Towards the eco-design of Artificial Intelligence and Big Data applications: a bibliometric analysis of related research

Zijia Wang and Han-Teng Liao

1New Media Research Center, Sun Yat-sen University Nanfang College, Guangzhou, Guangdong, 510970, China
*Corresponding author’s e-mail: h.liao@oxon.org

Abstract. Given the impacts of information and communications technologies on the planet and people, researchers from all disciplines need to pay attention to the environmental footprints and sustainable opportunities associated with the Artificial Intelligence (AI) and Big Data applications. In order to provide a preliminary discussion on the eco-design of AI and Big Data applications, the paper aims to map out the sources and topics to explore (1) the intersections of eco-design with AI and Big Data, and (2) the sustainable and eco-friendly design. Based on a bibliometric analysis of 236 articles gathered from the Web of Science (WoS) database, the paper has identified main research topics, publication outlets, research fronts, and intellectual bases and explored their inter-relationship and grouping. The leading application disciplines include construction & building technology, automation & control system, computer & information science, and business & economics. Multi-disciplinary and inter-disciplinary journals such as Sustainability, Journal of Cleaner Production, and Sustainable Cities and Society have been proven to be more receptive to such eco-design research outputs. As the notion of eco-design of AI and Big Data applications is expected to be pertinent and relevant for designing greener strategies, products and services for green digital transformation, we argue that more concerted efforts must be made to advance both the theoretical and empirical research on the nascent topic among researchers, funding bodies, policy-makers and industry professionals.

1. Introduction

The environment impact of Information and Communication Technologies (ICT), including its use and assets, has been an important agenda for research activities such as the eco-design of ICT, computing within limits, tech for good, etc. Indeed as often associated with the notion that 80% of all product-related impact is defined during the design phase of a product[1,2], eco-design of digital services[3] and green ICT[4] has become important areas for policy-making and innovation, as an important piece for sustainable growth[5]. For instance, the European Framework Initiative for Energy & Environmental Efficiency in the ICT Sector, or ictfootprint.eu, has gathered 4,000 community members, 21 ICT sustainable suppliers, etc., promoting low-carbon ICT standards and communities.

As ICT technologies have advanced the socio-economic development of human societies, we expect that the latest iterations of Artificial Intelligence (AI) and Big Data technologies and applications will have or already have had impacts on human environmental footprints, be them positive or negative. Indeed, as major institutions such as Facebook, Google, Microsoft, UNICEF, etc., founded the Partnership on Artificial Intelligence to Benefit People and Society in 2016 [6,7], researchers and policy makers must examine both negative and positive impacts of AI and Big Data applications on sustainable development. We need to “transform ourselves as innovators”, as stated by the UN Chief Information
Technology Officer [8]. We need to leverage Big Data for sustainable development[9]. Thus, any Big Data and AI application may need to pay attention to environmental and sustainable challenges.

Some efforts have been made to review the design of Big Data or AI applications for sustainable development, including smart sustainable cities [10], green building [11,12], sustainable industry[13,14], etc. Yet none of them has provided a comprehensive enough overview of the state-of-art research. In order to provide one such overall roadmap for exploring the related research development on the eco- and sustainable designs of Big Data and AI, the paper aims to map out how the sources and topics are involved in such efforts to explore the intersections of AI and Big Data on one hand, and the sustainable and eco-friendly designs on the other.

2. Data and methods
To capture relevant the literature on the topic of eco-design of Big Data and AI applications, this bibliometric analysis starts with the Web of Science (WoS) “Advanced Search” query designed as below:

\[(TS = \text{("Artificial Intelligence" OR "machine learning" OR "Big Data") AND (TS = \text{("design" AND "sustainability" OR "sustainable development" OR "sustainable consumption*" OR "sustainable production*" OR "cleaner production*" OR "circular economy") OR TS = \text{("ecodesign" OR "eco-design" OR "sustainable design" OR "green design") OR TS = \text{("ICT4D" OR "HCI4D" OR "Positive Technolog*")}})\]

Such a systematic data collection leads to 236 articles from the WoS database (including SCI-EXPANDED, SSCI, CPCI-S, and CPCI-SSH). Both VOSviewer and Python visualization packages were used for analyzing and mapping results.

3. Research mapping results
Given the scope of collected data, the paper presents the mapping results from the broader trends, productive countries, organizations, publication outlets, and their clusters.

3.1. Annual trends
Figure 1(a) shows that the number of publications has largely risen exponentially, especially since around 2013. Also, Figure 1(b) shows that the number of citations takes off after around 2017, indicating the increasing significance of such topics in research. In addition, based on the slope value of regression lines shown in Figure 1(c), the growth rate after 2013 appears to be much faster than before.

![Figure 1. Annual Trends](image)

3.2. Keyword co-occurrence network analysis
Based on the interconnections among author keywords, or keyword co-occurrence network, we identify 4 clusters, as shown in Figure 2. The first cluster (in red color) features the central concepts of sustainability and big data, along with terms such as data mining, internet of things, circular economy, industry 4.0 and sustainable manufacturing. The second cluster (in green color) features artificial intelligence, sustainable development, case-based reasoning, and decision support system. The third cluster (in blue color) has keywords such as energy efficiency, smart cities and big data analytics. The final cluster (in yellow color) features more technical terms such as machine learning and optimization.
3.3. Top productive countries and organizations

Figure 3 shows the outcomes of the co-authorship network analysis. While the United States, China and England appear to dominate the country network, as shown in Figure 3(a), the organization networks reveal a more nuanced picture of cross-country and -institution collaboration, as shown in Figure 3(b).

In addition, Figure 3(b) also reveals the loosely-coupled co-citation network at the level of organization, where Chinese institutions such as Zhejiang University and Chinese Academy of Science stand out at the core of the network.

3.4. Two top multidisciplinary publication outlets

Two publication outlets, Sustainability and Journal of Cleaner Production, clearly dominate the publication landscape of the topic, each with 19 and 18 articles in the dataset. The distant third, Sustainable Cities and Society, only has 5 articles. These journals all belong to the Web of Science category of “Green & Sustainable Science & Technology”, with the top two also belonging to those categories of “Environmental Sciences” and “Environmental Studies”, and the last one belonging to “Construction & Building Technology”.

Altogether, the top three journals appear to be more receptive to eco-design research outputs, with topics ranging from circular economy, sustainable consumption, green manufacturing to smart cities. However, it is noted that while the authorship in the top two is distributed more evenly across a wider range of authors, one author has contributed to 4 out of 5 articles published in Sustainable Cities and Society, and 3 of them focus on the notion of smart sustainable city [10,15–17].

The prominent role of the top two journals can also be shown in Figure 4(a).
3.5. Bibliographic coupling network and clusters
To identify research fronts and intellectual bases [18], both bibliographic coupling and co-citation networks of publication outlets are constructed and visualized, as shown in Figure 4.

Four clusters have been identified on the bibliographic coupling network, as shown in Figure 4(a). The first cluster (in red color) includes *Journal of Cleaner Production*, *Supply Chain Management*, *Management Decision*, *International Journal of Logistics Management*, etc. The second cluster (in green color) contains *Sustainability*, *Sustainable Cities and Society*, *Journal of Urban Technology*, etc. The third cluster includes *Computers in Industry*, *International Journal of Production Research*, and *Process Safety and Environmental Protection*, and *CRIP Annals- Manufacturing Technology*.

Five clusters have been identified on the co-citation network, as shown in Figure 4(b). The first cluster has *Journal of Cleaner Production*, *International Journal of Production Research*, *Supply Chain Management*, etc. as its prominent nodes. The second energy-building cluster has *Energy Buildings*, *Renewable and Sustainable Energy Reviews*, etc. as its central and prominent nodes. The third sustainable city cluster has *Sustainable Cities Society*, *Sustainability Basel*, *Cities*, etc. The fourth cluster includes *Waste Management*, *Resources, Conservation & Recycling*, etc. The last cluster has two often-cited journals such as *MIS Quarterly* and *Nature*.

4. Conclusion
The paper has reviewed AI- and Big Data-related articles on the topic of eco-design, which sees tremendous growth in publications since 2013, and in citations since around 2017, indicating strong-growing attention on the topic. Also, the findings about the productive countries and organizations show a healthy development in research across developing and developed countries, with co-citation networks indicating some level of cross-country collaboration. Further findings on both bibliographic coupling and co-citation networks at the level of publications reveal that *Sustainability*, *Journal of Cleaner Production*, and *Sustainable Cities and Society* are more receptive to eco-design research on the topic of AI and Big Data. In addition, *Journal of Cleaner Production* has dominant position in the co-citation network. Although the data is limited to the WoS database, the findings nevertheless provide necessary groundwork for exploring the eco-design application of AI and Big Data.

As the notion of eco-design of AI and Big Data is expected to be pertinent and relevant for designing greener strategies, products and services for greener digital transformation, we argue that more concerted efforts among researchers, funding bodies, policy-makers and industry professionals must be made to advance both the theoretical and empirical research on the nascent topic. Several questions can be asked as follows: How can we apply the most relevant design thinking and system thinking knowledge to the advancement of AI and Big Data with Eco-design? Considering the impact of ecological, material, energetic, and societal limits on both interaction and computing resources, what are the new methods to facilitate the innovative design of Big Data, Artificial Intelligence, and their cloud services and applications? In short, how can we conduct the eco-design of digital services for green digital transformation? To begin answering the questions above, researchers, funding agencies,
policy-makers and industry practitioners may find the paper helpful in mapping out the fruitful topics and publication outlets.

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