

In response to these pressing concerns, various strategic roadmaps have been implemented to mitigate fossil fuel depletion (Jouhara et al., 2018; Olabi et al., 2020a, 2020b, 2021; Elsaid et al., 2020; Egilegor et al., 2020;

Abdelkareem et al., 2021; Hossain et al., 2020; Rabaia et al., 2021; Sayed et al., 2020; Hossain et al., 2019). These efforts focus on developing efficient energy conversion technologies with minimal environmental impact (Abdelkareem et al., 2021; Olabi et al., 2020a, 2020b; Hossain et al., 2020) and promoting the adoption of environmentally friendly renewable energy (RE) sources (Rabaia et al., 2021; Sayed et al., 2020; Abdelkareem et al., 2018; Hossain et al., 2019).

Despite progress in environmental sustainability, the European Union (EU) remains a significant contributor to global greenhouse gas emissions, exceeding Africa’s emissions despite having a smaller population (748 million compared to Africa’s 1.3 billion). Although the EU's greenhouse gas emissions have decreased by 23.2% since 1990, critics argue that the projected 65% reduction target in carbon emissions by 2030 is unlikely to be met. Criticism has also been directed at bureaucratic reluctance to adopt the proposed 65% reduction, as advocated by the European Parliament, which falls short of the Paris Agreement’s goal of limiting global warming to below 1.5°C by 2050 (Aldieri et al., 2021).

A separate study examines the impact of climate policy on energy transitions in G7 and EU countries, revealing only a modest acceleration. Notably, recent low-carbon growth has been 50% slower than during 1980–1985. Given the increasing reliance on fossil fuels, achieving the 2035 decarbonization target poses significant challenges. The report also acknowledges the limitations of focusing solely on industrialized nations, recommending further research on the Global South to develop more comprehensive climate strategies (Suzuki et al., 2023).

Between 1990 and 2017, Alola et al. (2022) analyzed the impact of bureaucracy, socioeconomic factors, and fossil fuel consumption on environmental quality across 25 EU countries. Their findings indicate that rising carbon emissions from fossil fuel consumption negatively affect environmental performance. However, bureaucracy and socioeconomic factors positively contribute to environmental quality, underscoring the necessity for clean energy development and improvements in both bureaucratic efficiency and socioeconomic conditions within the EU to enhance environmental sustainability.

Hence, Riemer et al. (2023) introduce the concept of "sectoral benchmarking" to assess EU net-zero scenarios using energy intensity metrics. Their findings reveal considerable variations between system-wide models (EU TIMES, NEMESIS) and sector-specific models (ALADIN, FORECAST), particularly in transportation. Similarly, Backe et al. (2023) explore the impact of net-zero emission neighborhoods on Europe’s heat and electricity grid, concluding that large-scale technological investments are making European decarbonization increasingly cost-effective.

Another study examines the environmental impact of energy efficiency and renewable energy adoption in the United States and the EU from 1990 to 2019. Using Kernel-Based Regularized Least Squares, the research identifies substantial reductions in greenhouse gas emissions, particularly through improved non-renewable energy efficiency. However, the study also notes that urbanization and natural resource consumption increase emissions, particularly in the EU. Policy recommendations are provided for the United States, the EU, and global stakeholders to enhance sustainability efforts (Özkan, Alola, & Adebayo, 2023).

To mitigate environmental pollution and climate change, numerous initiatives have been launched to develop nearly zero-energy buildings (NZEBs) across the EU. Integrating smart energy solutions into nearly zero-energy homes can significantly reduce energy demands (Belussi et al., 2019). Since around 2000, extensive research has been conducted on nearly zero-energy buildings in the EU (Panagiotidou & Fuller, 2013). Currently, numerous computational and analytical studies are underway to evaluate the potential of nearly zero-energy buildings (Kosai & Tan, 2017; Wang et al., 2017).

Despite the extensive literature on energy efficiency, climate policies, and renewable energy adoption in the EU, a notable research gap persists regarding the holistic and interconnected factors influencing NZEB development. While existing studies focus on individual aspects—such as national definitions, compliance levels, and benchmark impacts—there is a lack of comprehensive research that integrates these elements to examine their collective influence on NZEBs. Furthermore, limited statistical analyses on the installation costs of various renewable energy resources across EU Member States highlight the need for a deeper understanding of the economic feasibility and challenges associated with NZEB adoption.

Existing literature predominantly addresses environmental concerns, climate targets, and policy implications. However, an integrated analysis incorporating the socio-economic, policy, and environmental dimensions of NZEB development remains scarce. This gap underscores the necessity for a multidimensional approach that considers both qualitative and quantitative aspects, ultimately fostering a more comprehensive and actionable understanding of NZEB development in the EU.

The present study aims to bridge this gap by adopting a holistic perspective that encompasses the diverse factors influencing NZEB implementation. By integrating these elements, this research contributes to a more robust and effective transition toward sustainable and energy-efficient building practices in the European Union.

1.1. Aim and Objectives

The aim of the current research paper is to provide a comprehensive assessment of the development of Nearly Zero Energy Buildings (NZEBs) in European Union (EU) countries, with a specific focus on national definitions, compliance with Article 9 of the Energy Performance of Buildings Directive (EPBD), European Commission benchmarks, and the statistical analysis of installation costs for various renewable energy resources.

Additionally, this research addresses the following objectives:

- To analyze and compare the national definitions of NZEBs across EU countries and evaluate the strategies employed in their development.
- To assess the levels of compliance with EPBD Article 9 among EU Member States and investigate how variations influence the NZEB development process.
- To examine the impact of European Commission benchmarks on building energy performance and renewable energy adoption in residential and office buildings, enhancing the understanding of their role in improving energy efficiency standards.
- To conduct a statistical analysis of the installation costs of different renewable energy resources across EU Member States, identifying trends, variations, and key factors influencing cost differences.

2. Methodology

ScienceDirect and Scopus were utilized in this study to conduct a comprehensive investigation of the latest advancements in Nearly Zero Energy Buildings (NZEBs) from 2000 to 2023. The primary sources of data for this review include EPBD reports (CA, Concerted Action EPBD, 2018), BPIE policy briefings (BPIE, 2021), Cravezero guidelines (CRAVEZERO, 2018), and existing literature on NZEBs (ZEROPLUS, 2019; NERO, 2019; CONZEB, 2019; Craft et al., 2017). Figure 1 illustrates the entire process of paper selection:

- What are the levels of compliance with Article 9 of the Energy Performance of Buildings Directive (EPBD) across EU Member States, and how do variations impact the progress of NZEB development?
- How do the building energy performance and renewable benchmarks set by the European Commission influence the construction and operation of residential and office buildings in the EU?
- What are the installation costs associated with different renewable energy resources across various EU Member States, and how do these costs affect the adoption and feasibility of NZEBs?

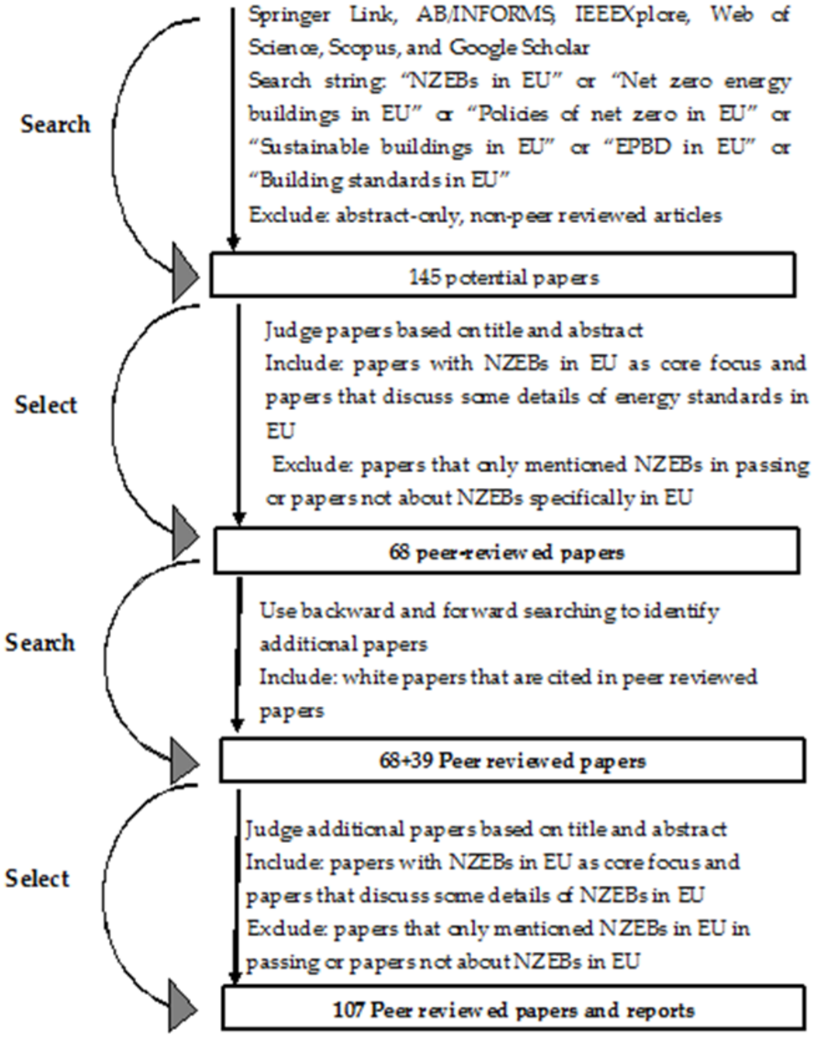

Figure 1: Complete methodology for the selection of articles (made by the author)

3. Strategies to develop NZEBs

Various approaches have been examined, re-tested, measured, validated, and evaluated to develop Nearly Zero Energy Buildings (NZEBs). To achieve optimal energy efficiency goals, it is essential to conduct payback period assessments and energy demand modeling. Figure 2 outlines the key conditions for achieving NZEB construction, based on research conducted across three major climate regions, as presented in Table 1.

Notable differences exist among these case studies: all of them incorporate photovoltaic (PV) systems for electricity generation and ensure high indoor thermal comfort levels. However, the specific criteria for NZEBs vary significantly between hot-humid, cold, and mild climate zones. Weather conditions play a crucial role in shaping building design and construction strategies across different temperature regions.

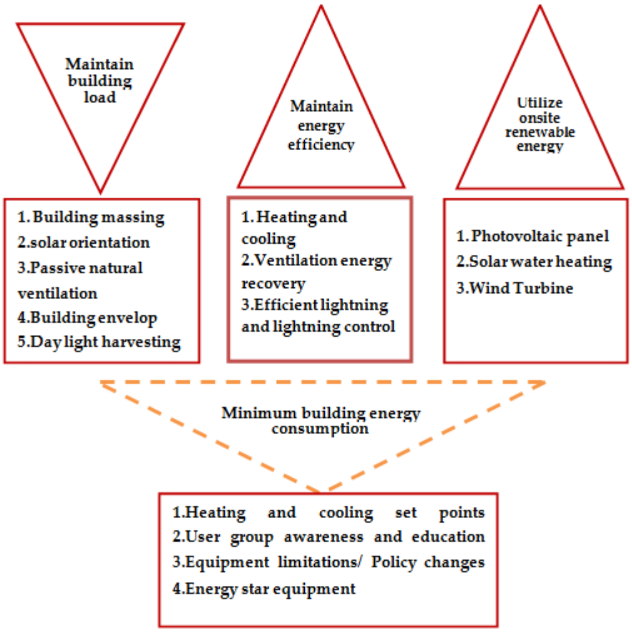

Figure 2: Strategies to develop NZEBs (made by the author)

Table 1: Requirements for NZEB development in different regions of the EU (made by the author)

Cold Climate Zone	**Moderate Climate Zone**	**Humid Climate**
Photovoltaic/BIPVT	Photovoltaic	Photovoltaic
Groundwater heat pump	Biomass boiler	Sun protection model
Growth and activation of thermal storage mass	Ecological building materials	Natural ventilation
Mechanical ventilation by heat recovery	Mechanical ventilation by heat recovery	Ceiling fans
Solar thermal collectors	Solar thermal collectors	Mechanical ventilation and dehumidifying
South oriented building	Acquiring shares in external wind power systems	Use of natural daylight
Large south-facing windows	South-facing windows/South-oriented building	Thermal mass applied in cautious amounts and must not be very thick
High thermal insulation	High thermal insulation	Lightweight structure
Passive charge concrete slab and brick wall	Passive solar heating and lighting	Building orientation for utilizing sea wind
Internal thermal mass	Internal thermal mass	
Heavyweight structure	Heavyweight structure	

4. Statistical analysis of Renewable energy sources and net primary energy requirement (BPIE, 2021)

In compliance with Clause 3 of Article 9 of the Energy Performance of Buildings Directive (EPBD), EU Member States must define their Nearly Zero Energy Building (NZEB) requirements in their national plans using numerical indicators of primary energy consumption per year. These indicators may vary across different building typologies within a country, depending on factors such as climate zones, HVAC systems, and building geometry. Member States have established specific criteria for various building types, taking these factors into account.

Figures 3–6 present the midpoint of the range, as well as the upper and lower limits, for primary energy consumption across EU Member States. The European Commission has carefully considered climatic variations both across the EU and within individual countries, ensuring that benchmarks reflect regional differences. In 2016, the European Commission established a benchmark threshold for NZEB primary energy consumption, accounting for the four major climatic zones: Mediterranean, Oceanic, Continental, and Nordic (European Union, 2016).

Figures 3–6 provide a summary of benchmark values for single-family houses and office buildings, facilitating a comprehensive review and comparison with established European Commission recommendations. The data indicate that net primary energy demand is lowest in countries with moderate climates, where the share of renewable energy sources is also the highest. However, across all four climatic zones, the variation in required building energy consumption remains relatively narrow, regardless of whether the energy source is renewable or non-renewable.

As shown in Figure 4, the net primary energy demand for single-family houses ranges from 50–90 kWh/m²/a, whereas for office buildings, it ranges from 80–100 kWh/m²/a. Among the four climatic zones, net energy demand is highest in the Nordic region and lowest in the Mediterranean.

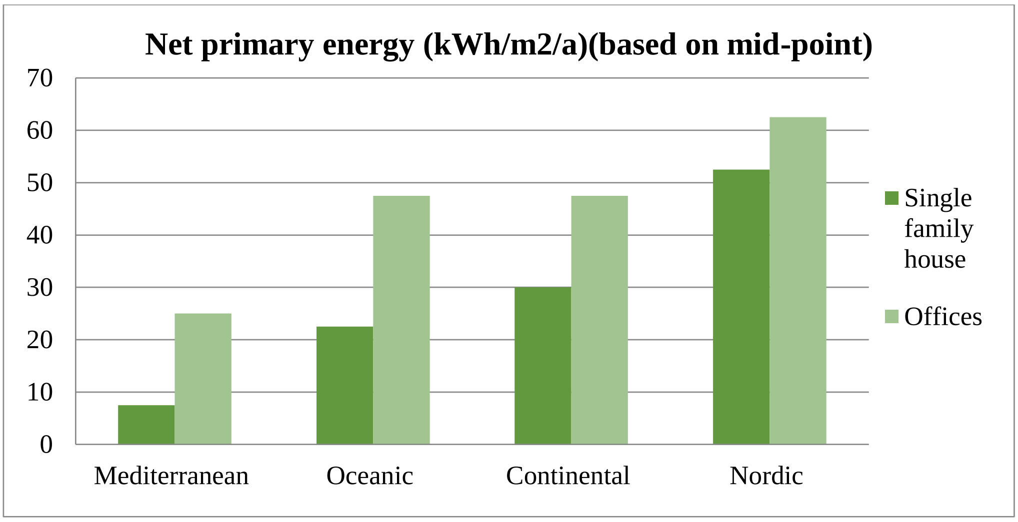

Figure 3: Net primary energy benchmark for different climatic zones in the EU (made by the author)

Figure 4 summarizes the benchmarks for energy supplied from renewable energy sources. For single-family houses in the Mediterranean zone, the benchmark is 50 kWh/m²/a, followed by offices, which have a benchmark of 60 kWh/m²/a. However, the lowest renewable energy requirement is observed in the Nordic zone, with values of 25 kWh/m²/a for single-family houses and 30 kWh/m²/a for offices.

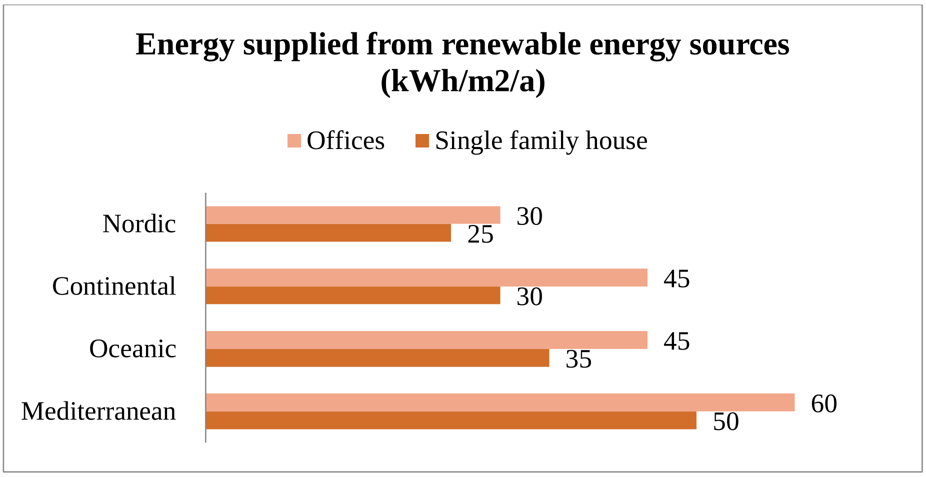

Figure 4: Benchmark of energy supplied from renewable energy resources for different climatic zones in the EU (made by the author)

Figure 5 presents the percentage of renewable energy as a share of total primary energy across different climatic zones in the EU. The highest share is observed in the Oceanic zone, accounting for 61%, whereas the Nordic zone has the lowest share, with a value of 32%.

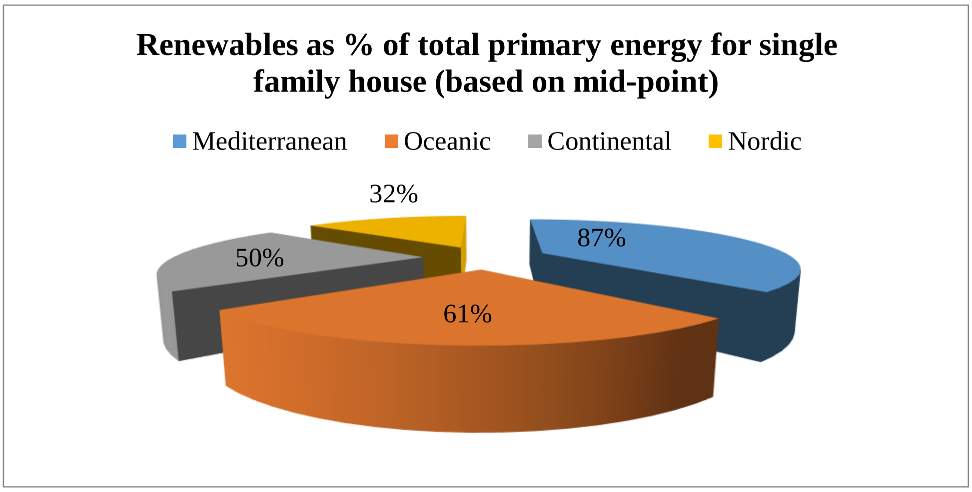

Figure 5: Benchmark of percentage of renewable energy for different climatic zones in the EU (made by the author)

Figure 6 illustrates the total primary energy demand, including both renewable and non-renewable sources. Among all categories, offices in the Nordic region exhibit the highest total primary energy consumption.

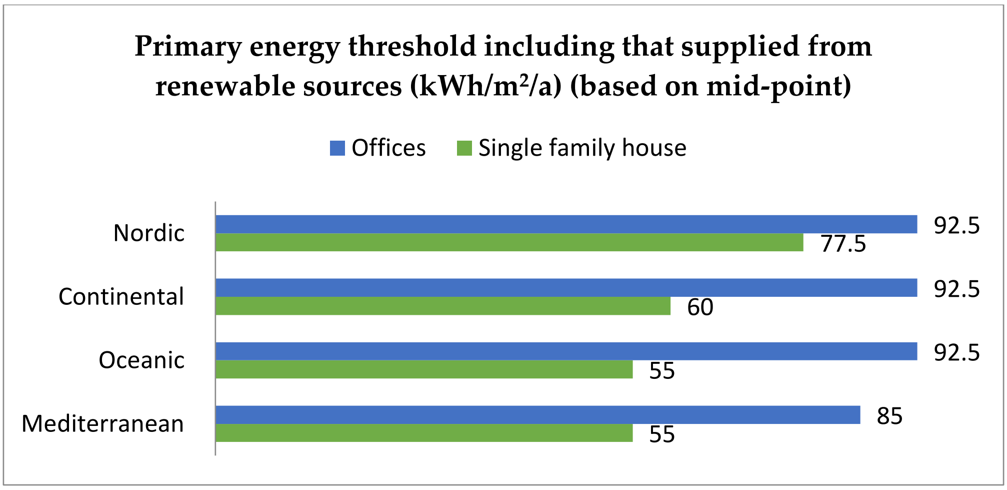

Figure 6: Benchmark of total primary energy for different climatic zones in the EU (made by the author)

The analysis reveals notable variations in renewable energy utilization and energy efficiency thresholds across different climate zones for both single-family houses and offices in EU Member States. The Nordic climate zone tends to have higher mean values for net primary energy, and energy supplied from renewable and primary energy thresholds, indicating potentially higher energy demand. The Mediterranean climate zone stands out with the highest percentage of renewable in single-family houses, emphasizing a stronger reliance on sustainable energy sources. These insights contribute to a comprehensive understanding of regional energy consumption patterns, facilitating targeted policies and strategies for achieving EU energy efficiency and sustainability goals.

5. Conclusions

This study analyzed and compared national definitions of Nearly Zero Energy Buildings (NZEBs) across EU Member States, assessing compliance with the Energy Performance of Buildings Directive (EPBD) and strategies for NZEB implementation. The findings confirm that the EPBD has set clear regulatory targets to reduce greenhouse gas emissions, increase renewable energy adoption, and mandate NZEB compliance for all new buildings from 2021 onwards. However, significant disparities remain among Member States due to variations in climate conditions, energy policies, and economic factors.

The analysis of EPBD Article 9 compliance revealed differences in public building legislation and primary energy consumption across EU Member States, emphasizing the need for a more harmonized approach to NZEB policies. Additionally, the study found that European Commission benchmarks for energy performance and renewable energy adoption have influenced residential and office buildings differently, with climatic and environmental factors playing a critical role in shaping NZEB strategies.

One of the key challenges identified is the cost variability of renewable energy installations across Member States, which directly impacts the feasibility and adoption of NZEBs. The study also highlights the importance of integrating NZEB principles into both new and existing buildings, particularly in addressing the complexities associated with retrofitting older structures to meet high energy efficiency standards.

From a policy perspective, the findings suggest that greater financial incentives, technical support, and cross-border collaboration are needed to accelerate NZEB adoption across diverse climatic regions. More standardized benchmarks, combined with country-specific flexibility, could help address variations in implementation.

While this study provides a comprehensive assessment of NZEB development in the EU, further research is needed to explore:

The long-term economic feasibility of NZEB adoption across different Member States, considering installation costs, operational expenses, and return on investment.

More advanced statistical models to analyze the impact of renewable energy sources on NZEB performance in different climatic zones.

The role of emerging digital technologies (e.g., BIM and smart grids) in improving NZEB efficiency and cost-effectiveness.

In conclusion, this study contributes to the growing body of knowledge on NZEB development, offering valuable insights for policymakers, urban planners, and industry stakeholders aiming to enhance energy efficiency, reduce carbon emissions, and transition toward a more sustainable built environment in the European Union.

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Not applicable.

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The author declares that there is no conflict of interest regarding the publication of this paper.

References

Abdelkareem, M. A., Elsaid, K., Wilberforce, T., Kamil, M., Sayed, E. T., & Olabi, A. G. (2021). Environmental aspects of fuel cells: A review. *Science of The Total Environment*, 752, 141803. https://doi.org/10.1016/j.scitotenv.2020.141803

Alola, A. A., Okere, K. I., Muoneke, O. B., & Dike, G. C. (2022). Do bureaucratic policy and socioeconomic factors moderate energy utilization effect of net zero target in the EU? *Journal of Environmental Management*, 317, 115386. https://doi.org/10.1016/j.jenvman.2022.115386

Aldieri, L., Gatto, A., & Vinci, C. P. (2021). Evaluation of energy resilience and adaptation policies: An energy efficiency analysis. *Energy Policy*, 157, 112505. https://doi.org/10.1016/j.enpol.2021.112505

Backe, S., Pinel, D., Askeland, M., Lindberg, K. B., Korpås, M., & Tomasgard, A. (2023). Exploring the link between the EU emissions trading system and net-zero emission neighbourhoods. *Energy and Buildings, 281*, 112731. https://doi.org/10.1016/j.enbuild.2022.112731

Belussi, L., Barozzi, B., Bellazzi, A., Danza, L., Devitofrancesco, A., Fanciulli, C., & Scrosati, C. (2019). A review of performance of zero energy buildings and energy efficiency solutions. *Journal of Building Engineering, 25*, 100772. https://doi.org/10.1016/j.jobe.2019.100772

Boitier, B., Nikas, A., Gambhir, A., Koasidis, K., Elia, A., Al-Dabbas, K., Alibaş, Ş., Campagnolo, L., Chiodi, A., Delpiazzo, E., Doukas, H., Fougeyrollas, A., Gargiulo, M., Le Mouël, P., Neuner, F., Perdana, S., van de Ven, D. J., Vielle, M., Zagamé, P., & Mittal, S. (2023). A multi-model analysis of the EU's path to net zero. *Joule*, *7*(12), 2760–2782. https://doi.org/10.1016/j.joule.2023.11.002

Buildings Performance Institute Europe. (2020). *On the way to a climate-neutral Europe: Contributions from the building sector to a strengthened 2030 climate target*. https://www.bpie.eu/wp-content/uploads/2020/12/On-the-way-to-a-climate-neutral-Europe-_Final.pdf

CONZEB. (2019). Why nearly zero energy buildings are the right choice: experiences, expectations and co-benefits of living in NZEBs.

Craft, W., Ding, L., Prasad, D., Partridge, L., & Else, D. (2017). Development of a regenerative design model for building retrofits. *Procedia Engineering, 180*, 658–668. https://doi.org/10.1016/j.proeng.2017.04.225

CRAVEZERO. (2018). *Cost reduction and market acceleration for viable nearly zero-energy buildings*. https://cravezero.eu/

Dong, J., Lan, H., Liu, Y., Wang, X., & Yu, C. (2020). Indoor environment of nearly zero energy residential buildings with conventional air conditioning in hot-summer and cold-winter zone. *Energy and Built Environment*, *3*(2), 129–138. https://doi.org/10.1016/j.enbenv.2020.12.001

Egilegor, B., Jouhara, H., Zuazua, J., Al-Mansour, F., Plesnik, K., Montorsi, L., & Manzini, L. (2020). ETEKINA: Analysis of the potential for waste heat recovery in three sectors: Aluminium low pressure die casting, steel sector and ceramic tiles manufacturing sector. *International Journal of Thermofluids, 1–2*. https://doi.org/10.1016/j.ijft.2019.100002.

Elsaid, K., Sayed, E. T., Abdelkareem, M. A., & Wilberforce, T. (2020). Recent progress on the utilization of waste heat for desalination: A review. *Energy Conversion and Management*, 221, 113105. https://doi.org/10.1016/j.enconman.2020.113105

European Commission. (2019). The European green deal, COM (2019) 640 final, communication from the commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee, and the Committee of the Regions. Retrieved from https://ec.europa.eu/info/sites/info/files/european-green-deal-communication_en.pdf

Hossain, N., Mahlia, T. M. I., & Saidur, R. (2019). Latest development in microalgae-biofuel production with nano-additives. *Biotechnology for Biofuels 2019 12:1*, *12*(1), 1–16. https://doi.org/10.1186/S13068-019-1465-0.

Hossain, S., Abdalla, A. M., Suhaili, S. B., Kamal, I., Shaikh, S. P., Dawood, M. K., & Azad, A. K. (2020). Nanostructured graphene materials utilization in fuel cells and batteries: A review. *Journal of Energy Storage, 29*, 101386. https://doi.org/10.1016/j.est.2020.101386

Janda, K. B. (2011). Buildings don't use energy: People do. *Architectural Science Review*, 54(1), 15–22. https://doi.org/10.3763/asre.2009.0050

Jouhara, H., Ahmad, D., & Ezzuddin, H. (2018). Waste heat recovery technologies and applications. *Thermal Science and Engineering Progress*, 6, 268–289. https://doi.org/10.1016/j.tsep.2018.04.017

Kosai, S., & Tan, C. K. (2017). Quantitative analysis on a zero energy building performance from energy trilemma perspective. *Sustainable Cities and Society*, *32*, 130–141. https://doi.org/10.1016/J.SCS.2017.03.023.

Li, Y., Kubicki, S., Guerriero, A., & Rezgui, Y. (2019). Review of building energy performance certification schemes towards future improvement. *Renewable and Sustainable Energy Reviews*, 113, 109244. https://doi.org/10.1016/j.rser.2019.109244.

Özkan, A., Alola, A. A., & Adebayo, T. S. (2023). Environmental benefits of nonrenewable energy efficiency and renewable energy intensity in the USA and EU: Examining the role of clean technologies. *Sustainable Energy Technologies and Assessments*, 58, 103315. https://doi.org/10.1016/j.seta.2023.103315

Olabi, A. G., Wilberforce, T., & Abdelkareem, M. A. (2020a). Fuel cell application in the automotive industry and future perspective. *Energy*, 214, 118955. https://doi.org/10.1016/j.energy.2020.118955

Olabi, A. G., Wilberforce, T., Sayed, E. T., Elsaid, K., & Abdelkareem, M. A. (2020b). Prospects of Fuel Cell Combined Heat and Power Systems. *Energies 2020, Vol. 13, Page 4104*, *13*(16), 4104. https://doi.org/10.3390/EN13164104.

Panagiotidou, M., & Fuller, R. J. (2013). Progress in ZEBs—A review of definitions, policies and construction activity. *Energy Policy, 62*, 196–206. https://doi.org/10.1016/j.enpol.2013.06.099

Rabaia, M. K. H., Abdelkareem, M. A., Sayed, E. T., Elsaid, K., Chae, K.-J., Wilberforce, T., & Olabi, A. G. (2021). Environmental impacts of solar energy systems: A review. *Science of The Total Environment, 754*, 141989. https://doi.org/10.1016/j.scitotenv.2020.141989

Riemer, M., Wachsmuth, J., Boitier, B., Elia, A., Al-Dabbas, K., Alibaş, Ş., Chiodi, A., & Neuner, F. (2023). How do system-wide net-zero scenarios compare to sector model pathways for the EU? A novel approach based on benchmark indicators and index decomposition analyses. *Energy Strategy Reviews, 50*, 101225. https://doi.org/10.1016/j.esr.2023.101225.

Sayed, E. T., Wilberforce, T., & Abdelkareem, M. A. (2020). A critical review on environmental impacts of renewable energy systems and mitigation strategies: Wind, hydro, biomass and geothermal. Science of The Total Environment, 766, 144505. https://doi.org/10.1016/j.scitotenv.2020.144505

Shaikh, P. H., Nor, N. B. M., Nallagownden, P., Elamvazuthi, I., & Ibrahim, T. (2014). A review on optimized control systems for building energy and comfort management of smart sustainable buildings. *Renewable and Sustainable Energy Reviews*, 34, 409–429. https://doi.org/10.1016/j.rser.2014.03.027

Shehata, N., Abdelkareem, M. A., Kannan, A. M., & Wilberforce, T. (2020). Hybrid renewable energy systems for desalination applications. *Renewable and Sustainable Energy Reviews*, 123, 109752. https://doi.org/10.1016/j.rser.2020.109752

Suzuki, M., Jewell, J., & Cherp, A. (2023). Have climate policies accelerated energy transitions? Historical evolution of electricity mix in the G7 and the EU compared to net-zero targets. *Energy Research & Social Science, 106*, 103281. https://doi.org/10.1016/j.erss.2023.103281

Wang, N., Phelan, P. E., Gonzalez, J., Harris, C., Henze, G. P., Hutchinson, R., & Pyke, C. (2017). Ten questions concerning future buildings beyond zero energy and carbon neutrality. *Building and Environment*, *119*, 169–182. https://doi.org/10.1016/j.buildenv.2017.04.006

Wilberforce, T., El Hassan, Z., Khatib, F. N., Al Makky, A., Baroutaji, A., & Olabi, A. G. (2020). Developments of electric cars and fuel cell hydrogen electric cars. *International Journal of Hydrogen Energy*, 45(11), 25657–25668. https://doi.org/10.1016/j.ijhydene.2020.06.015

Yi, Z., Lv, Y., Xu, D., Xu, J., Qian, H., Zhao, D., & Yang, R. (2020). Energy saving analysis of a transparent radiative cooling film for buildings with roof glazing. *Energy and Built Environment*, *2*(2), 214–222. https://doi.org/10.1016/j.enbenv.2020.07.003.