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Fast Fashion Footprint: An Online Tool to Measure Environmental Impact and Raise Consumer Awareness

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Abstract

Fast fashion is a rapidly expanding sector characterized by high production volumes, low costs, and short product lifecycles. While recent efforts have focused on improving sustainability within supply chains, consumer behavior remains a critical yet underexplored driver of environmental impacts. This study presents a web-based calculator tool designed to estimate both the carbon and plastic footprints associated with individual fast fashion consumption, with a particular focus on shopping behaviors, garment disposal, and laundry habits. Adopting a geographical perspective, the analysis explicitly considers the spatial dynamics of consumption and logistics within the urban context of Milan (Italy), a dense metropolitan area representative of high fashion activity and mobility. By incorporating user-reported travel patterns, logistics routes, and localized emission factors, the tool links consumer habits to place-specific environmental impacts. By involving over 360 users, the tool not only quantifies emissions and plastic waste (including microfibers) but also serves an educational function, raising awareness about the hidden consequences of fashion-related choices. Results reveal high variability in environmental impacts depending on user profiles and behaviors, with online shopping, frequent use of private vehicles, and improper garment disposal contributing significantly to emissions and plastic pollution. Our findings highlight the importance of integrating consumer-focused educational tools into broader sustainability strategies. The tool's dual function as both calculator and awareness-raising platform suggests its potential value for educational and policy initiatives aimed at promoting more sustainable fashion consumption patterns.

Keywords: fast fashion calculator; environmental impacts; carbon footprint; plastic footprint; urban geography; consumer behavior; mobility geography

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Academic Editor: Luca Salvati

Received: 25 July 2025
Revised: 20 August 2025
Accepted: 22 August 2025
Published: 23 August 2025

Citation: Senese, A.; Filippelli, E.; Barbagallo, B.; Petrosillo, E.; Diolaiuti, G.A. Fast Fashion Footprint: An Online Tool to Measure Environmental Impact and Raise Consumer Awareness. *Geographies* **2025**, *5*, 44. https://doi.org/10.3390/geographies5030044

1. Introduction

Fast fashion emerged as a response to increasing consumer demand for affordable yet trendy clothing, driven by changes in retail strategies and global market dynamics. Originating in the UK during the 1990s, retailers began to accelerate their production cycles by introducing mid-season collections in addition to the traditional two-season calendar [1]. This approach allowed them to offer fashionable items at low prices, giving rise to what was initially termed the "throwaway market." Over time, this model evolved into what is now recognized as fast fashion: a business strategy built on rapid turnover, low production costs, and high-volume sales [2].

From a geographical standpoint, fast fashion is not only a globalized phenomenon, but one that manifests through distinct spatial patterns of consumption, distribution, and environmental impact, particularly in urban settings. The rapid turnover of garments and intense flows of materials and people—between production sites, retail hubs, and consumers—constitute a spatial system that deserves critical examination. Understanding how these flows interact with the urban geography of cities, and how behaviors are shaped by local infrastructures and mobility patterns, is essential to developing effective mitigation strategies.

To remain competitive in a saturated market, brands emphasized speed-to-market and trend replication, ultimately reshaping the way clothing is designed, produced, and consumed [3,4]. Since the early 2000s, fashion brands have nearly doubled the number of collections they release annually, significantly accelerating production cycles and increasing the volume of clothing placed on the market [5].

The fast fashion industry is associated with multiple environmental concerns, including the use of toxic chemicals during low-cost manufacturing, greenhouse gas emissions from global transportation, and the short lifespan of garments leading to substantial textile waste [6]. For instance, in 2018, the fashion industry generated an estimated 2.1 billion metric tons of greenhouse gas (GHG) emissions, with fast fashion accounting for nearly half of this total [7]. In fact, the carbon footprint of manufacturing a single medium-sized polyester t-shirt is estimated at 5.5 kg of CO_2, more than double that of an organic cotton t-shirt, which emits approximately 2.34 kg of CO_2 [5].

Among the environmental impacts, water pollution and plastic contamination have emerged as particularly critical issues. These include water scarcity, untreated wastewater discharge, and the dissemination of microplastics across aquatic ecosystems [5,6,8]. The environmental burden of textile production arises from multiple stages of the process, including the treatment of raw materials and the fabrication of filaments, which often involve the use of a wide array of synthetic chemicals aimed at enhancing the quality of the final products. Furthermore, the generation of solid textile waste represents an additional critical concern, further undermining the environmental sustainability of fabric manufacturing [9]. Unlike luxury or high-end fashion, fast fashion heavily depends on synthetic, petroleum-derived materials such as polyester and nylon. This predominance is largely explained by the lower production costs and greater market availability of fossil fuel-based synthetic fibers, compared to natural alternatives like cotton or wool [10]. Notably, synthetic fibers such as polyester tend to shed plastic microfibers both during the manufacturing process and through everyday consumer practices such as washing and drying [11,12]. A 2021 study revealed that polyester microfibers comprised up to 75% of microplastics found in Arctic Ocean samples, illustrating the global scale of fashion-linked pollution [13].

In addition, the massive volume of water used in fiber and garment production contributes to growing pressure on freshwater resources, especially in regions already suffering from water stress. The dyeing and finishing stages, in particular, are known to consume thousands of liters of water per kilogram of textiles while releasing wastewater containing heavy metals, dyes, and processing chemicals into rivers and streams [5].

Although major brands have begun to implement sustainability-oriented practices (e.g., sustainable supply chain management (SSCM), improved transparency, or recycled fiber use), current efforts remain insufficient in addressing the systemic environmental burden of fast fashion. Without a substantial shift in both production models and consumption patterns, the fast fashion sector is projected to cause irreversible environmental damage by 2030 [7].

Reducing the environmental impacts of fast fashion requires more than improving production processes; it also demands a shift in consumer behavior. While supply-side solutions such as SSCM are essential, demand-side actions, including more conscious purchasing habits and responsible clothing disposal, play a critical role. In this context, raising public awareness becomes vital, particularly among younger generations who are key drivers of fashion consumption trends. We developed a web-based tool precisely to address this need: by engaging users directly and providing personalized feedback, it fosters greater awareness of the carbon and plastic footprints linked to everyday fashion choices.

This study addresses the environmental challenges posed by fast fashion by presenting a web-based calculator tool that estimates individual impacts in terms of both carbon and plastic footprints. In particular, the analysis includes user-reported behaviors (such as shopping frequency, garment care (e.g., laundry habits), and disposal practices) factors often overlooked in broader assessments. By capturing these habits, the tool identifies key behavioral drivers behind fast fashion's environmental footprint and supports awareness-raising, especially among younger consumers who tend to engage more frequently with fast fashion.

Adopting a geographical perspective, the study explores how spatial contexts shape environmental impacts. Specifically, the tool's calculations are tailored to the urban setting of Milan, Italy (i.e., a dense metropolitan area characterized by intense fashion consumption and well-developed logistics and transportation infrastructures). Emission estimates are derived from actual distances between key logistics nodes (e.g., Malpensa Airport, courier hubs, retail stores) and assumed user locations across the city. Additionally, self-reported mobility data offers insights into how consumers travel to physical stores, adding a spatial dimension to their environmental impact. This spatially grounded approach allows for a more nuanced understanding of how urban geography (such as transport systems, delivery density, and population concentration) affects individual carbon and plastic footprints. It also highlights the importance of place-based strategies for encouraging sustainable consumption patterns within the fashion sector.

Despite the growing attention to the environmental impacts of the fashion industry, there remains a critical gap in tools that allow individuals to directly estimate their own carbon and plastic footprints related to clothing consumption, and that also support behavioral change through education and self-assessment. Most available studies rely on aggregated life-cycle assessments (LCAs) or supply chain analyses [14,15], which provide valuable insights at the product or sector level but are not designed for end-user engagement or self-assessment.

Existing tools targeting individual behavior include lifestyle-oriented applications like the WWF Footprint Calculator, which addresses general categories (e.g., diet, mobility) but does not differentiate fashion-specific impacts. A few platforms or apps (e.g., Good On You, Carbonfact) provide brand or garment impact ratings but lack integration of user behaviors such as washing, shopping channels, or disposal habits. A consumer-facing example is ThredUP's Fashion Footprint Calculator, which estimates an individual's annual carbon emissions based on shopping and laundry frequency (https://www.thredup.com/fashionfootprint/, accessed on 22 August 2025). Similarly, the Ethical Clothing Fashion Footprint Calculator offers simple carbon footprint estimates derived from purchase and disposal data (https://www.ethical-clothing.com/fashion-calculator/, (accessed on 22 August 2025). Meanwhile, Farfetch's Fashion Footprint tool enables users to explore how design choices (e.g., materials like linen, polyester, cotton) affect environmental impacts such as CO_2 emissions and water use via a web-based interface (https://www.farfetch.com/it/fashionfootprinttool/, accessed on 22 August 2025)). While each of these tools contributes valuable perspectives, they predominantly focus on carbon emissions and do not incorporate plastic-related dimensions like microfiber pollution or material waste. In contrast, our web app uniquely combines both carbon and plastic footprint estimation and is grounded in self-reported user behaviors (including shopping patterns, laundry frequency, and garment life cycle practices) resulting in a more comprehensive and behavior-oriented environmental assessment.

To our knowledge, no existing tool provides a combined estimate of both carbon and plastic footprints of fashion consumption that includes variables such as shopping frequency, transportation mode, delivery type, material composition, and laundry habits, all of which significantly influence environmental outcomes [5–7]. This gap underscores the originality and relevance of our integrated, user-centered web-based tool, which not only estimates personal environmental impact but also serves as an educational intervention to raise awareness and promote more sustainable choices, targeting especially younger demographics. Through this approach, the tool enables users to better understand the hidden environmental costs of their clothing choices and fosters more sustainable behaviors.

2. Methods

To estimate the environmental impact of individual purchasing behaviors related to fast fashion, we developed a web-based calculator using the Zoho Forms platform. This tool builds upon previously validated methodologies for estimating the carbon and plastic footprints of daily activities [16,17]. In addition to serving as a scientific data collection instrument and educational resource, the tool adopts a spatialized framework that allows for the analysis of geographically grounded behaviors, particularly those shaped by urban infrastructures, transportation systems, and localized logistics.

Designed to capture both environmental outcomes and their spatial determinants, the tool integrates geographical variables such as mobility distances, transport modes, and proximity to retail and logistics hubs. By anchoring the analysis in the metropolitan context of Milan, the methodology reflects the spatial complexity of consumer practices and enables the assessment of place-based environmental impacts.

2.1. Web App Development

The web-based application we developed is designed to serve both as: (i) a scientific data collection instrument; and (ii) as an awareness-raising tool aimed at guiding users toward more sustainable consumption choices.

The tool allows to anonymously estimate the overall environmental impact as the sum of (i) CO_2-equivalent ($CO_{2\text{-eq}}$) emissions related to transportation and packaging, considering both in-store and online shopping, and (ii) macro- and micro-plastic release associated with clothing materials. By explicitly considering spatial variables such as trip distance, transport infrastructure, and delivery density, the tool connects individual choices to spatially structured emissions.

Data were collected between January and June 2024 through the web-based calculator (the prototype is available at https://forms.zohopublic.eu/unimi1/form/FastFashionFootprint/formperma/TJKtaV4wxOAHWuJtYz1urZ61ZO5xVcbik8256ASd7Vw, accessed on 22 August 2025). Participation was entirely voluntary and anonymous. The survey was promoted across the three main campuses of the University of Milan (UNIMI) (i.e., the Milan city center campus, which hosts humanities courses; the Città Studi campus, the hub for science and technology; and the Sesto San Giovanni campus, where language studies are concentrated) as part of a university course on climate change and citizen science. Students participating in the course were encouraged to complete the survey and to further disseminate it among peers and acquaintances. Additional outreach activities were conducted in the framework of dual (learning and working) training projects (Percorsi per le Competenze Trasversali e l'Orientamento, PCTO), involving students from secondary schools in Milan and Bergamo provinces. As a result, the majority of respondents were university and high school students from Lombardy, although participation was not restricted to this region. This recruitment strategy aligns with the study's educational objective and reflects a population segment highly engaged in fast fashion consumption and online behaviors.

2.2. Web App Structure

The web app is structured into four sections: (i) user profile and awareness: age, gender, province of residence, perception of synthetic fiber content in clothes, purchasing habits, and awareness of fast fashion brand emissions; (ii) $CO_{2\text{-eq}}$ emissions from shopping behaviors includes distance to physical stores, transportation mode, number of trips, and the number of online orders and returns; (iii) plastic footprint from clothing use: estimation of synthetic fiber content in purchased garments, frequency and type of garment disposal, and laundry and dryer usage frequency to estimate microfiber release; and (iv) user reflection and feedback: assessment of perceived usefulness and awareness raised by the tool (Figure 1 and Table 1).

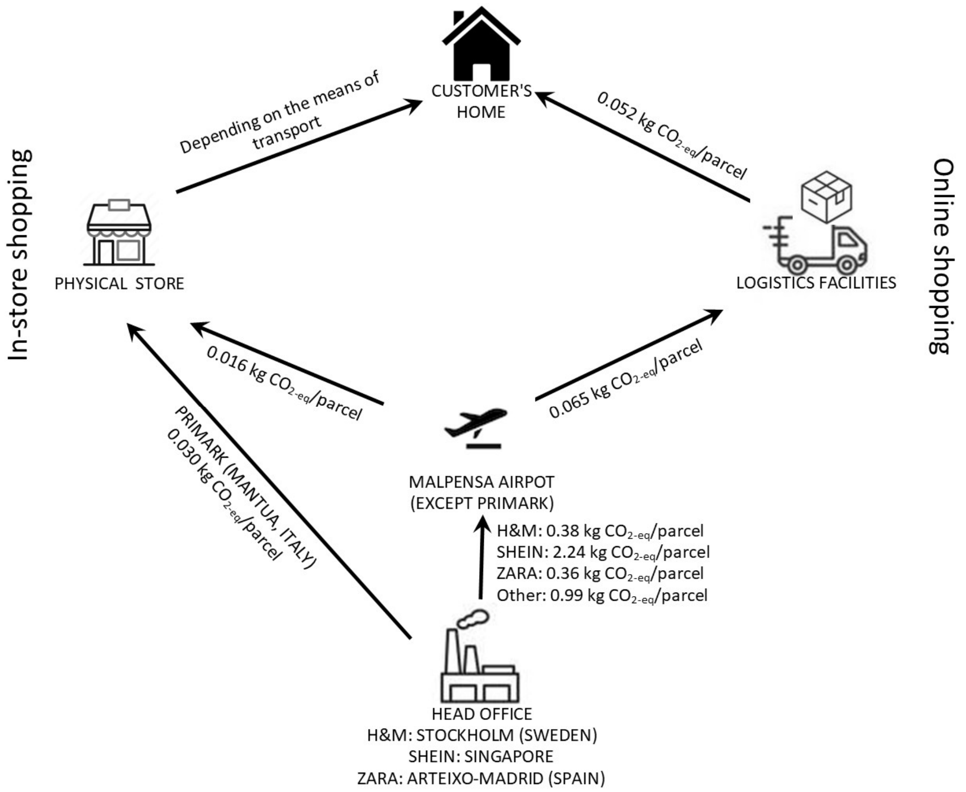

Figure 1. Schematic representation of the methodology used to estimate the carbon footprint of fashion purchases. Emissions were calculated for each transport phase, considering different delivery routes for online and in-store shopping. Parcel-based estimates account for vehicle load assumptions (e.g., 100 parcels for couriers, 2000 for shops). A separate route was considered for Primark (Mantua–Milan).

Questions on the level of awareness of the impacts of fast fashion (all based on the 5-point Likert scale) are alternated with targeted questions for impact estimation (Table 1). The first of these questions relates to the dramatic increase in the production of synthetic fiber fabrics, citing a published scientific study. The second question ascertains knowledge of the fact that H & M, Primark, Shein, and Zara are among the fast fashion brands with the highest environmental impact in Europe. This question refers to data reported in Statista [18]. At the end of the section regarding the impact of online shopping, participants are asked if they are aware that buying products from physical shops reduces CO_2 emissions [19]. Finally, the last question asks if participants have learnt anything about the negative impact of fast fashion thanks to this questionnaire.

Table 1. Questions and possible answers proposed in the webapp. With asterisk (*) are reported the open-ended questions, to be given in numerical format. With hashtag (#) are reported the open-ended questions, to be given in no-numerical format.

Question Number	Question	Answers
(1) User profile and awareness		
1	Age	*
2	Gender	Female Male I prefer not to answer
3	Province of residence	#
4	Indicate, as a percentage, how much you think your clothes on average contain synthetic fibres	*
5	Did you know that the production of polyester-based fabrics, which are made from plastics, is increasing dramatically?	5-point Likert scale
6	Where do you usually buy clothes?	Large shopping malls Trusted stores Tailoring Online Other
7	Indicate your preferred retailer from the list below	Shein Zara H & M Primark Purchase from other retailers Other
8	Did you know that Zara, H & M, Primark and Marks & Spencer are among the most influential fast fashion brands in Europe?	5-point Likert scale
(2) $CO_{2\text{-eq}}$ emissions from shopping behaviors		
9	How far is it from your home if you buy products from a physical store?	I don't buy from physical stores Close to home Less than 1 km Between 1 and 5 km Between 5 and 10 km Between 10 and 15 km More than 15 km Other
10	Which method do you most frequently use to travel to the store?	I don't buy from physical stores Walk or bike Scooter Motorcycle Car Public transport

Table 1. *Cont.*

Question Number	Question	Answers
11	If you were to buy from a physical store, would you be accompanied on your journey?	I don't buy from physical stores No, I go alone Yes, there are two of us Yes, there are three of us Yes, there are four of us Other
12	How often do you go shopping if you buy products from a physical shop?	Almost never I buy a few times a year I buy once every two months I buy once a month I buy twice a month I buy three times a month or more
13	How many items of clothing do you buy in shops in a year?	*
14	How many times do you buy clothes online?	I don't buy products online Almost never I buy a few times a year I buy online once every two months I buy online once a month I buy online twice a month I buy online three times a month I buy online more than four times a month
15	How many items of clothing do you buy online in total each year?	*
16	Indicate how often you return purchased items as a percentage.	*
17	Did you know that buying products from physical shops can reduce CO_2 emissions?	5-point Likert scale
(3) Plastic release		
18	What size do you wear?	S or smaller M L XL XXL or larger
In the following fields, please indicate the number of outfits that you replace each year, throw away and therefore do not reuse in a sustainable manner. (Remember that, if synthetics are correctly disposed of after use, they can become 'secondary raw material' used to build, for example, shockproof playgrounds or athletics tracks.)		
19	Sporty outfits consisting of a sporty sweatshirt and long trousers or leggings that you change into every year and then throw away, meaning you do not reuse them in a sustainable way.	*
20	Elegant suits (long suits or shirts and trousers) that you change every year and then throw away, meaning they cannot be reused.	*

Table 1. *Cont.*

Question Number	Question	Answers
21	Casual outfits consisting of a T-shirt and trousers or a skirt that you change every year and then throw away, meaning they are not reused in a sustainable way.	*
22	Winter outfits consisting of heavy trousers and sweatshirts that you change every year and then throw away, meaning they are not reused in a sustainable way.	*
23	Summer outfits consisting of shorts or a skirt and a tank top that you change every year and then throw away, meaning you don't reuse them in a sustainable way.	*
24	Underwear sets (pairs of boardshorts or two-piece women's underwear sets) that you only wear for a year before throwing them away, meaning they are not reused.	*
25	Costumes (such as pairs or two-piece sets of underwear) that you change into every year and then throw away, meaning they cannot be reused.	*
26	Pairs of socks that you replace every year and then throw away, meaning they are not reused in a sustainable way.	*
In the following fields, please indicate the number of accessories that you replace and throw in the bin every year, and which you therefore do not reuse in a sustainable manner. (Remember that, if disposed of correctly after use, synthetics can become 'secondary raw material' used to build shockproof playgrounds or athletics tracks, for example.)		
27	Bags that you replace every year and then throw in the rubbish, meaning you are not managing reuse in a virtuous way.	*
28	Hats that you replace every year and then throw in the rubbish, meaning you are not managing reuse in a virtuous way.	*
29	Slippers that you replace every year and then throw in the rubbish, meaning you are not managing reuse in a virtuous way.	*
30	Hair elastics that you change every year and then throw away, so they are not reused in a sustainable way.	*
31	Sunglasses that you change every year and then throw away, so they are not reused in a sustainable way.	*
32	Gloves (excluding woollen ones) that you replace every year and then throw away, meaning they are not reused in a sustainable way.	*
33	Shoes that you replace every year and then throw away, meaning they are not reused in a sustainable way.	*
34	Scarves or foulards that you change every year and then throw away, meaning they are not reused in a sustainable way.	*
35	How many times do you use your washing machine per week?	*
36	How many tumble-drying cycles do you use per week?	*
37	Thanks to this questionnaire, did you learn anything new about the negative impact of fast fashion?	3-point Likert scale

Notably, several questions are designed to elicit spatial data (e.g., distances to physical stores, transport modes used, and place of residence) which enable a geographically contextualized estimation of emissions and plastic footprints. This spatial layer of data collection is critical for understanding how individual impacts are embedded in specific urban geographies.

2.3. CO_2-Eq Emissions Estimation

The web app calculates the $CO_{2\text{-eq}}$ emissions associated with both mobility and packaging, with variations based on purchasing behaviors and transportation modes. These calculations are grounded in a spatially explicit methodology that considers geographic distances, vehicle emission factors, delivery routes, and return rates.

According to Yang et al. [19], average packaging emissions are 0.103 kg CO_2/parcel ($EF_{pack\text{-}ps}$) and 0.163 kg CO_2/parcel ($EF_{pack\text{-}online}$) for in-store and online shopping, respectively. For this reason, the survey included a question about the number of products purchased per month or year in physical shops (n_{ps}, asked by question number 12, Table 1) and online (n_{online}, asked by question number 14, Table 1). To estimate the $CO_{2\text{-eq}}$ emissions due to packaging (E_{pack}), the applied equation is:

$$E_{pack} = EF_{pack\text{-}ps} \cdot n_{ps} + EF_{pack\text{-}online} \cdot n_{online} \quad (1)$$

To estimate emissions due to mobility, we considered the methods reported by Senese et al. [20] and Senese et al. [17], in which case GHG emissions depend on the distance traveled and the emission factor of the transport method used (Figure 1).

In particular, we focused on four of the fast fashion brands with the highest environmental impact in Europe (i.e., H & M, Primark, Shein and Zara, [1,7,21], question number 7, Table 1). Therefore, the first important investigation was whether products purchased online came from physical shops or warehouses. Unlike other brands (such as Decathlon), H&M, Shein and Zara products do not come from physical shops. Instead, they come directly from the main retailer, which is often located at the headquarters where the products are manufactured. Primark was excluded from the calculation of online emissions because direct online shopping is not permitted; it is only possible to check the availability of selected garments in shops.

Moreover, the Department of Environmental Science and Policy at the University of Milan (Milan, Italy), where the researchers conducting this study are based, was considered the customer's home for both physical and online purchases. Therefore, Milan Malpensa International Airport was considered as the transport destination from the country of production to Italy, as it is the closest airport to Milan with the highest number of commercial flights in Italy.

For in-store shopping, we considered emissions from (i) the cargo plane journey from the country of production to Malpensa Airport, (ii) transport by heavy goods vehicles from Malpensa Airport to the physical shop, and (iii) the customers' journey from the physical shop to their home. For online purchases, we considered emissions due to (i) the cargo plane journey from the country of production to Malpensa Airport, (ii) transport by heavy goods vehicles from Malpensa Airport to the courier depot, and (iii) the courier's journey to the customer's home.

To estimate the distance between the country of production to Malpensa Airport, we evaluated the locations of the four retailers' headquarters that we focused on in this study (i.e., H & M, Primark, Shein and Zara) by looking for information directly on their websites. In Sweden, 21 suppliers and factories produce H&M clothing and accessories; the company's headquarters are in Stockholm. Primark does not have any factories and relies on suppliers around the world. SHEIN is headquartered in Singapore and serves customers in over 150 countries from operations centers around the world. Finally, fifty percent of Zara's products are manufactured in Spain, particularly in Arteixo, Galicia, where the Inditex Group is headquartered. As far as Primark is concerned, we chose the largest of the four Italian factories depicted on the portal, i.e., the one with the most employees: 246 employees at the location on Via Don Primo Mazzolari 9 in Casaloldo, Mantua, 46040 (https://globalsourcingmap.primark.com/, accessed on 22 August 2025). We then calculated the distance from these cities to Milan, following commercial interlines. For Stockholm (H & M), Singapore (SHEIN), and Arteixo (Zara), we considered traveling by plane to Milan Malpensa Airport. For Mantua (Primark), we evaluated the distance by truck from the head office to the physical shops.

As for Arteixo (Zara), there is a 610 km stretch of land before the Madrid Airport (d). We assessed these emissions ($E_{land\text{-}mobility}$) from transporting goods by articulated truck (considering the emission factor of 0.605 kg $CO_{2\text{-eq}}$/km of heavy goods vehicles, EF_{HGV}, Table 2) as:

$$E_{land\text{-}mobility} = \frac{d \times EF_{HGV}}{number\ of\ parcels} \quad (2)$$

In particular, we divided the total calculated emissions (369.1 kg $CO_{2\text{-eq}}$) by the number of packages transported per trip (number of parcels). A medium-duty diesel truck (7.5 t) can transport up to about 2000 kg. Assuming each parcel weighs 500 g (i.e., the weight of a coat), the truck can transport approximately 4000 parcels. Only the emissions from the outbound journey are taken into account. This is because it is assumed that the return truck is not empty and that these emissions are attributed to the goods transported during the return journey. Therefore, the average impact per parcel per land trip from Arteixo to Madrid Airport is 0.092 kg $CO_{2\text{-eq}}$/parcel.

Although several calculators for estimating air freight emissions are available, we used the one from WebCargo, following Senese et al. [20]. Depending on the departure and arrival airport and the weight of the imported cargo (0.5 kg), the WebCargo calculator provides values defined as tank-to-wheels GHG emissions in kilograms of CO_2 equivalent (Figure 1). If the users declares that they are going to buy from another retailer (i.e., not H & M, Primark, Shein or Zara), we have calculated the emissions as the average value among the considered brands.

Once we arrived at Malpensa Airport, we tried to figure out the journey that the purchased goods would take. To keep things simple, we started with online purchases, for which delivered parcels can be tracked. We found out through their technical support that H&M and Zara do not provide data on their couriers. However, by consulting their order tracking site, we found that H&M mainly uses SDA Express. Shein's main couriers are GLS, BRT and DHL [22]. We then verified the information received from the administration and the sites by purchasing some products to determine which courier company they were referring to. We purchased two products from H & M: a nail polish with order number 60687089925 and a lip gloss with order number 60657244865. The package weight for the nail polish was 0.7 g and the package weight for the lip gloss was 0.2 g. Both products arrived via SDA courier (Italian postal service), as stated by support. The H & M depot name (Madrid Wh) and the product sorting center name (Stardella, Pv) were also written on the carton. We did the same for Zara. We purchased a set of Christmas adhesive tapes with order number 53563194225. However, it arrived in a private blue vehicle. The name of the depot, Calle Pi Albardiales, was also marked on the carton, but there was no storage center in Italy. Thus, various intermediaries are involved in the storage and distribution of goods. However, we can more accurately identify the location of the couriers' storage areas than the warehouses they refer to, which may vary by product and brand. We have therefore simplified the calculation, considering only the distance from the logistics facilities of the couriers to the customers.

On average, the distance between courier departure points and the Department of Environmental Science and Policy at the University of Milan is 10.9 km (i.e., GLS: 11.9 km, DHL: 18.6 km, SDA: 6.5 km). Given that Malpensa Airport is 65 km from the Department, we simplified the estimation of the average distance between Malpensa Airport and the courier departure points around the Department to be 54.1 km (i.e., by the difference between 65 km and 10.9 km). We considered the emission factor of heavy goods vehicles (0.605 kg$CO_{2\text{-eq}}$/km, [23]). Unlike the journey from Arteixo to Madrid Airport, where all the garments have to be shipped (with an assumed vehicle capacity of 4000 parcels), not all the garments arriving at Malpensa Airport have to reach the same courier departure point. Therefore, we cannot consider the full load for the emission breakdown. To account for the fact that intermediate transport from the airport may serve multiple distribution centers or couriers, we conservatively assumed that only one-eighth of the truckload (≈500 parcels) was destined for the courier hub under consideration. Then, using the distance of 54.1 km and assuming 500 parcels are transported per vehicle, we applied Equation (2) and estimated total emissions per trip to be 0.065 kg $CO_{2\text{-eq}}$/parcel. Similarly for the journey from Arteixo to Madrid, we only considered the outward journey of the goods as it is assumed that the vehicles are not returned empty but are used for other deliveries to reduce costs.

Finally, we estimated the impact of the final step of the journey of the goods purchased online (i.e., the section operated by the courier to the customer's home). When calculating the number of parcels transported by a courier, we considered the volume rather than the transportable weight: the Italian Postal Service's shipping site reports the transport of around 150 parcels per vehicle. Although the maximum load capacity can reach up to 150 parcels per trip, we considered a realistic average of 100 parcels, accounting for partial loads and non-optimized routes. Assuming a light commercial vehicle with an emission factor of 0.239 kg $CO_{2\text{-eq}}$/km [23] and an average distance traveled of 21.8 km (round-trip), the total emissions per courier journey are 0.052 kg $CO_{2\text{-eq}}$/parcel (applying Equation (2)).

Regarding in-store purchases, it is challenging to estimate the exact location of the stores. Therefore, we applied the same transport distance (54.1 km) and the same emission factor (0.605 kg $CO_{2\text{-eq}}$/km) used for the intermediate leg of online purchases (i.e., from Malpensa Airport to courier hubs,). However, we adjusted the number of transported parcels to reflect the wholesale nature of deliveries to physical shops. Specifically, we assumed that physical retailers receive significantly larger shipments in terms of quantity and product homogeneity, leading to a higher number of items per delivery vehicle compared to individual online orders. Based on an estimated shipment of 2000 parcels per truck, the resulting emissions were calculated as approximately 0.016 kg $CO_{2\text{-eq}}$/parcel. In the case of Primark, a different assumption was made, the most representative Italian supplier was identified in Casaloldo (Mantua), approximately 100 km from Milan. We assumed that the transport from this location to the physical shops occurs via heavy-duty trucks with an emission factor of 0.605 kg $CO_{2\text{-eq}}$/km. Given the wholesale nature of these deliveries, we estimated a load of 2000 parcels per trip, resulting in emissions of approximately 0.030 kg $CO_{2\text{-eq}}$/parcel. Finally, the GHG emissions due to transport from the shop to the customer's home (E_{ps}) depend on the means of transport chosen. This calculation takes into account the distance between the shop and the customer's home (d, asked by question number 9, Table 1), the most frequently used means of transport (asked by question number 10, Table 1) influencing the emission factor (EF_{t-ps}, Table 2), how many people the customer is traveling with (*pass*, asked by question number 11, Table 1), and how many purchases are made per year (t, asked by question number 12, Table 1) multiplied by two to account for the return journey:

$$E_{ps} = \frac{d \times EF_{t-ps}}{pass} \cdot t \cdot 2 \quad (3)$$

Specifically, for shared trips, the emissions are divided by the number of passengers.

Finally, all emissions calculated in this section are multiplied by a factor according to the percentage of returns made (asked by question number 15, Table 1).

Table 2. List of all emission factors considered in this study and the relative source.

Vehicle	Emission Factor	Source
Walk or bike	0 kg $CO_{2\text{-eq}}$/km	
Scooter	0.053 kg $CO_{2\text{-eq}}$/km	[23]
Motorcycle	0.091 kg $CO_{2\text{-eq}}$/km	[23]
Car	0.166 kg $CO_{2\text{-eq}}$/km	[23]
Public transport	0.014 kg $CO_{2\text{-eq}}$/km/pass	[17]
Heavy goods vehicles	0.605 kg $CO_{2\text{-eq}}$/km	[23]
Light goods vehicles	0.239 kg $CO_{2\text{-eq}}$/km	[23]

By simulating logistics flows and consumer movements anchored in the urban geography of Milan (e.g., routes from Malpensa Airport to courier hubs, from stores to consumers, and between distribution centers) the methodology reflects the role of urban form, infrastructure, and territorial organization in shaping emissions. This reinforces the tool's value for geographical research, particularly in urban environmental studies and mobility geography.

2.4. Plastic Release Estimation

To estimate the environmental impact of plastic waste, we assessed the number of outfits and accessories discarded annually by each user (asked by question number from 19 to 34, Table 1). While the estimation is grounded in self-reported behaviors, it is spatially contextualized by integrating factors such as body size (which varies culturally and geographically), local brand prevalence, and regional purchasing habits. Importantly, the spatial location of respondents (captured through the "province of residence" field) enables potential future analyses of geographical variability in plastic footprint intensity across urban and non-urban settings.

The estimation model incorporates average garment weights by type and size, adjusting for user-reported body size (a variable with both individual and demographic implications). The percentage of synthetic fibers is differentiated by fashion retailer, reflecting the spatial segmentation of supply chains, and consumer markets. For example, the synthetic content of garments varies across brands like Shein or Zara, which are more prevalent in certain geographic areas or income brackets.

By linking fiber composition, garment types, and usage patterns to user profiles and brand preferences, the model provides a geographically nuanced estimate of plastic waste. This spatialization of clothing disposal behaviors helps highlight how local consumption patterns, brand geographies, and material flows interact in shaping the environmental footprint of fast fashion.

For each outfit, we considered the average weight (g) for a medium size (M) (Table 3). To adjust the weight according to size (asked by question number 18, Table 1), we applied a 5% decrease for size S, a 5% increase for size L, a 10% increase for size XL, and a 15% increase for size XXL or larger. The percentage of synthetic fibers used in the calculation varied depending on the main brand mentioned by the user (asked by question number 7,

Table 1). Specifically, if the user indicated Shein as their most frequently purchased brand, the synthetic fiber percentage was taken from column 3 of Table 3. If they selected H & M, Primark, or Zara the percentage from column 4 of Table 3 was applied. For other brands, the percentage from column 5 of Table 3 was used. This differentiation allowed us to better reflect the variability in plastic content among different fashion retailers. The content of synthetic materials for each accessory is shown in Table 4.

Table 3. List of outfit considered in this study and the relative average weight (g) for a medium size (M) and the percentage of contained synthetic textile fibers differentiated by brand.

Outfit	Average Weight (g) for a Medium Size (M)	% Synthetic Textile Fibers for Shein	% Synthetic Textile Fibers for H & M, Primark and Zara
Sporty outfits	600	83	75
Elegant suits	550	68	57
Casual outfits	650	63	25
Winter outfits	700	82.5	40
Summer outfits	450	80	48
Underwear sets	250	50	50
Costumes	100	100	100
Pairs of socks	52.5	50	52.5

Table 4. List of accessories considered in this study and the relative average weight (g) and the percentage of synthetic textile fibers contained.

Accessory	Average Weight (g)	Average % of Contained Synthetic Textile Fibers
Bags	400	100
Foulards or scarved	100	50
Gloves	100	50
Hair elastics	40	100
Hats	100	50
Shoes	600	100
Slippers	130	100
Sunglasses	50	100

To estimate unintentional microplastic release, we considered release due to washing machine or tumble dryer use. In addition to the frequency with which these appliances are used (asked by question number 33 and 34, Table 1), we asked what percentage of garments are made of synthetic textile fibers (asked by question number 4, Table 1). We assumed an average release of 0.2 g/kg from the washing machine and 0.8 g/kg from the tumble dryer, with an average capacity of 7 kg for both appliances [16]. The release resulting from the first wash (equal to 0.33% [24]), which is considerably higher than the subsequent washes, was included in this calculation.

3. Results

The analysis was conducted on 374 completed questionnaires. After a quality control check, we considered a database of 363 users. To better contextualize the findings and support the replicability of the study, we report here the main demographic characteristics of the survey participants. The majority of respondents identified as female (62%), followed by male (37%), with 1% choosing not to disclose their gender. In terms of age, the most represented age group was 21–30 years old, accounting for approximately 38% of the sample. This age range reflects a population segment particularly engaged in online activities and more likely to be frequent consumers of fast fashion. The sample also included a smaller proportion of respondents aged 31–50 (8%) and over 50 years (14%). The prevalence of younger participants reflects the dissemination strategy adopted for this study, which focused on educational environments. In particular, the web-based tool was promoted during a university course on climate change and citizen science at the University of Milan, with activities organized across its three main campuses (i.e., Humanities at city center, Science and Technology at Città Studi, and Languages at Sesto San Giovanni). Additionally, the tool was disseminated among high school students in Milan and the province of Bergamo through educational outreach programs (PCTO). The gender imbalance, with a higher number of female respondents, likely results from greater interest in the topic of sustainable fashion among women. Since participation in the survey was entirely voluntary and no gender-based recruitment was conducted, this disproportion reflects spontaneous engagement rather than selection bias.

From a geographical perspective, this sample is spatially concentrated in Northern Italy, with a significant number of respondents located in and around the Milan metropolitan area. This urban-centric sample allows us to explore how spatial features (e.g., population density, access to logistics infrastructure, and urban mobility behaviors) influence the environmental footprint of fast fashion consumption.

The results highlight a wide variability in consumer behavior and environmental impact related to fast fashion purchases. The mean annual carbon footprint due to fashion-related shopping was 27.24 kg $CO_{2\text{-eq}}$, with values ranging from 1.04 to 371.20 kg $CO_{2\text{-eq}}$. The high standard deviation (41.82 kg $CO_{2\text{-eq}}$) reflects heterogeneous behaviors, including frequent online shopping and long-distance transportation.

These emissions stem primarily from physical store purchases (mean = 13.57 kg $CO_{2\text{-eq}}$/year, SD = 21.11 kg) and online purchases (mean = 10.88 kg $CO_{2\text{-eq}}$/year, SD = 27.62 kg), with additional contributions from packaging emissions for both behaviors (mean = 1.49 kg $CO_{2\text{-eq}}$ for physical store and 1.30 kg $CO_{2\text{-eq}}$ for online).

Spatial dynamics play a key role in shaping these patterns. In-store shopping emissions are influenced not only by trip frequency but by urban mobility configurations—such as the distribution of stores, transportation modes, and travel distances within dense metropolitan areas. In contrast, online shopping emissions depend heavily on the structure and efficiency of last-mile delivery networks. The Milan context, characterized by relatively compact geography and multimodal transport options, offers a representative case for understanding how urban form mediates environmental impacts of fast fashion logistics

Regarding consumption behavior, respondents reported an average of 14.5 garments/year purchased in physical stores and 8.0 online, with some individuals declaring up to 150 items/year per channel. This wide variability (standard deviation of 19.4 and 13.7, respectively) supports the idea that a small subset of highly active consumers disproportionately contributes to the environmental footprint, especially when combined with inefficient transportation or packaging practices.

The standard deviations in both emission totals and purchase volumes emphasize the diversity of fast fashion habits, ranging from "low-impact users" to "super-consumers".

Despite the fact that the total annual carbon footprint was slightly higher for physical store purchases than for online shopping, a closer analysis of emissions per parcel reveals a more nuanced picture.

This result is strongly linked to geography: in densely populated areas like Milan, consumers often rely on private vehicles for short- to medium-range shopping trips, which leads to significant per-trip emissions. Conversely, online logistics benefit from consolidated deliveries and optimized routes, features that are more effective in urban areas with high delivery density. These findings confirm the spatial dependence of environmental outcomes, showing that both travel behavior and delivery emissions are mediated by the geography of infrastructure and population distribution.

Specifically, online shopping results in higher per-unit emissions, mainly due to the lower number of parcels transported per shipment. For physical store purchases, intermediate transport emissions were estimated at 0.016 kg $CO_{2\text{-eq}}$/parcel (from Malpensa Airport to shops), or 0.030 kg $CO_{2\text{-eq}}$/parcel in the case of Primark, whose products are sourced from a supplier in Mantua (Italy). By contrast, the same transport leg for online shopping (i.e., from Malpensa Airport to the courier hubs) results in emissions of 0.065 kg $CO_{2\text{-eq}}$/parcel, due to the smaller number of items per shipment. The environmental impact of reaching the store is therefore considerable, especially when using private vehicles for relatively short trips

When considering the entire logistics chain, emissions per parcel for Shein, whose supply chain includes long-distance air freight from Singapore, reached up to 2.36 kg $CO_{2\text{-eq}}$/parcel. Similarly, products from H&M and Zara showed values of 0.50 and 0.48 kg $CO_{2\text{-eq}}$/parcel, respectively, based on transport from their production countries to Malpensa Airport and subsequent local delivery.

Overall, although total yearly emissions are higher for physical shopping due to greater purchase frequency, online shopping tends to have a disproportionately larger environmental impact per item.

However, the customer's trip to the store is not included in these calculations, which can significantly increase the overall footprint depending on the distance traveled and transport mode used. In fact, a significant share of emissions from physical store purchases is influenced by how users travel to the store. Survey responses revealed that 63% of participants use a private car, while only 11% go on foot or by bicycle and 23% rely on public transportation (Figure 2). The environmental impact of reaching the store is therefore considerable, especially when using private vehicles for relatively short trips.

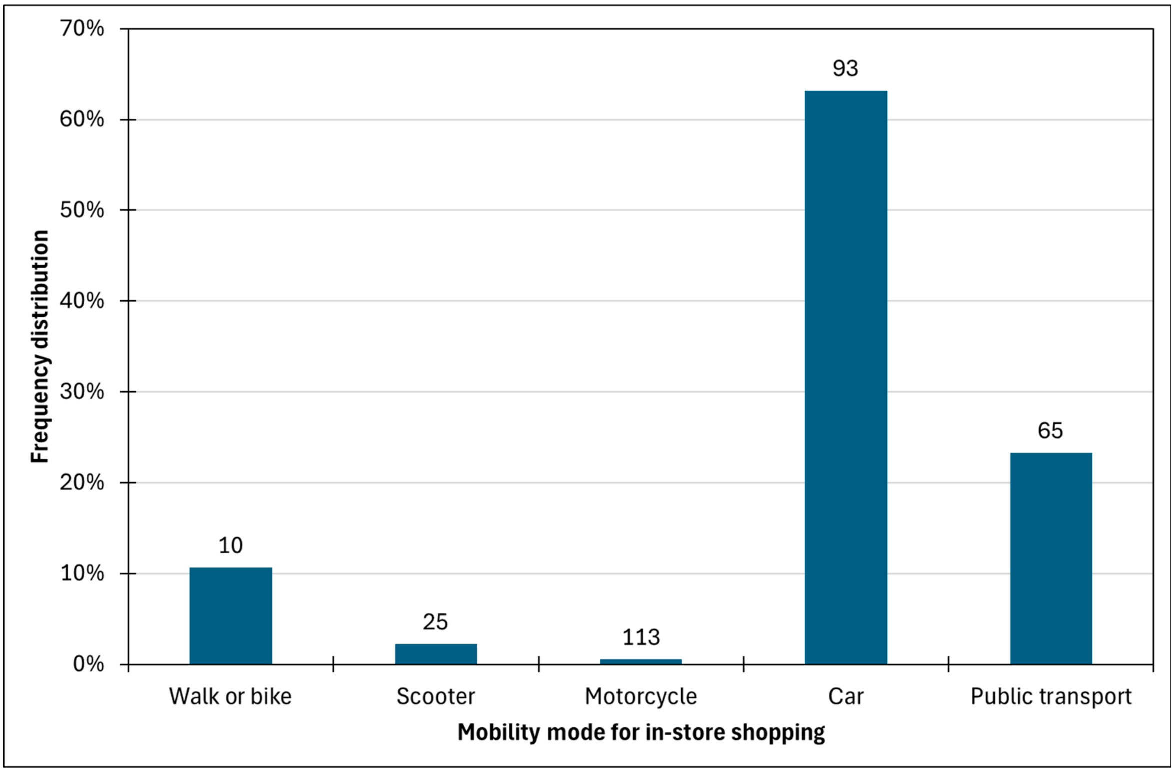

Figure 2. Distribution of respondents by transportation mode used to reach physical stores.

This confirms a key insight from mobility geography: transport-related emissions are not only a function of mode and distance, but also of urban form, trip frequency, and passenger occupancy. In compact urban settings, unsustainable mobility patterns can rapidly offset the emission savings of centralized logistics. Encouraging shifts toward active or shared mobility thus requires both behavioral change and urban policy interventions that reshape accessibility and transport alternatives.

Distance also plays a key role (Figure 3): while 31% of users travel between 1 and 5 km to reach the store, another 26% cover between 5 and 10 km, and 34% travel more than 10 km. These values suggest that a large portion of users engage in short- to medium-distance car trips, which can generate substantial emissions when performed individually.

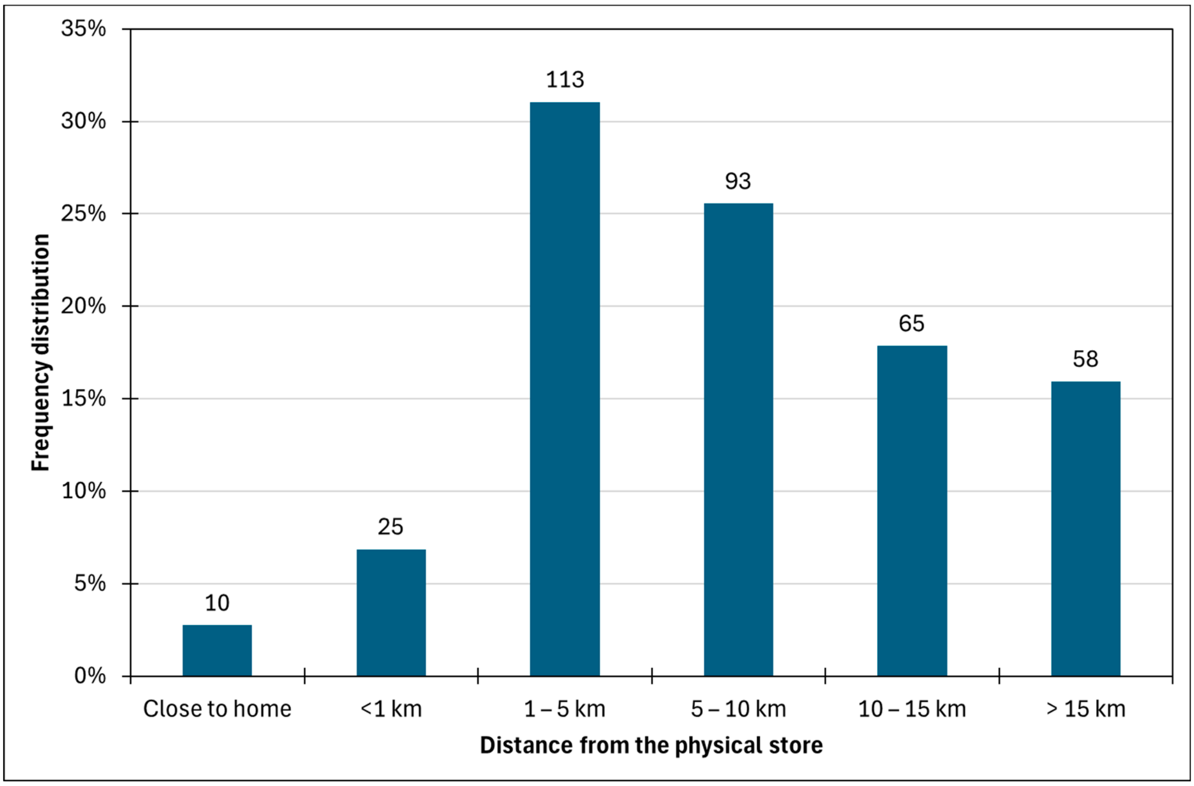

Figure 3. Distance traveled by respondents to reach physical stores.

Regarding vehicle occupancy, only 10% of respondents drive alone, while 37% report being accompanied by one other person, and another 17% share the trip with two or more passengers. These values help distribute the emissions per person but do not completely offset the dominance of private vehicle use in the overall footprint.

When combined, these mobility patterns indicate that transportation to physical stores contributes significantly to the total carbon footprint of in-store purchases, and in many cases may equal or exceed the emissions from upstream logistics (e.g., transport from airport or distribution hub to the store). This highlights the importance of promoting sustainable mobility options in addition to addressing supply chain impacts.

The cross-analysis of transportation mode and distance traveled to reach physical stores reveals important patterns with implications for environmental impact (Figure 4). As expected, car use dominates across all distances, and becomes especially prevalent beyond 2.5 km: car users represent the majority of trips from 1 to more than 15 km, with peak frequencies between 1 and 5 km (63 respondents, equal to 17.3%) and between 5 and 10 km (62 respondents, equal to 17.0%). Given the relatively high emission factor of car travel (0.166 kg $CO_{2\text{-eq}}$/km), these trips contribute significantly to the overall footprint of in-store purchases. In contrast, walking and biking are largely restricted to short distances: 83% of those using active mobility (i.e., walk or bike) travel between 1 and 5 km or less, confirming the strong dependency of sustainable transport modes on urban proximity. Similarly, public transportation is used mainly for intermediate distances, with a notable presence between 1 and 5 km (31 respondents, equal to 8.5%) and between 5 and 10 km (20 respondents, equal to 5.5%), reflecting accessibility and availability constraints. Two-wheeled motorized vehicles (scooters and motorcycles) are used infrequently, and primarily in the range between 1 and 10 km, contributing marginally to overall mobility emissions. This analysis confirms that car dependency increases with distance, and that even moderate trips to physical stores (between 5 and 15 km) made by car can offset the logistical advantages of centralized wholesale delivery.

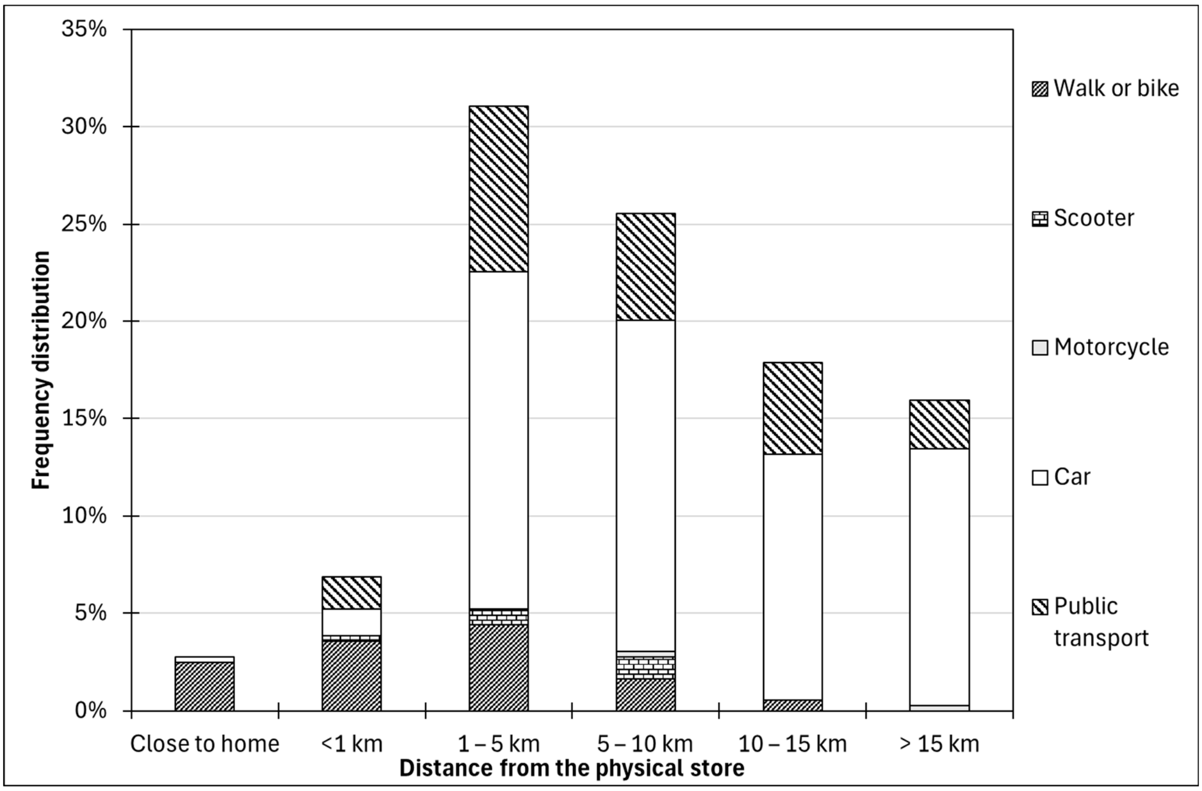

Figure 4. Cross-analysis of transportation mode and distance traveled to reach physical stores.

From a spatial planning perspective, these findings underscore the need for better integration of sustainable mobility options into urban retail geographies. The location of stores, accessibility of public transport, and urban walkability directly influence individual environmental footprints. Understanding these spatial interactions is critical for formulating place-based policies for sustainable consumption.

The analysis of plastic waste associated with fashion consumption reveals a high variability among users.

This variability is not only behavioral but also spatial, reflecting how purchasing habits, disposal options, and awareness levels differ across territorial contexts. Urban residents may have easier access to recycling infrastructure or donation centers, while consumers in peripheral areas may rely more on landfill disposal. Though not the focus of this analysis, these underlying spatial disparities merit further investigation in future studies.

To validate user responses, we performed a cross-check between the total number of garments purchased in one year (both in-store and online) and the number of outfits declared as discarded. This comparison allowed us to identify and exclude inconsistent entries, ensuring the internal consistency and reliability of the dataset used for plastic footprint estimation. The average annual amount of plastic attributed to discarded clothing and accessories was 5.04 kg/year, with a minimum of 0.00 kg/year and a maximum of 72.71 kg/year per user. This wide range reflects different consumption behaviors and disposal practices. The standard deviation of 7.24 kg/year further highlights the heterogeneity of user habits. This variability can be further explored by examining the types and quantities of garments and accessories discarded annually, as reported by users.

User-reported data on clothing and accessory disposal revealed considerable variability across item types. On average, respondents discarded 2.42 casual outfits, 1.92 summer outfits, 1.24 sports outfits, 1.16 winter outfits, and 0.73 elegant outfits per year without applying sustainable end-of-life management. The average number of discarded underwear sets reached 3.83, while 5.10 pairs of socks were thrown away annually. Items such as scarves (0.37), bags (0.30), and hats (0.16) showed lower average turnover, yet maximum values indicate that some users reported discarding up to 94 scarves, 12 bags, and 8 hats in a single year. Accessories like gloves, shoes, and elastic hairbands were also frequently discarded, with average annual values ranging between 1.25 and 3.22 items, and maximum values as high as 100 units (for hairbands). Figure 5 offers a visual representation of the distribution of annual item disposal across different garment and accessory categories. For clarity, the figure displays frequency counts up to 30 discarded units per year per user, although a small number of responses exceeded this threshold, particularly for items like hair elastics, scarves, and underwear sets, which reached up to 100 units. The graph highlights that the majority of users reported discarding between 0 and 5 items per year, confirming the highly skewed nature of the dataset. Nonetheless, the presence of outliers underscores the diversity of consumer behavior and the importance of capturing both average trends and extreme cases in plastic impact assessments. These results highlight the importance of including a wide range of garments and accessories in plastic impact assessments, as non-traditional clothing items can significantly contribute to the total plastic footprint.

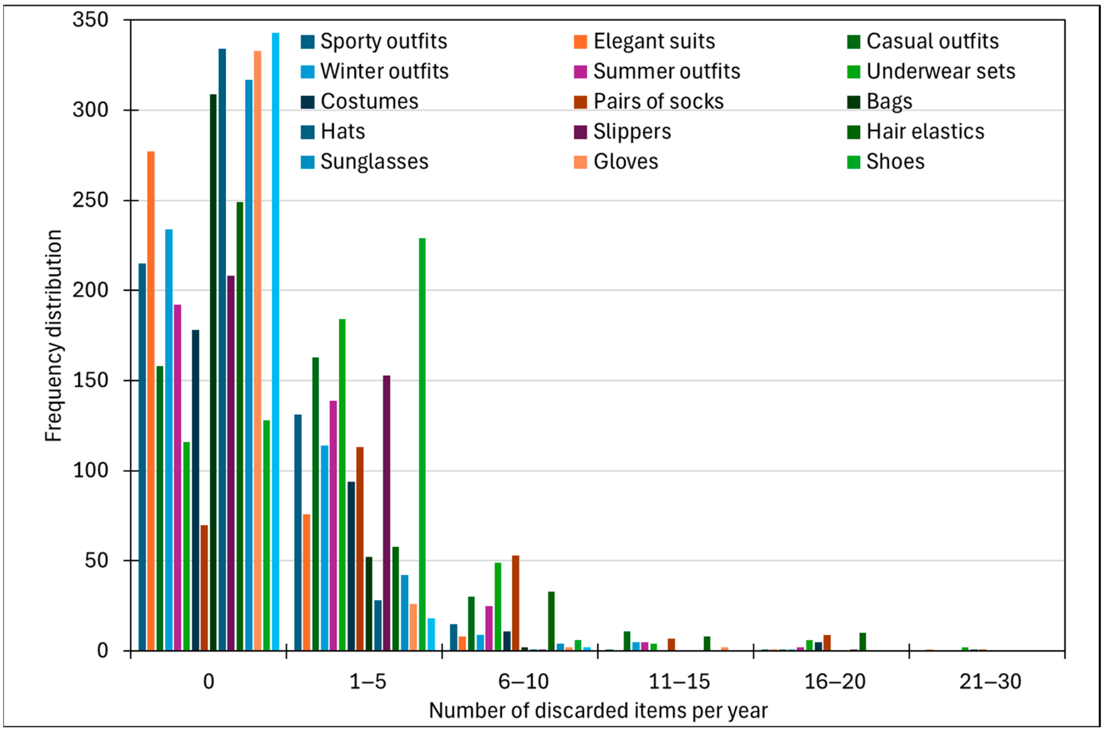

Figure 5. Number of users who reported discarding each type of outfit or accessory, grouped by intervals of discarded items per year.

Additional contributions to plastic pollution were estimated from microfiber release during washing and drying. The average annual emission of plastic microfibers from washing machines was 0.25 kg/year, while tumble dryers contributed 0.34 kg/year on average. Although these values are lower than the plastic footprint from discarded items, they still represent a non-negligible source of microplastic dispersion, especially for frequent users of synthetic garments. Maximum values reached 8.62 kg/year for washing and 9.23 kg/year for drying, confirming the potential impact of these everyday activities.

To contextualize the observed behaviors, our findings were compared with previous research on fashion consumption and environmental impact. For example, [5] report that younger consumers, particularly those aged between 20 and 35, are more likely to engage in frequent fast fashion purchases while showing growing environmental awareness, patterns that are reflected in our sample. Moreover, a recent study by [25] conducted in Norway with over 1200 participants examined how consumers' attitudes toward natural and synthetic fibers are influenced by technocentric versus ecocentric worldviews. While most respondents in that study preferred natural fibers and associated them with higher sustainability, this perception was not necessarily linked to lower clothing consumption. In fact, the authors observed a paradoxical effect: stronger beliefs in the sustainability of certain fibers correlated with continued or even increased consumption, thereby undermining the potential environmental benefits. By contrast, our tool focused on the behavioral and quantitative aspects of consumption, emphasizing not just material preferences but actual shopping frequency, laundry habits, and disposal practices. This approach enables a more direct estimation of the environmental footprint. However, it also highlights a similar concern: even among participants aware of sustainability issues, impactful behaviors such as frequent shopping or inadequate disposal were still common. Our results support the argument made by [25] that material substitution alone is insufficient. Reducing fast fashion's environmental burden requires addressing consumer behavior more broadly, promoting degrowth-oriented attitudes and consumption reduction, alongside material innovation.

4. Discussion

The results of our study highlight the complex and spatially structured nature of the environmental impacts associated with fast fashion consumption. By using an integrated, web-based tool informed by geographical assumptions and spatial data, we were able to quantify both the carbon and plastic footprints of user-reported behaviors. This approach reveals how individual choices (often seen as isolated) are embedded within specific urban geographies, shaped by infrastructure, mobility patterns, and retail logistics.

Beyond quantification, the tool offers a spatial lens to interpret consumption behaviors, enabling the identification of place-based drivers of environmental impact. In doing so, it contributes to the emerging field of geography-informed sustainability research, where environmental outcomes are understood as the result of interactions between people, infrastructure, and place.

4.1. Mobility and Transport as Major Carbon Hotspots

While the total annual carbon footprint was higher for in-store purchases (average 14.48 purchases/year compared to online shopping (average 7.97 purchases/year), this outcome largely reflects behavioral frequency. However, the spatial configuration of transport systems plays a decisive role in shaping per-item emissions. In the case of Milan (i.e., a dense, multimodal urban environment) our analysis shows how private vehicle use for short-to-medium distances significantly contributes to the environmental footprint of in-store shopping.

These findings resonate with literature in urban geography and transport studies, which emphasizes the role of urban form, modal availability, and trip chaining in determining mobility emissions. Our results confirm that even in dense cities, the persistence of car-oriented shopping behavior undermines the environmental advantages of physical retail. Moreover, spatial disparities in store accessibility and last-mile logistics further differentiate the environmental burden of online vs. in-store shopping.

Yang et al. [19] identified transportation, packaging, and returns as the main contributors to online shopping emissions, while in-store purchases are primarily impacted by transportation and store operations. Their study demonstrates that the relative carbon efficiency of online versus in-store shopping strongly depends on the distance traveled by consumers. Specifically, total carbon emissions per consumer increase by 29% for online shopping when the physical store is less than 2 km away. However, emissions decrease by 29% and 50% when the distance exceeds 20 km and 40 km, respectively. This aligns with our findings, which indicate that for many users who travel short-to-medium distances by car to reach stores, individual trips may negate the emission benefits of centralized logistics. In fact, over 60% of respondents reported using a private car to reach stores, with 43% covering distances greater than 5 km. When trips are made individually, the emissions from the customer's journey can exceed those of upstream logistics. Browne et al. [26] also point out that buying in physical stores can have a greater impact because of the home-store trip, which can result in higher energy consumption per product than the total energy used for transportation from the factory to the store. In fact, the impact of the consumer reaching the physical store depends on the type of vehicle used, the distance traveled, and the number of items purchased. This suggests that behavioral shifts toward sustainable transport modes (e.g., walking, biking, or using public transport) could play a key role in reducing fashion-related emissions.

Moreover, Yang et al. [19] highlight that last-mile logistics in online shopping—although generally perceived as inefficient—can benefit from optimization strategies such as consolidated deliveries and the use of neighborhood delivery points. In such scenarios, small parcels are delivered to hubs close to consumers' homes, who then walk to pick them up. If scaled appropriately, this model could lower emissions compared to individualized trips to physical stores. This suggests that promoting consolidated delivery options and investing in local pickup infrastructure may be a promising direction for reducing the environmental impact of fashion-related logistics.

Previous research has also highlighted that the net environmental impact of online versus in-store shopping depends on multiple interacting factors, which must be carefully considered in footprint assessments. Van Loon et al. [27] distinguished between first-, second-, and third-order effects. First-order impacts include the energy consumption and lifecycle emissions associated with ICT infrastructure used for processing online purchases, such as servers, data centers, and consumer devices [28,29]. Yang et al. [19] reported that the average Google search (including both the Google servers and the consumer PC) emits from 0.2 to 7 g of CO_2. Second-order effects involve the transformation of supply chains: while replacing energy-intensive physical stores with more efficient warehouses may reduce emissions [30,31], actual savings depend heavily on logistics factors such as delivery density, time windows, packaging requirements, and failed deliveries [28]. It is also important to note that transport-related emissions tend to dominate over warehousing emissions in retail supply chains. The typical ratio between transport-related CO_2 and warehouse-related CO_2 is around 9:1 [32], meaning that logistics emissions are overwhelmingly driven by distribution rather than storage. As a result, the net carbon impact of e-commerce logistics depends critically on the efficiency of outbound deliveries from storage or sortation centers. Importantly, higher packaging use in e-commerce can offset some of the gains from centralized distribution [33]. Third-order (or rebound) effects refer to behavioral patterns that may reduce the substitution between store visits and home deliveries [29]. For instance, consumers may still engage in shopping-related travel (e.g., for browsing, social purposes, or complementary purchases), which undermines the assumed environmental advantage of online channels [34]. Van Loon et al. [27] ultimately emphasized that comparisons between online and in-store retailing are highly sensitive to assumptions about system boundaries, particularly regarding last-mile logistics and consumer travel behaviors.

It is also important to bear in mind that the emission estimates presented in this study were based on the hypothetical scenario of a consumer living in the metropolitan area of Milan, a dense Italian urban setting with relatively optimized delivery logistics. However, delivery emissions are highly sensitive to drop density (i.e., the number of deliveries made per route). As highlighted in previous research [35], delivery rounds in rural areas can generate up to five times more CO_2 emissions per item than those carried out in compact city centers. This suggests that applying our model to low-density or peripheral regions could result in significantly higher carbon footprints, and therefore, the estimates reported here may represent a conservative scenario in terms of delivery efficiency.

From a methodological standpoint, our model introduces a geographically disaggregated structure for estimating emissions, accounting for actual distances between logistics nodes (e.g., Malpensa Airport, courier hubs, retail stores) and consumers' reported positions in the urban territory. This spatial breakdown enhances the realism and applicability of footprint estimations, offering a replicable framework for other cities.

4.2. Clothing Disposal and Plastic Waste: Beyond Garments

The analysis of plastic waste reveals not only behavioral but also territorial variability, suggesting that spatial context plays a role in shaping garment disposal habits. Although our current analysis focused primarily on the Milan area, future disaggregation by province or urban-rural categories could reveal significant patterns in plastic impact tied to place-specific factors such as infrastructure availability, waste collection practices, and fashion culture.

Plastic waste analysis revealed a substantial annual footprint (5.41 kg/year on average), primarily due to discarded synthetic clothing and accessories. While the average user reported discarding a few items per year (e.g., 2.41 casual outfits, 5.03 pairs of socks), outliers (particularly for hair elastics, underwear sets, and scarves) showed disposal rates as high as 100 items/year.

Therefore, our analysis revealed that the environmental burden of plastic waste is not limited to traditional garments. While the estimated annual plastic footprint was greater for clothing items (average = 3.88 kg/year; max = 44.15 kg/year), accessories still contributed significantly, with an average of 0.98 kg/year and peaks of up to 9.90 kg/year. The relatively high standard deviations (5.57 kg/year for clothing and 1.20 kg/year for accessories) highlight considerable heterogeneity among users. These findings emphasize the need to include accessories (often overlooked in environmental impact assessments) within strategies aimed at reducing fashion-related plastic waste. Importantly, we validated reported disposal rates by cross-checking them against declared purchases, which enhanced the internal consistency of the dataset. This methodological step reinforces the reliability of the findings and underscores the importance of integrating qualitative and quantitative validation when working with self-reported data.

In addition, microplastic release from domestic laundering, while not spatially located in emissions terms, is nevertheless influenced by local energy systems, appliance types, and housing characteristics—all of which are geographically mediated.

In fact, microfiber release from washing and drying machines emerged as a secondary but still relevant source of plastic pollution (up to 9.23 kg/year in extreme cases), pointing to the need for both behavioral and technological interventions. This concern is supported by global evidence: according to a 2019 United Nations report, households in the United States and Canada alone release over 878 tons of plastic microfibers annually into the oceans through laundry activities. These microplastics can travel long distances and persist in remote environments. Indeed, Amelia et al. [36] found that polyester fibers, commonly used in fast fashion garments, accounted for approximately 75% of the microplastics identified in the Arctic Ocean. Such findings underscore the far-reaching consequences of microfiber pollution and reinforce the importance of addressing both domestic laundering practices and material choices in clothing production.

These findings highlight the need to expand the geographical lens beyond mobility, encompassing the full material cycle of fashion consumption and its spatial variations—from purchase to disposal.

4.3. Environmental Awareness and User Engagement

User responses to awareness-related questions suggest that while environmental consciousness about production impacts is relatively widespread, the geographical dimension of consumption impacts—especially those related to mobility and logistics—is less recognized. This indicates a knowledge gap where spatial education could play a transformative role.

User responses to the awareness-related questions embedded in the survey reveal important insights into the general level of knowledge about the environmental impacts of fast fashion. While a majority of respondents were already aware of the increasing use of synthetic fibers in clothing (39% "definitely", 41% "quite a lot"), and of the high environmental impact of brands like H&M, Primark, and Zara (41% "definitely", 36% "quite a lot"), fewer participants were aware that shopping in physical stores can reduce CO_2 emissions (only 24% answered "definitely", and 29% "quite a lot"). This gap suggests that while the issue of plastic use in fashion is relatively well recognized, the environmental implications of consumer behaviors (particularly transport-related emissions) are less understood. Notably, 80% of users reported learning something new about the environmental impact of fast fashion thanks to our web-app, indicating that the web-based tool succeeded in its dual goal of data collection and awareness-raising. These findings highlight the need for broader education initiatives focused not only on production impacts but also on the hidden consequences of logistics and mobility choices associated with fashion consumption.

The strong engagement observed among respondents demonstrates that spatialized, personalized feedback is an effective way to raise awareness. By making the geographical consequences of individual actions visible and measurable, our tool functions as both a research device and a geographical education platform.

5. Conclusions

The web app developed in this study demonstrated its dual role as both a data collection tool and a spatially informed awareness platform. By engaging users in a highly localized and personalized estimation process, the tool exposed the often-overlooked geographical dimensions of fast fashion's environmental impact. This confirms the potential of interactive digital tools not only to foster environmental literacy, but also to enhance spatial awareness among consumers, particularly younger generations.

One of the key contributions of this study lies in its methodological integration of spatial variables (e.g., travel distances, transport modes, delivery routes, and urban density) into the estimation of both carbon and plastic footprints. This spatial framework grounds environmental metrics in the lived geographies of consumers, revealing how place matters in shaping both behaviors and impacts. Milan, as a case study, offers a rich urban laboratory where fashion consumption, logistics networks, and dense mobility infrastructures converge.

Based on our findings, several place-based intervention areas emerge. First, promoting sustainable urban mobility (e.g., walking, cycling, or shared transport) could significantly reduce emissions linked to in-store shopping, especially in compact urban settings. Second, encouraging logistics optimization (e.g., consolidated deliveries, neighborhood pickup hubs) may mitigate emissions from online shopping, particularly in metropolitan areas. Third, raising awareness about the spatial lifecycle of fashion items, from global production routes to local disposal practices, can support more informed and geographically grounded consumption decisions. Fourthly, circular practices, such as reuse, donation, and recycling of textiles, should be promoted, focusing also on technologies to capture microfibers in domestic appliances

Finally, this research lays the groundwork for further comparative geographical analyses of fashion-related environmental impacts across different urban, peri-urban, and rural contexts. By adapting the tool to diverse territorial settings, future work could explore how infrastructure, access, and social practices vary geographically and shape sustainable consumption outcomes. In this way, the study contributes not only to environmental assessment, but also to the growing field of spatially explicit sustainability science, where geography is not background, but framework, variable, and driver.

Author Contributions: Conceptualization, A.S. and G.A.D.; methodology, A.S., E.P. and G.A.D.; software, A.S., E.F. and E.P.; validation, A.S., E.P., B.B., E.P. and G.A.D.; formal analysis, A.S.; investigation, A.S., E.P., B.B., E.P. and G.A.D.; data curation, A.S.; writing—original draft preparation, A.S. and G.A.D.; writing—review and editing, A.S. and G.A.D.; visualization, A.S. and G.A.D.; supervision, A.S. and G.A.D.; project administration, A.S. and G.A.D. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: According to Italian legislation as interpreted by data privacy and academic integrity frameworks, ethics committee approval is not required for anonymous, non-invasive surveys where no sensitive personal data are collected. Our study used no identifiable or sensitive information, and the collected data were anonymized and processed in aggregate form.

Informed Consent Statement: Informed consent for participation was obtained from all subjects involved in the study.

Data Availability Statement: Dataset available upon request from the authors.

Acknowledgments: The researchers involved in the study are grateful to Sanpellegrino Levissima S.p.A., Stelvio National Park (ERSAF), DARA—Department for Regional Affairs and Autonomies—of the Italian Presidency of the Council of Ministers, ECOFIBRE s.r.l., EDILFLOOR S.p.A., Geo & tex 2000 S.p.A., Manifattura Fontana S.p.A. for their support.

Conflicts of Interest: The authors declare no conflicts of interest.

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