Lean and Green: Computational Efficiency and Nudging for Sustainable Fashion Recommendation

Angelo Geninatti Cossatin[1,*,†]

[1]Università degli Studi di Torino

Abstract

Sustainability is a complex topic, and it needs consideration in all aspects of recommendations. For example, the fashion industry's significant environmental and social impact necessitates new approaches to promote sustainable consumption behaviors. This work focuses specifically on two critical and interconnected aspects of sustainable recommendation: promoting environmentally conscious user behavior and reducing the computational environmental footprint of recommendation algorithms. First, it investigates the application of digital nudging techniques in fashion recommender systems to encourage environmentally conscious purchasing decisions. It describes a comprehensive user study with 251 participants, testing three interface designs that incorporate textual nudges and visual sustainability labels. Results demonstrate remarkable success in promoting second-hand garment selection, with 50-67% of participants choosing used items compared to a 7% market rate. However, the computational requirements of multimodal recommendation systems introduce their own environmental considerations. To address this paradox, this work describes a Transformer-based architecture leveraging attention bottlenecks for more efficient multimodal fusion. Early experiments suggest a significant reduction in representation dimensionality while maintaining recommendation performance. The main goal of this work is to provide a complete picture of what sustainability in recommendation entails, from consumer decisions to resource usage by recommendation algorithms.

Keywords

Digital nudging, Sustainable fashion, Recommender systems, Multimodal fusion, Green consumption, User interface design, Computational efficiency

1. Sustainability in Recommendation

Sustainability represents a complex topic and is attracting attention due to the increasing necessity to move towards a more environmentally friendly lifestyle: in 2015, the United Nations defined the Sustainable Development Goals (SDGs) in the 2030 Agenda for Sustainable Development[1], and public awareness is increasing. Recommender systems present opportunities and challenges across multiple sustainability dimensions, including supply chain impacts, algorithmic fairness, resource consumption, and behavioral influence. This work focuses specifically on two critical and interconnected aspects of sustainable recommendation: promoting environmentally conscious user behavior and reducing the computational environmental footprint of recommendation algorithms.

Regarding the first aspect, recommender systems have the potential to influence consumer behavior toward more sustainable choices. The fashion industry exemplifies this opportunity, where traditional recommendation approaches typically optimize for immediate user satisfaction while overlooking the environmental and social implications of suggested purchases [1]. However, by incorporating sustainability awareness into the recommendation process through techniques such as digital nudging, these systems can guide users toward responsible consumption without compromising their autonomy or satisfaction. One possible approach for this is detailed in Section 3.

At the algorithmic level, the computational infrastructure powering modern recommender systems introduces its own environmental footprint. Contemporary multimodal recommendation approaches,

IIR2025: 15th Italian Information Retrieval Workshop, 3th - 5th September 2025, Cagliari, Italy

*Corresponding author.

angelo.geninatticossatin@unito.it (A. G. Cossatin)

0009-0007-5378-7061 (A. G. Cossatin)

[1]https://sdgs.un.org/2030agenda

while offering enhanced accuracy through rich data representations, demand substantial computational resources for both training and inference. Section 4 describes our approach to reduce this impact.

Starting from these approaches, the goal is their integration as a step toward holistic, sustainable recommendation systems that consider both the outcomes they promote and the resources they consume in achieving those outcomes.

2. Nudging

The concept of nudging, originally developed in behavioral economics, involves modifying subtle aspects within choice environments to encourage specific decisions while preserving individual freedom of choice. Weinmann et al. defined digital nudging as "the use of user-interface design elements to guide people's behavior in digital choice environments" [2]. This approach has gained significant traction in the digital realm, where interface design can subtly influence user decisions without restricting their options. In traditional brick-and-mortar retail environments, nudging has been implemented through various strategies, such as using color-coded labels to communicate the healthiness of food products [3]. However, the digital environment allows for sophisticated nudging mechanisms that can adapt to individual user preferences and behaviors in real-time, increasing the potential of this technique, and its complexity. The application of digital nudging in recommender systems represents a particularly promising frontier. While traditional recommender systems focus primarily on predicting user preferences to optimize suggested items, they often overlook orthogonal factors that could benefit both users and society. For instance, a recipe recommendation system might suggest comfort food that maximizes user satisfaction but neglects nutritional considerations; an e-commerce platform might recommend products that satisfy immediate desires while ignoring their environmental impact due to long-distance shipping. Digital nudges offer a path toward a more holistic approach to recommendation, encouraging virtuous choices while maintaining user autonomy [4, 5, 6]. This is particularly relevant in domains where individual choices have broader societal implications, such as environmental sustainability and health [7].

As a test bed for nudging, we focused on fashion, as it presents a particularly interesting case study for digital nudging applications due to its significant environmental and social footprint. Promoting sustainable fashion consumption is particularly challenging, as several complex factors influence buying decisions. Fashion serves as a symbol of personal identity and social status [8], making it particularly resistant to rational decision-making processes. Even environmentally conscious consumers often abandon their sustainable principles when making fashion purchases, prioritizing style, price, and trends over environmental and ethical considerations [9]. Furthermore, research has consistently shown a strong preference for new clothing over second-hand alternatives. Studies indicate that even environmentally conscious consumers rarely purchase second-hand daily goods, including clothes [10]. For example, in Sweden, the revenue from second-hand clothes sales amounted to only 7% of total clothing revenue in 2020 [11], highlighting the significant gap between sustainability awareness and actual purchasing behavior.

3. Nudging for Green Fashion Consumption

To investigate the effectiveness of digital nudging in promoting sustainable fashion consumption, we conducted a comprehensive user study involving 251 participants [12]. The study tested three user interfaces designed to encourage selecting environmentally friendly and ethically produced clothing items. For each interface, we first asked participants to choose a garment they liked to infer their search goals. Then, we displayed similar items employing a different nudging strategy for each user interface. Participants could decide whether to keep the originally chosen item or swap it for one of the suggested options. The interfaces were the following. (i) *SH* recommended only second-hand garments. It featured textual nudges promoting clothes with the message "Take a look at these second-hand products: you could save money and help the environment with a GREEN choice". (ii)

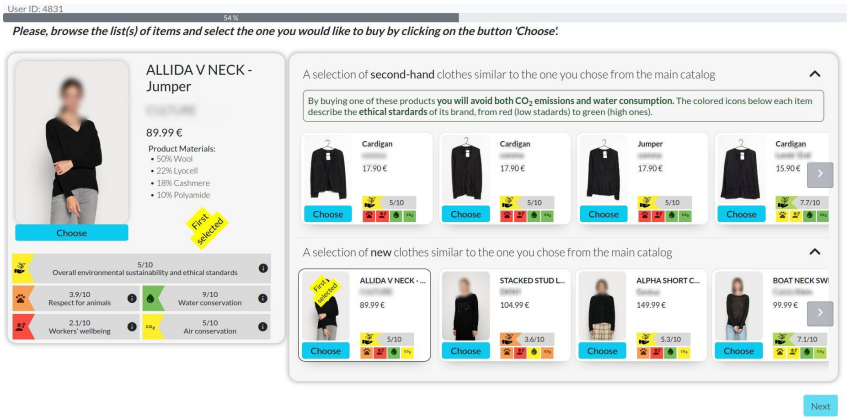

Figure 1: Recommendations page of the LABELSHNEW user interface. The other interfaces only differ in the type of nudging and/or items displayed.

LABELSH recommended only second-hand garments but combined textual nudges with visual labels summarizing sustainability and ethical standards, including detailed information about CO_2 emissions, water consumption, workers' well-being, and respect for animals. (iii) *LABELSHNEW* presented both new and second-hand alternatives with the same visual labels as LABELSH.

The results of the experiment showed remarkable success in promoting second-hand garment selection. Across the different user interfaces, 50-67% of participants chose second-hand products as their final selection, a dramatic improvement over the 7% estimated from previous market studies [11]. Specifically, LABELSHNEW achieved a 50% conversion rate to second-hand, while SH and LABELSH achieved 64% and 67% respectively. For LABELSHNEW, 21% of users chose a new cloth, but in 57% of cases the item was more ethical and sustainable than the original garment. Interestingly, users chose many more environmentally sustainable items: 80% had a better air conservation score, and 70% a better water conservation score. On the contrary, only 38% had a better workers' wellbeing score, and 27% had a better animal welfare score. This suggests that ethical considerations influenced user behavior less than the ones about environmental sustainability.

After interacting with each user interface, we asked users to evaluate the decision-making process, the interface adequacy and their satisfaction. The LABELSH interface received the highest ratings for decision-making support, with users finding the visual labels particularly useful for product comparison. Conversely, the LABELSHNEW interface was perceived as the most intuitive and informative, benefiting from its comprehensive presentation of product types. It also received the best overall satisfaction score.

Additionally, we asked users to pinpoint the factors that influenced their choices. While price was the most influential (ranging from 56 to 59%, depending on the interface), as well as style (39-49%), color (60-64%), and materials (43-53%), users also frequently considered environmental sustainability (33-38%) and ethical standards (38-40%). This is in contrast with the data from final selections above, which show that environmental sustainability is more influential in practice than ethical standards.

The preliminary results we obtained suggest increasing the adoption of nudges in clothes recommender systems to enhance user awareness about items, their sustainability, and their social impact.

4. Resource Consumption and Sustainable Computing

The environmental impact of digital systems has gained increasing attention as data centers and machine learning operations consume growing amounts of energy.

While digital nudging can promote sustainable consumption behaviors, the computational infrastructure supporting recommender systems introduces its own environmental considerations. Modern systems, particularly those utilizing multimodal item representations (incorporating text, images, audio, and other data types), require substantial computational resources for training and operation.

Multimodal recommendation algorithms often rely on very high-dimensional data. For example, in

the context of an e-commerce website for fashion, the following information could be fed as input to the algorithm: (i) Visual features: High-resolution image embeddings capturing style, color, and aesthetic properties; (ii) Textual descriptions: Natural language processing of product descriptions, materials, and brand information; (iii) User interaction data: Historical preferences and behavioral patterns.

While these rich representations enable more accurate and nuanced recommendations, they also create computational challenges. The high dimensionality of multimodal features introduces significant overhead in terms of memory usage, processing time, and energy consumption during both training and inference phases. At the same time, however, different modalities could share some information, resulting in redundancy. As a high-level example, a garment's color might be present both in the visual embeddings from the product image, and in the textual description. Information fusion involves combining multiple information sources into one [13, 14], and may be exploited to reduce this, with the goal of optimizing the computational cost of training and inference.

Traditional approaches to multimodal fusion have been applied to recommendation in the literature [15, 16, 17], but the state of the art lacks focus on a custom information fusion architecture with the goal of reducing the computational cost of recommendation.

We are currently experimenting with a novel Transformer-based architecture leveraging attention bottlenecks [18] to develop a plug-and-play approach for more efficient multimodal recommendation, which is agnostic to the specific algorithm used. Early experiments suggest that this approach can significantly reduce representation dimensionality while maintaining or even improving recommendation performance across multiple algorithms and datasets.

5. Future Directions

The above findings on digital nudging effectiveness and computational efficiency challenges point toward an important future direction, i.e., the development of comprehensive, sustainable recommendation systems that integrate user-centered sustainability promotion and resource-efficient algorithmic design. Rather than treating these as separate concerns, future research should focus on creating unified frameworks that optimize simultaneously for sustainable user behavior and minimal environmental impact. For example, we plan to further develop our fusion mechanism, making it possible to prioritize salient features such as sustainability and ethics, enabling seamless integration with the user interface for the nudging we developed.

Furthermore, using the data collected in [5, 12], this architecture may be adapted to be personalized to the user (e.g., based on individual sensitivities to different sustainability and ethics aspects), with the potential of optimizing the sustainability and ethics profile of items selected by users based on their tendencies, in addition to the visual nudges we already explored.

The ultimate vision encompasses recommender systems that serve as comprehensive sustainability platforms, integrating efficient algorithmic design with effective behavioral interventions to create measurable positive environmental impact while maintaining user satisfaction and commercial viability.

Acknowledgments

I want to thank my supervisors, Liliana Ardissono and Noemi Mauro, for their invaluable guidance and support, which has been essential in developing this work.

Declaration on Generative AI

During the preparation of this work, the author used Claude[2] to: Paraphrase and reword, and Grammar and spelling check. After using these tools, the author reviewed and edited the content as needed. The author takes full responsibility for the publication's content.

[2] https://claude.ai/

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