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User Experience (UX) for Energy Awareness: A Global Bibliometric Analysis of Interface Design in Sustainability Contexts

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ABSTRACT

As energy efficiency and environmental sustainability gain global importance, user-centered digital solutions have become vital in promoting energy awareness. This study presents a comprehensive bibliometric analysis of scholarly literature at the intersection of User Experience (UX), interface design, and sustainability, with a specific focus on how digital systems support behavioral change and energy literacy. Using the Scopus database and VOSviewer software, a total of 156 peer-reviewed articles published between 2000 and 2025 were analyzed to uncover co-occurrence patterns, author collaborations, keyword evolution, and country-level partnerships. The results identify *sustainable development*, *user experience*, and *interface design* as dominant research themes, while emerging trends such as *artificial intelligence*, *visualization*, and *electronic commerce* reflect a shift toward adaptive, intelligent systems for sustainability. The study reveals a strong research presence from China, the United States, and Europe, with notable gaps in Global South representation and education-oriented UX research. The findings offer critical insights into the thematic evolution and future directions of this interdisciplinary field, emphasizing the need for more inclusive, collaborative, and human-centered innovation in energy interface design.

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1. INTRODUCTION

In the last two decades, the urgency of environmental sustainability has transformed the way societies and technologies interact. Energy consumption, a core issue within sustainability discourses, has increasingly been linked not only to industrial and infrastructural choices but also to individual and household behaviors [1]. In this context, the role of digital technologies—particularly user-facing interfaces—has become increasingly relevant in shaping how people understand, monitor, and alter their energy usage. With the rise of smart homes, mobile applications, and interactive dashboards, user experience (UX) design is no longer a mere convenience but a critical tool in promoting energy-efficient behaviors. Designers now face the challenge of embedding persuasive,

educational, and accessible elements within interfaces that can drive sustainable choices at scale [2], [3].

User Experience (UX) as a field has matured significantly, integrating principles from cognitive psychology, human-computer interaction (HCI), and behavioral economics to influence how people interact with technology. Within the sustainability domain, this integration becomes particularly potent. Studies have shown that visual feedback, gamification, goal setting, and social comparisons embedded in interface design can significantly influence energy behavior [4], [5]. However, the effectiveness of such approaches hinges on careful attention to user needs, contextual relevance, and cultural adaptability. UX design, when executed with empathy and inclusivity, becomes a medium for awareness, engagement, and long-term behavior change—especially in energy-related applications.

At a global level, there has been a growing academic interest in the intersection between UX and sustainable energy practices. This includes the design of systems that provide real-time energy feedback, educational tools to teach environmental impact, and interfaces that personalize sustainability journeys for users [6], [7]. Furthermore, the rapid digitalization in both developed and developing regions has opened new avenues for context-sensitive interface design. For example, low-income communities may require simplified yet informative dashboards, while tech-savvy users might seek detailed analytics with AI-powered insights. Thus, understanding the global landscape of UX for energy awareness is essential to identifying best practices, emerging trends, and potential research gaps.

Bibliometric analysis provides a robust methodological approach to map the evolution of scientific literature and intellectual structures within a field. Applying this to UX in the sustainability context allows scholars to identify the most influential authors, institutions, keywords, and research clusters shaping the discourse. Previous bibliometric studies in related domains have successfully illuminated the trajectory of environmental psychology, sustainable HCI, and green technology adoption. However, a focused and comprehensive bibliometric study specifically addressing UX for energy awareness, particularly through the lens of interface design, remains underdeveloped. This gap underscores the need for a systematic mapping to understand how the field has evolved globally and where future efforts should be directed.

The emergence of cross-disciplinary collaborations—between designers, engineers, environmental scientists, and behavioral researchers—further accentuates the complexity and richness of this research space. As global policy agendas like the UN's Sustainable Development Goals (SDG 7: Affordable and Clean Energy) gain traction, there is heightened pressure on technological solutions to contribute meaningfully. UX design, often underappreciated in technical discussions, becomes a central enabler in aligning user behaviors with sustainable energy goals. It is, therefore, vital to investigate how academic research has approached this intersection and how interface design has been framed, conceptualized, and empirically tested in various global contexts.

Despite the increasing visibility of user-centered approaches in sustainability research, several core problems persist. First, there is fragmentation in the literature across disciplines such as computer science, psychology, and environmental studies, which hinders knowledge consolidation. Second, the conceptualization of "energy awareness" varies significantly, ranging from cognitive understanding to behavioral outcomes, leading to inconsistencies in design approaches and evaluations. Third, there is a lack of global comparative studies that account for cultural, economic, and infrastructural variations in energy use and interface design. Lastly, while numerous prototypes and applications have been developed, few are grounded in scalable, replicable UX frameworks that can be adapted across contexts. These limitations reveal a need for a comprehensive, quantitative

synthesis of existing research to clarify trends, gaps, and future directions. This study, therefore, aims to conduct a global bibliometric analysis of the scholarly literature on user experience (UX) for energy awareness, with a particular focus on interface design in sustainability contexts.

2. METHODS

This study employed a quantitative bibliometric approach to systematically map the global research landscape on user experience (UX) design in the context of energy awareness and sustainability. The data were retrieved from the **Scopus** database, one of the largest and most comprehensive repositories of peer-reviewed scientific literature. Scopus was selected due to its multidisciplinary coverage, high-quality indexing, and suitability for bibliometric analysis in social science and technology fields [8]. The search query was carefully constructed to include combinations of keywords such as *"user experience," "UX design," "interface," "energy awareness,"* and *"sustainability"*. Only articles published between **2000 and 2025** were considered to capture the evolution of this interdisciplinary field. The search was further filtered to include only peer-reviewed journal articles, conference papers, and review articles published in English.

After the initial data extraction, the resulting corpus of documents was exported in BibTeX format, which was then processed using **VOSviewer** (van Eck & Waltman, 2010)—a widely used software tool for constructing and visualizing bibliometric networks. The analysis focused on several key bibliometric indicators: (1) co-authorship analysis to identify collaborative networks among researchers and institutions; (2) co-occurrence of keywords to uncover thematic clusters and research hotspots; (3) citation analysis to highlight the most influential publications and journals in the field; and (4) temporal trend mapping to observe how scholarly interest and themes have shifted over time. Prior to visualization, data cleaning was performed to consolidate author name variants and harmonize keyword inconsistencies using VOSviewer's thesaurus file feature.

3. RESULTS AND DISCUSSION

3.1 Keyword Co-Occurrence Network

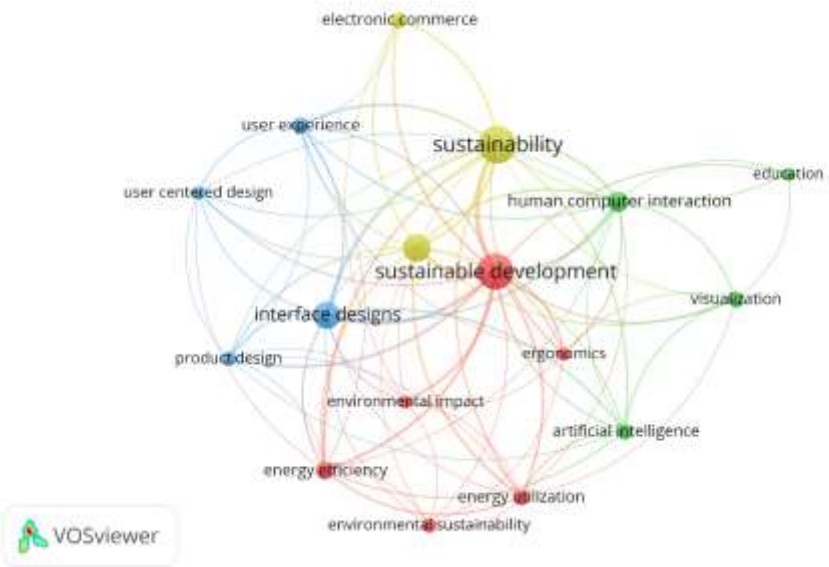

Figure 1. Network Visualization
Source: Data Analysis Result, 2025

The red cluster, centered around the keyword *"sustainable development"*, highlights a core thematic focus in this research domain. It connects with terms such as *"environmental impact," "environmental sustainability," "energy utilization,"* and *"energy efficiency"*. This indicates a strong emphasis on how interface design contributes to broader sustainable development goals, particularly in relation to energy consumption and ecological impact. The presence of *ergonomics* and *artificial intelligence* in this cluster also reflects a growing interest in smart, adaptive systems that not only display sustainability metrics but respond to user behavior in ways that promote efficiency and conservation. This cluster likely represents literature grounded in engineering, energy policy, and environmental science with applied UX insights.

The blue cluster is anchored by "user experience," "interface design," and "user-centered design". These terms are closely linked to "product design", showing a clear UX-focused strand within the dataset. This cluster represents work centered on HCI (Human-Computer Interaction) and interaction design, where the goal is to create interfaces that are intuitive, engaging, and behaviorally persuasive. The tight interconnections suggest a robust body of work examining how user-centric design principles can improve energy awareness, for example, by offering real-time feedback or gamification features that motivate behavioral change. This cluster likely draws from computer science, design research, and cognitive psychology.

The green cluster, consisting of "human computer interaction," "visualization," "education," and "artificial intelligence", reflects the pedagogical and interactive dimensions of UX for energy awareness. Visualization tools are particularly important in making abstract concepts like carbon footprint or real-time energy usage tangible to users. The inclusion of education signals that many UX systems are not just about functionality but also about educating users—perhaps through infographics, tutorials, or interactive simulations—on how to adopt more sustainable habits. This cluster seems to align with research from educational technology, behavioral science, and learning design.

The yellow cluster, which includes "sustainability," "electronic commerce," and "sustainable development", seems to bridge between economic dimensions and technological adoption. The connection to e-commerce suggests an emerging interest in how digital interfaces within online platforms can promote sustainable consumer behavior—for example, by highlighting energy-efficient products or embedding sustainability indicators in digital shopping environments. This reflects a commercial application of UX design to promote environmental values, blending marketing, consumer behavior, and sustainability communication.

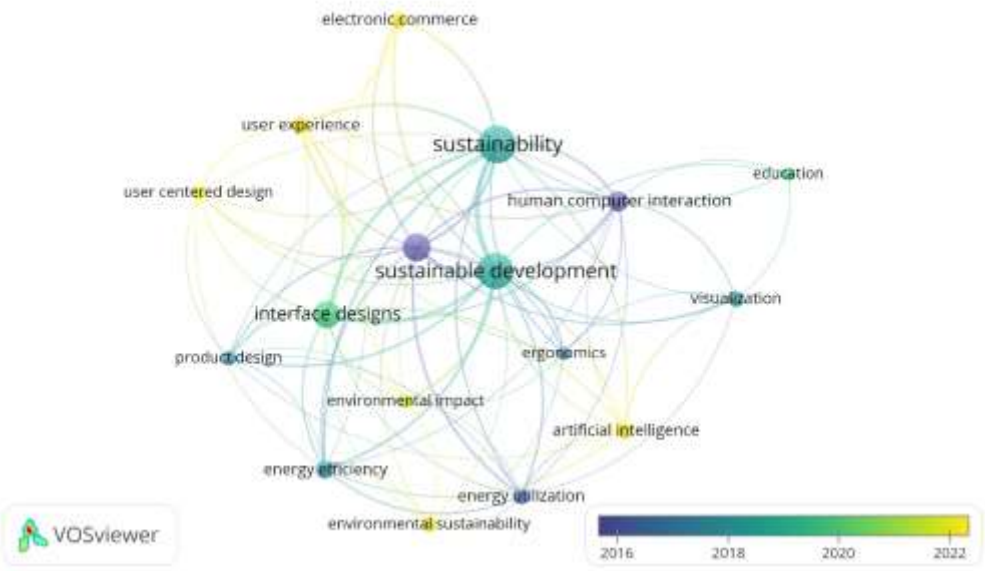

Figure 2. Overlay Visualization
Source: Data Analysis Result, 2025

This overlay visualization from VOSviewer illustrates the temporal evolution of keywords in the research field combining *user experience (UX)*, *interface design*, and *sustainability*. The color scale ranges from purple (older publications, ~2016) to yellow (more recent publications, ~2022), helping identify which topics have emerged recently and which have matured over time. At the center of the map, *"sustainable development"* remains a foundational and long-standing theme, as shown by its purple hue, suggesting that it has been a consistently dominant topic in earlier works. This core theme connects strongly with *environmental impact*, *ergonomics*, and *energy efficiency*, all of which also appear to have developed earlier in the literature. In contrast, keywords such as *"user experience"*, *"user centered design"*, *"electronic commerce"*, and *"artificial intelligence"* are highlighted in yellow, indicating that these areas represent more recent research interests. This shift implies an evolving focus in sustainability research, now increasingly emphasizing the role of personalized, intelligent systems in shaping energy awareness. The emergence of AI as a recent node connected to UX and interface design underscores a growing interest in adaptive interfaces that leverage machine learning to personalize sustainability-related feedback or automate energy-saving behaviors. Meanwhile, keywords such as *"interface design"*, *"visualization"*, *"education"*, and *"human-computer interaction"* fall in the green spectrum, suggesting they have been actively explored between 2018 and 2020. These terms act as bridges between foundational concepts like sustainable development and newer trends like AI and e-commerce. Their intermediate temporal position reflects a transitional phase, where researchers began integrating design-based approaches to foster environmental awareness through interactive tools.

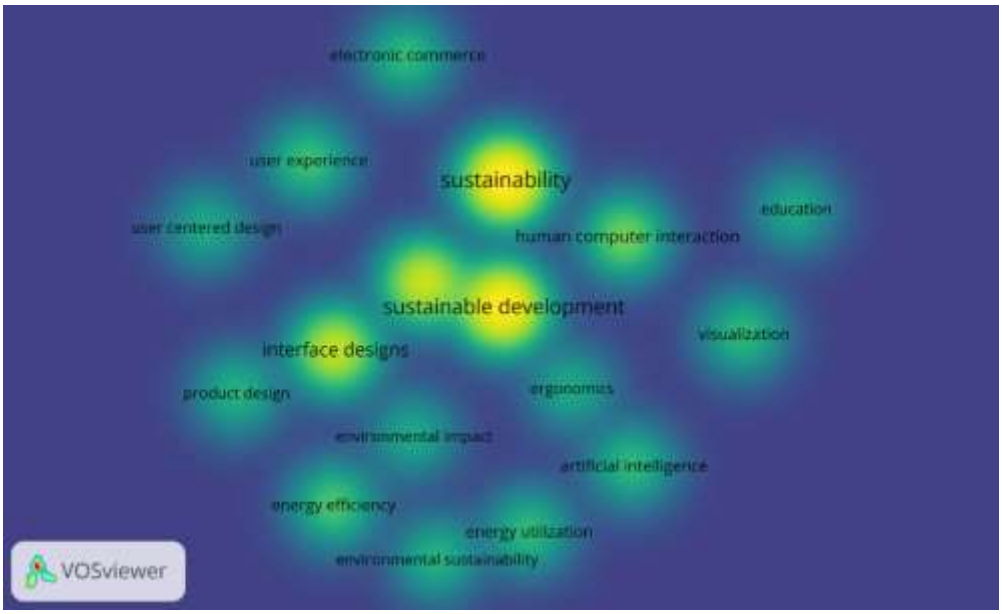

Figure 3. Density Visualization
Source: Data Analysis, 2025

Figure 3 provides an overview of the research intensity based on keyword occurrences in the field of *user experience (UX)* and *interface design* within the context of *sustainability*. The keywords displayed in brighter yellow regions, such as *"sustainable development"*, *"sustainability"*, and *"interface designs"*, indicate areas of high publication frequency and relevance. These terms represent the conceptual core of the field, suggesting that most scholarly efforts have centered around how design-oriented digital solutions contribute to larger sustainability and development goals. The strong presence of *"human-computer interaction"* and *"user experience"* further emphasizes the increasing role of user-centered digital systems in facilitating sustainable behaviors.

Conversely, keywords in the green to dark blue spectrum, such as *"education"*, *"energy utilization"*, *"artificial intelligence"*, and *"electronic commerce"*, show moderate to emerging research intensity. While these areas are less saturated, they signal growing interest and future potential in the field—particularly where innovative technologies and behavioral learning intersect with energy efficiency goals. The spread and proximity of topics like *"visualization"*, *"ergonomics"*, and *"environmental impact"* imply that the field is multidisciplinary, blending technical, cognitive, and environmental perspectives.

3.2 Co-Authorship Network

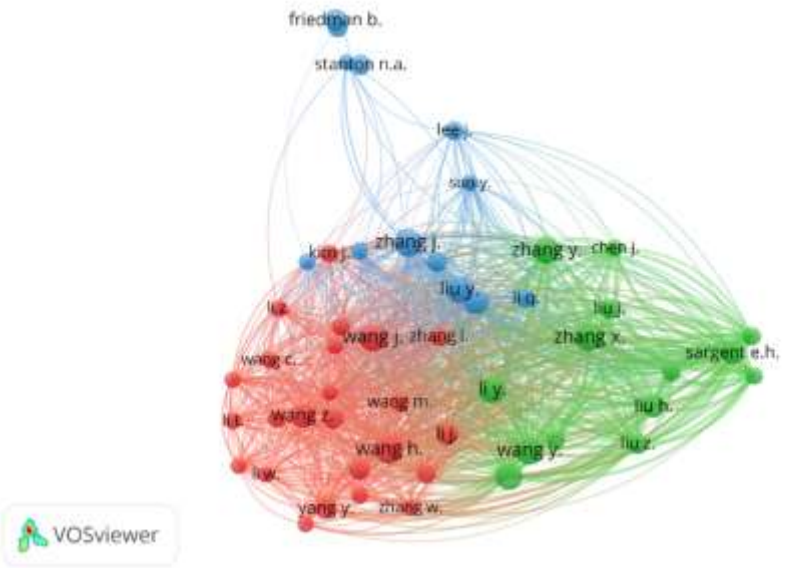

Figure 4. Author Collaboration Visualization
Source: Data Analysis, 2025

Figure 4 highlights the collaborative landscape among researchers in the field of *UX, interface design,* and *sustainability*. Each node represents an author, while the links denote co-authored publications. The map is divided into three main clusters, represented by different colors: the red cluster consists largely of Chinese authors such as Wang J., Wang Z., and Liu J., indicating a strong internal collaboration network possibly centered around environmental or interface design research in Chinese institutions. The green cluster, featuring authors like Zhang X., Sargent E.H., and Liu H., shows a broader international orientation, suggesting collaborations that may span disciplines like artificial intelligence and sustainable technology. The blue cluster, which includes Friedman B., Stanton N.A., and Sun Y., appears to represent scholars rooted in human-computer interaction and user-centered design, particularly in Western academic settings.

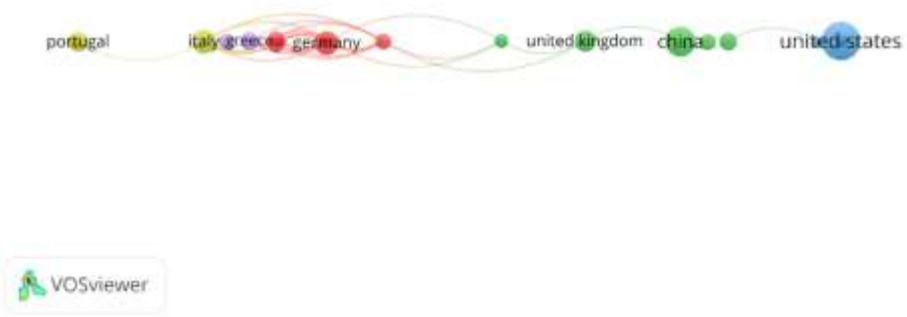

Figure 5. Country Collaboration Visualization
Source: Data Analysis, 2025

Figure 5 illustrates the global partnerships among nations in the field of *UX, interface design,* and *sustainability research*. Each node represents a country, with larger nodes (like the United States, China, and Germany) indicating a higher volume of publications and centrality in the collaboration network. The thickness of the connecting lines reflects the strength of co-authorship links between countries. Notably, the United States appears as a central hub, closely connected to China and the United Kingdom, suggesting strong transatlantic and transpacific research collaborations. European countries—such as Germany, Italy, Greece, and Portugal—form a tight sub-network, indicating regional cooperation, especially within the EU. While China holds an influential position in Asia, it also bridges East and West through its ties with both the US and the UK.

3.3 Citation Analysis

Table 1. Top Cited Research

Citations	Authors and year	Title
437	[9]	VALUE SENSITIVE DESIGN AND INFORMATION SYSTEMS
145	[10]	SUNtool - A new modelling paradigm for simulating and optimising urban sustainability
50	[11]	Discover Digital Libraries: Theory and Practice
42	[12]	Personal informatics in practice: Improving quality of life through data
41	[13]	Youtopia: A collaborative, tangible, multi-touch, sustainability learning activity
39	[14]	A Review of Immersive Technologies, Knowledge Representation, and AI for Human-Centered Digital Experiences
36	[15]	Designing participation in agile ridesharing with mobile social software
31	[16]	Effects of Interface Design and Live Atmosphere on Consumers' Impulse-Buying Behaviour from the Perspective of Human–Computer Interaction
30	[17]	A Novel Development of Concrete Structures: Composite Concrete Structures丨混凝土结构的新发展-组合混凝土结构
28	[18]	Logistics service providers' energy efficiency initiatives for environmental sustainability

Source: Scopus, 2025

Discussion

1) Central Themes and Research Priorities

The co-occurrence network showed that *"sustainable development"* and *"sustainability"* remain the most prominent keywords, signifying their function as conceptual anchors within this research space. These terms are tightly connected to others such as *"environmental impact," "energy efficiency,"* and *"interface designs,"* indicating that much of the literature is motivated by practical applications—specifically, the use of digital interfaces to foster environmentally responsible behaviors. This aligns with earlier research emphasizing the role of real-time feedback and eco-visualization in influencing household energy use [7], [19].

Equally important is the presence of *user experience* and *user-centered design* as frequently co-occurring terms, which confirms a persistent shift from techno-centric solutions toward human-centered approaches in sustainability interfaces. The increasing attention to how users perceive, engage with, and learn from digital tools reflects a convergence between environmental psychology and interaction design. Designers are not only developing interfaces that function, but ones that *educate, persuade, and*

adapt to user needs—consistent with the principles of persuasive technology and behavioral change theory [20], [21].

2) Temporal Evolution of the Field

The overlay visualization adds a temporal dimension to this landscape, showing that terms like *"user experience," "artificial intelligence,"* and *"electronic commerce"* have gained traction more recently (2019–2022), whereas concepts such as *"sustainable development"* and *"environmental impact"* have longer-standing roots (pre-2016). This shift reveals a research transition: from foundational, policy-oriented sustainability work toward more nuanced, technology-driven inquiries focused on personalization, automation, and user motivation.

The emergence of *AI* as a keyword—linked to interface designs and sustainability—suggests the field is moving into a new phase where smart systems play a greater role in adapting energy feedback to individual consumption patterns. This trend is consistent with current efforts in smart grid user interfaces, which aim to provide adaptive feedback using learning algorithms. The appearance of *e-commerce* also implies a growing interest in sustainable digital marketplaces, where UX design can influence eco-conscious consumer behavior through nudging, labeling, and value framing.

3) Research Density and Saturation

The density visualization reinforces the dominance of *sustainable development* and *interface design* as the most heavily saturated areas. These "hot spots" represent the theoretical and empirical center of gravity for this field. The brightness around terms such as *product design*, *energy efficiency*, and *human-computer interaction* also highlights topics that receive moderate scholarly attention and function as bridges between broader themes.

However, several areas remain relatively "cool," indicating research opportunities. For instance, despite the educational intent of many energy-awareness interfaces, the keyword *education* appears on the periphery with lower density. This suggests a gap in formally linking educational theory to UX interventions, particularly in sustainability contexts. Similarly, *visualization*—a key component in eco-feedback systems—is underrepresented in density, even though its communicative and behavioral impact is well acknowledged in literature [21]. These discrepancies point to thematic blind spots where further conceptual development and empirical testing are warranted.

4) Author Collaboration Patterns

The co-authorship network reveals distinct regional research clusters, with a strong representation from China-based scholars (e.g., Wang J., Liu J., Zhang L.), suggesting a robust national research agenda around interface design and sustainability. The green cluster, which includes global researchers like Sargent E.H. and Liu H., indicates international collaboration in areas like smart technology and environmental informatics. Meanwhile, the blue cluster—led by names such as Friedman B. and Stanton N.A.—appears to represent the HCI-focused community, emphasizing values-centered and participatory design frameworks.

Importantly, authors such as Liu Y. and Zhang J. act as bridges between clusters, showing their role in fostering interdisciplinary and cross-regional collaborations. These "connector scholars" are vital in a field as multidimensional as UX for sustainability, where convergence between environmental science, behavioral psychology, and design engineering is essential. The high density of intra-cluster links within China and the relatively lower cross-national links (except with the U.S.) suggest that while regional productivity is high, global integration remains uneven.

5) Global Collaboration and Geopolitical Patterns

The country collaboration map underscores the dominant role of the United States, which serves as a central node connecting with both European and Asian countries. China also appears as a major contributor, with strong ties to the U.S. and

UK, reflecting global leadership in both AI-driven UX and energy applications. European nations—especially Germany, Italy, and Greece—form a tightly connected subnetwork, indicative of EU-funded collaboration frameworks (e.g., Horizon Europe programs).

Notably, Portugal and Greece, while smaller in publication volume, are actively collaborating within the European block. Their position in the network suggests that smaller nations are leveraging strategic partnerships to contribute meaningfully to this research space. On the other hand, the relative absence of Global South nations—such as those in Africa, Latin America, or Southeast Asia—points to a geographical gap that risks limiting the contextual relevance of UX for sustainability across diverse socioeconomic and cultural environments.

6) Implications for Future Research

Several implications emerge from this bibliometric analysis. First, there is a need to further explore the integration of AI with UX in energy interfaces—not just from a technical standpoint, but also in terms of ethics, interpretability, and user trust. As AI systems become embedded in energy monitoring and behavior modification, UX researchers must ensure that interfaces remain transparent, inclusive, and respectful of user autonomy. Second, education-oriented UX research deserves more emphasis. This includes not only creating gamified or interactive feedback mechanisms but also applying learning theories (constructivism, experiential learning, etc.) to improve comprehension and retention of sustainability concepts. Partnering with educators and cognitive scientists could enhance the pedagogical value of these interfaces.

Third, as the field grows, it must increasingly account for diversity, equity, and localization. Designing energy-aware interfaces for users in low-resource settings, for example, will require distinct considerations compared to urban smart homes. This necessitates more inclusive methodologies, participatory design processes, and a shift toward global south inclusion in both authorship and case studies. While this study has provided a macroscopic view, future bibliometric efforts could employ citation burst analysis, thematic evolution, or text mining to detect more granular shifts in subtopics—such as UX for electric vehicles, carbon footprint trackers, or demand-response platforms. Longitudinal studies might also examine how global events (e.g., energy crises, climate policy shifts) influence publication surges in this area.

4. CONCLUSION

This bibliometric study has mapped the intellectual structure, thematic trends, and global collaborations in the research domain of User Experience (UX) for Energy Awareness, with a focus on interface design in sustainability contexts. The findings reveal that *sustainable development*, *UX*, and *interface design* serve as foundational concepts driving scholarly inquiry, while emerging themes like *artificial intelligence*, *visualization*, and *e-commerce* suggest a shift toward more adaptive and personalized digital solutions. Temporal and density visualizations indicate that although the field has matured around core sustainability topics, new directions are gaining momentum—particularly in integrating behavioral insights and smart technologies into user-centered design. The analysis also highlights strong regional research clusters, with China, the United States, and parts of Europe leading in productivity and collaboration. However, gaps persist, especially in cross-regional integration and research on educational interfaces and inclusivity across diverse cultural and socioeconomic contexts. Moving forward, the field would benefit from deeper interdisciplinary collaboration, expanded global participation, and a continued commitment to designing UX systems that empower users to make informed, sustainable choices.

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