Proceedings of the 2023 Winter Simulation Conference
C. G. Corlu, S. R. Hunter, H. Lam, B. S. Onggo, J. Shortle, and B. Biller, eds.

SUSTAINABILITY ASSESSMENT THROUGH SIMULATION: THE CASE OF FASHION RENTING

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ABSTRACT

The fashion industry is widely known as one of the most environmentally impacting. To address the overconsumption issue, the fashion renting business model allows renting clothes or accessories instead of buying them, extending the useful life of products. However, concerns about the sustainability of fashion renting supply chains are arisen, especially due to reverse logistics. In this context, a hybrid simulation model is developed to support fashion companies in the design and evaluation of renting supply chain configurations. Through Discrete Event Simulation (DES) logistics flows are represented, while Agent-Based Modeling (ABM) integrated with Geographic Information System (GIS) allow to represent supply chain's nodes in the real environment. GIS concurs to estimate the sustainability of the supply chain importing effective data related to the covered distances. The proposed parametric model will enable performing scenario analyses to assess the best configuration in terms of environmental impact.

1 INTRODUCTION

In the last years, the attention paid on sustainability issues is globally increasing, representing a key challenge to be competitive on the market. The fashion industry is one of the main sector in terms of revenues and employment, being one of the most relevant economies in the global scenario. As reported by Costa et al. (2020), indeed, around 1,000 billion of euros are annually generated, covering 7% of the global exports. Besides, the fashion industry is widely recognized as one of the most polluting, due to the high water and energy consumption as well as waste generation (Ciarapica et al. 2017; Pereira et al. 2021). As stated by Sohn et al. (2021), production consistently emerges as the main contributor to the environmental impacts considering fashion items like jeans and t-shirts, even if the use phase needs also to be taken into account due to potential negligible customers' behaviors. Sustainability issues in this industry are indeed strictly related to the fast fashion trend. One of the key characteristics of this phenomenon is the creation of new collections in shorter time and lower price, to match the overconsumption in the fashion mass market. As stated in the "State of Fashion" report made by McKinsey & Company and The Business of Fashion (2019), indeed, one woman out of three considers a garment old when it has been wore twice. An increased amount of wastes is generated, as well as emissions and raw material consumptions. Fast fashion is therefore playing its part in the pollution problem of the fashion industry.

In this context, increasing products durability covers a key role to drastically reduce wastes and emissions, as well as new materials consumption. To maximize products utilization, new business models are gaining higher attention. For instance, the Collaborative Consumption Business Models (CCBM) are focused on moving from "ownership" to "usage" in a sharing perspective, guaranteeing at the same time customers to wear always something new. Although products durability can be increased through the use of high-quality and resistant materials, as well as repairing, consumers could nowadays be quickly bored of their prolonged use, dismissing these durable products prematurely. The collaborative consumption based on renting has been therefore become of particular interest as the overall durability of products is increased by sharing their usage among several consumers instead of by only the buyer. The fashion renting phenomenon has been developing in a global scale as part of the circular economy paradigm, overcoming the “buy, use and dispose” linear economy principle through reutilization.

Besides, some concerns have arisen about the effective sustainability of sharing strategies. The limited resolution and quality of existing data on fashion-induced environmental impact could indeed generate unreliable assumptions (Sohn et al. 2021), such as considering some supply chain strategies more sustainable than others under any circumstances. For instance, the Life Cycle Assessment (LCA) study conducted by Levänen et al. (2021) analyses the CO_2 emissions generated by a pair of jeans, comparing five ownership and end-of-life scenarios (i.e., base, reduce, reuse, recycle and share). The results show that the share scenario has the highest global warming potential, mainly due to increasing transportations linked to the products take back and refurbishment. On the other hand, Sohn et al. (2021) highlight that production represents the main contributor to the environmental impact in case of purchased products.

According to this, the simulation of supply chain processes, including logistics, covers a key role to evaluate their sustainability, supporting the identification of the best supply chain configuration in terms of CO_2 emissions. A preliminary assessment is even more critical due to the evidence that the introduction of circular business models, like renting, requires significant changes in the supply chain, such as the need to manage reverse logistics and refurbishment centers. In addition, moving from traditional to rental supply chain, as well as integrating these models, requires moving towards a Product Service System (PSS). The effectiveness of simulation modelling to evaluate sustainability in complex supply chains is confirmed by several contributions (Wang and Gunasekaran 2017; Rebs et al. 2019).

The paper therefore aims to realize a hybrid simulation model that integrates Discrete Event Simulation (DES), Agent Based Modelling (ABM) and Geographic Information System (GIS), using AnyLogic® as simulator software. The simulation model has been developed parametrically to guarantee flexibility in representing different supply chain configurations to evaluate how environmental impacts change moving from one to another.

This work is structured as follows: in section 2, an overview of the state of the art about simulation and sustainability in fashion renting is resumed; in section 3, the proposed simulation model is described, and results shown in section 4; finally, main conclusions are summed up in section 5.

2 SIMULATION AND SUSTAINABILITY IN FASHION RENTING

2.1 Simulation To Assess Sustainable Supply Chain Management

As stated by Adhitya et al. (2011) and Barbosa et al. (2023), the Sustainable Supply Chain (SSC) refers to the integration of environmental, economic and social aspects within supply chain operations. To manage a SSC, innovative tools towards operational excellence support the improvement of sustainable supply chain performances (Mangla et al., 2020). Simulation modelling addresses the need of testing sustainable alternatives to traditional supply chain configurations. Most of the contributions related to the application of simulation in the Sustainable Supply Chain Management (SSCM) refer to the energy sector (Allen et al. 2019; Che et al. 2022; Jaegler and Burlat 2012; Sukumara et al. 2014; Walzberg et al. 2019) and DES and ABM are often jointly applied (Barbosa et al. 2023; Fani et al. 2022; Taghikhah et al. 2021). To simulate distribution processes, GIS has been integrated to manage real paths for logistics fleet in the work of Barbosa et al. (2023). As widely known, simulation is mainly used to realize scenario analyses in order to compare different configurations following a “What if?” approach. Melkonyan et al. (2020), for instance, realize a System Dynamics (SD) model to compare sustainability among three different distribution configurations for a local food network. Adhitya et al. (2011) model the diaper supply chain to evaluate sustainability performances changing the distribution network (i.e., number and location of distributors) and reorder policies (e.g., shipping frequency). Even Che et al. (2022) compare different supply chain configurations, considering centralized and decentralized decision making approaches.

Considering the fashion industry, only two works can be found: Fani et al. (2022) use hybrid simulation to investigate the effects of customers behavior within stores and its influence to others and to the business performances during and after the rental service; Kumar et al. (2022) apply DES to model workwear garment renting in business-to-business scenario, focusing on the inventory management.

2.2 Fashion Renting Supply Chain

The fashion renting has been investigated by Hu et al. (2014), who describe it as a closed-loop supply chain in contrast with the regular fashion supply chain. On the one hand, in traditional purchasing processes consumers buy fashion products, use and wash them during their lifecycle and dismiss them at the end. On the other hand, in renting models consumers use only temporary the product and, at the end of the rental period, take it back to the store. Here, the product is checked to evaluate if it can be rented again or not: in the first case, the product is repaired if needed and refurbished before being available for renting again; in the second case, it is dismissed or recycled when possible. Washing and repairing services are quite often outsourced making, together with the taking back flow, the logistics process critical.

Successful fashion renting case studies have been presented by Lai et al. (2018) for the American and Chinese markets, with the Rent The Runway and Melizu platforms respectively. Besides, in the recent years several initiatives for renting garments and accessories have been developed, covering different configurations such as business-to-customer (B2C) or customer-to-customer (C2C) platforms, as well as brand-owning or third parties solutions. For instance, the Italian DressYouCan is a B2C platform for renting garments and accessories branded DressYouCan or made by emerging designers, as well as by well-known brands or made available by users from the DressYouCan community. Always in Italy, the Twinset brand has launched in 2019 the “Please don’t buy” initiative, developing a mono-brand collection dedicated to the rental service, while Sisterly is a startup funded in 2022 and totally based on the peer-to-peer renting of only luxury accessories, like the English By Rotation. Besides the cited cases, not only new products but also second-hand garments and accessories can be rent on some of those marketplaces, like Drexcode, and both online and offline distribution channels can be found as renting services. In addition, some of the rental include also subscription services to access discounts and offers, while Endless Wardrobe, for instance, allows to buy the fashion item at the end of the rental period with a discount of 80%.

As anticipated, even if the interest paid on collaborative models has grown in the last years due to the overconsumption issue linked to the fast fashion phenomenon, concerns about the effective sustainability of sharing business models are arisen. In particular, the trade-off between benefits like the increased durability of rented fashion products and cons related to the reverse logistics processes to manage their taking back and refurbishing is still a challenge. This issue is demonstrated by the work of Levänen et al. (2021), who conduct a LCA on the production and distribution of a pair of jeans resulting that the share scenario has the highest global warming potential, even compared with the traditional use, due to logistics-related emissions.

3 PROPOSED SIMULATION MODEL

3.1 Simulation Model Overview

Starting from the evidence of the state of the art, a hybrid simulation model to assess the environmental impacts of fashion supply chains for traditional and renting configurations has been proposed. DES is used to model distribution and return flows, while ABM integrated with GIS to model supply chain nodes as agents. The software AnyLogic® has been used due to its flexibility in managing different type of simulations (i.e., ABM and DES). Flexibility is one of the main criteria followed to develop the proposed model, in order to make easier the conduction of scenario analyses starting from the same model and only changing inputs, according to a data-driven approach. For instance, production facilities, distributors and stores are imported from a datasheet where their number and location can be easily changed and uploaded to assess different supply chain configurations.

To compare traditional and fashion renting supply chains, critical nodes for both the configurations have been included in the proposed model. On the one hand, the buying process for a fashion item has been modeled considering production plants, distributors, stores and customers as involved agents (i.e., for production, distribution and usage stages). On the other hand, fashion renting business models require to manage also the return flow, including washing and refurbishment centers. Reorders from stores to distributors and from distributors to production facilities are modeled for both the supply chain configurations and are generated considering different reorder points for agent type. Customers' buying or renting orders in store, indeed, trigger direct and reverse logistics flows according to the available stock along the supply chain. Despite traditional supply chains, customers entering the store for renting fashion items will come back to return them at the end of the service. For the returning flow, the proposed model includes the more impacting scenario, as consumers do not rent another item when returning the previous, as it has been considered more realistic, nowadays, that most of the customers approach the rental service just for special occasions. Taken-back products are checked at the store to evaluate if they can be rented again or dismissed (e.g., in case of non-repairable items). In the first case, they will be collected in store and delivered to the closest washing and refurbishment center according to the scheduled shipping frequency.

While the location of production plants, distributors and stores is read directly from the AnyLogic® database, customers location has been assumed considering an average distance from the store. Other assumptions included in the proposed model are the identification of a single item type per simulation run and an average renting period. These assumptions reduce complexity in simulation modelling without compromising the obtained results and suggestions, and can be integrated as data-driven in future developments of this work. More in details, the location of production plants, distributors and store are defined according to a real-case involving an Italian fashion company, having the production plant located in the Florentine district. The geographical distribution of warehouses and stores reflects the scenario analyses the company is evaluating, as well as the average distances of customers and washing and repairing centers from stores, and other parameters (e.g., initial stock per node, replenishment criteria and daily orders). On the other hand, generating a single item type per simulation run has set in order to evaluate if and how the item type influences the environmental impact of buying or rental options.

Traditional and fashion renting supply chains have been modeled as shown in Figure 1.

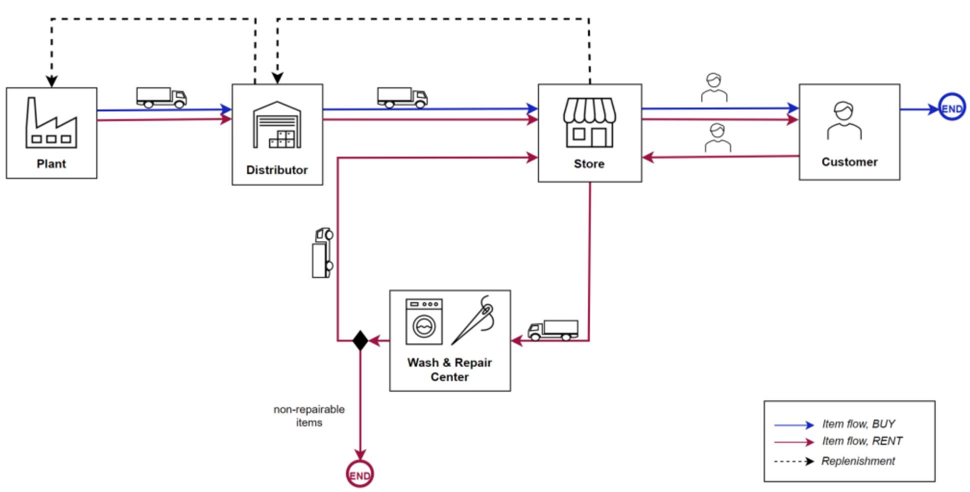

Figure 1: Traditional and Fashion Renting Supply Chain.

3.2 ABM

First step for the development of the simulation model has been the creation of the agents, in order to represent supply chain nodes, vehicles and both customers' and replenishment orders. Supply chain nodes are created as a population of agents, all with the same characteristics excepting for location. To represent deliveries, the geographical area has been created, as both orders and vehicles cover specific regions.

For distributors and stores, a population of agents is used because there are multiple nodes of this type in the supply chain, all with the same characteristics in terms of internal processes, but located in different positions. Similarly, vehicles used to transport orders from one node to another in the supply chain has been modeled as a population of agents. Orders have been modelled as an array collection associated to each region, that is has been modelled as an area in Anylogic. Each area is then associated with a fleet of vehicles, which are responsible for transporting orders within the perimeter of the area itself. In each area, there are distributors and stores that are served by the vehicles belonging to the same area; in particular, in the proposed model, a distributor is assumed for each region and a store in each provincial capital.

About orders, both customers' and replenishment ones need to be created.

The *ShopOrder* agent replicates orders made by customers, both for purchasing and renting. It has three parameters: lot quantity, the store where the customer places the order, and the assigned rental percentage (i.e., *rent_percentage*). We use one agent to simulate these orders, instead of separate agents for buying and renting, for two reasons. First, we want to mimic the real customer behavior. We don't know in advance whether the customer will buy or rent, but only find out when they place the order. Therefore, a generic order (i.e., *ShopOrder*) is initially generated and subsequently associated with the rental or purchase mode through the *rent_percentage* parameter. The second factor is related to the structure of the model. Modelling two types of entities forces to model two different process flows within a single store, or to replicate the store for renting. To make the model easier to understand and use, only the *ShopOrder* agent is defined, so that a single store node can be used.

The *RentOrder* and *BuyOrder* agents are used to describe the replenishment orders necessary to increase the stock, respectively, of items to be rented and purchased. They are characterized by two parameters: lot quantity and the store where the order is generated to replenish the stock.

The orders are written by the system in an array as a collection, one for each area. Once the agents for the orders have been defined, those for the nodes of the supply chain (i.e. distributors and stores), and the vehicles necessary for deliveries are created. In order to generate a parameterizable model, the input data are imported from a database built on Microsoft Excel®. The dataset created in Microsoft Excel® is composed by three tables, containing information related to distributors, stores and vehicle agents. At the model start-up, the population of agents is generated according to them, as the "*Loaded from database*" option is selected in AnyLogic®.

The population of distributors is loaded through the "*db_distributors*" dataset, composed by two columns: location (i.e., its position on GIS map) and area (i.e. the geographic area of belonging, which corresponds to a specific region). The belonging area is necessary to ensure that each distributor is served only by vehicles belonging to the same area.

The population of stores is loaded through the "*db_stores*" dataset, structured as the "*db_distributors*". Similarly to distributors, the belonging area is necessary to ensure that each store is only served by vehicles belonging to the same area.

Two fleets of vehicles have been defined: one for deliveries, both of customer orders and replenishment orders, and another for managing the returns flow at the end of the rental period. Both fleets have been defined using the "vehicle" object. The population of "vehicle" agents is loaded from the "*db_vehicles*" dataset. This database has four columns: vehicle id, name, area, and GIS location name. The regions represent the areas served by vehicles, while the home node is the node from which the means of transport is generated, as well as the node where the vehicle will return at the end of each delivery tour. Geographic area represents a constraint for vehicles, which can only delivery moving from nodes belonging to the same area. At the model start-up, an empy "*vehicle_coll*" population is loaded, then the "vehicle" objects defined from the data entered in the "*db_vehicle*" dataset are added to the collection, using a Java function. The same process occurs for objects defined in the "*db_stores*" and "*db_distributors*" datasets, but they are not grouped within specific collections. Two additional parameters, *distributor* and *store*, are defined for the vehicle object. These last two parameters have been defined and dynamically set in order to describe the starting and destination points for the vehicle's mission.

The logic on which the model was built foresees that, on a daily basis, each vehicle checks a collection of replenishment orders and rental orders and organizes a trip starting from the distributor to all the stores where at least one item needs to be delivered. Several assumptions have been made according to the company's perspective. It is assumed that the route is always the same, meaning that the vehicle does not stop at a specific store if there are no deliveries to be made. Moreover, it is assumed that the vehicle is capable of delivering everything that needs to be delivered during the day, both in terms of quantities and space on the vehicle, and in terms of time, meaning that the loop can be completed within 24 hours. It is also assumed to have a single distributor for each area, in the proposed case represented by each region. Furthermore, it is assumed that the stock at the distributor is sufficient, requiring no replenishment during the simulation period. Additionally, it is assumed that the laundries used by each retailer are close to them, with an average distance between each store and its respective laundry/reconditioning center. As shown in

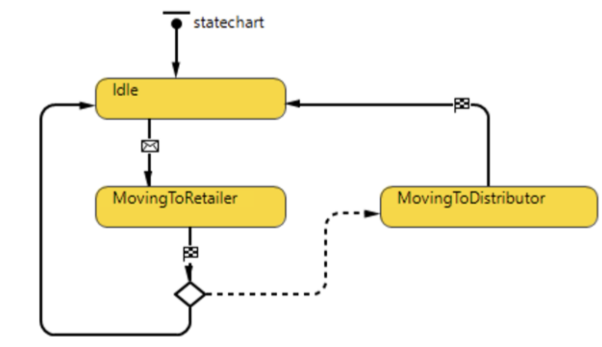

Figure 2: Vehicle agent state chart.

Figure 2, the states assumed by the vehicle agent are only those related to transport activities, while loading/unloading activities are not addressed.

The vehicle agent, initially, is in the *Idle* state, meaning it is ready to make a delivery within the reference area. Orders are assigned to vehicles through a message, which moves the agent from the *Idle* state to *MovingToRetailer* state. During this state, the vehicle is in transit from its starting point, that is the distributor, to the first store. Once it reaches the store, based on the list of orders to be delivered during the day, the vehicle can either return to the *Idle* state and wait to proceed to the next store (i.e., solid line) or return to the distributor (i.e., dashed line towards *MovingToDistributor* and then *Idle*). After completing daily deliveries, the vehicle remains in the *Idle* state until the next day, when it will plan another delivery round based on generated orders.

3.3 DES

Through discrete event simulation, a model representing the flows related to purchase/rental orders and supply has been developed. Entities are created within the source block by setting an arbitrary arrival frequency. In the proposed model, the frequency has been set to 30 entities per day, but it could also be distributed via inter-arrival distribution or loaded from a database. The agent created and flowing within this logic is the *ShopOrder*, which represents the customer's purchase/rental order. A fictitious delay block has been inserted after the source block, necessary for the AnyLogic® logic to function.

ShopOrder agents pass through the *selectOutput* block, where the output is randomly determined using probability. Based on the *rent_percentage* parameter value, *ShopOrder* agents are divided into rental orders, which proceed in a specific part of the process, and purchase orders, that goes into another part.

The rent and buy branches are constructed with the same logic and operate similarly. For simplicity, the implemented logic in the rent branch is reported. *ShopOrder* agents pass through a select block based on condition. If the *rent_stock* variable, which represents the stock of rental items, is greater than 20, the order can be fulfilled, and the variable is decremented by one (*rent_stock* --). If the condition is false, a replenishment order is generated to replenish the stock to the minimum level. In particular, the lot parameter is generated, which takes values from a uniform_discr(10,20) distribution and represents the quantity of the replenish order. Once the lot is defined, a *RentOrder* type supply order is created (*r_order* = new *RentOrder*(lot, this)), characterized by a quantity equal to lot. The *r_order* will be therefore associated with the store determined by this function, which returns the store that requires the replenishment order or the one where the entity is currently located.

At this point, the nearest vehicle to the destination store, which is in an *Idle* state so ready for transportation, is searched for. If a free vehicle agent is present, then a message containing *r_order* information is sent to initiate *MovingToRetailer* status. The vehicle will transport the lot quantity to the store. Once the entity exits the select block, it passes through the delay block, where the stock is updated by adding the quantity from the corresponding supply order: *rent_stock* = *rent_stock* + *agent.lot*.

The same operating logic applies to the buy branch, with the differences being only in the stock and type of supply orders implemented. The stock considered will be *buy_stock*, representing the available items for purchasing option, and, consequently, the supply order will be of type *b_order*, related to the *BuyOrder* agent.

3.4 Environmental Impacts

To assess environmental impacts for each supply chain configuration, CO_2 emissions for the following four stages are calculated: production, usage, washing and refurbishment, and transportation. The production step covers transformation processes from raw materials to final products. Within the proposed model, CO_2 emissions for production are calculated for each item reordered by distributors to production facilities. Every article shipped from production plants, indeed, represents a new fashion item to produce. To evaluate CO_2 emissions per item according to the article type, data from the “Second Hand Effect 2020” report by the Swedish IVL Institute has been considered, moving from t-shirts (2 kg of CO_2 per item) to jeans (33.4 kg of CO_2 per item). The environmental impacts included in the analyzed study cover the beginning- and middle-of-life, forcing to consider the end-of-life disposal transportation as future development, in order to be consistent. Emissions related to utilization need to be differently calculate in buying and renting scenarios. When customers buy fashion items, they will be used more than once and washed until their end of life. Environmental impacts related to product usage are therefore related to how many times they are washed. As reported by Levänen et al. (2021), the average number of washing for fashion items can be assumed as 20 before their dismission, with equivalent 0.64 kg of CO_2 for washing along the whole lifecycle (as each washing requires 0.032 kg of CO_2 per item) (ISPRA 2022). For the renting business model, washing-related emissions are not included in the utilization stage, but in the washing and refurbishment activities after the rental period. According to this, washing emissions for renting are calculated as 0.032 kg of CO_2 per rented item. Finally, emissions related to transportations consider two flows: customers who reach the store for buying or renting fashion items (and taking them back after the rental period in the second case); vehicles which move items for direct and reverse logistics. In both cases, CO_2 emissions are calculated according to the kilometers travelled and the specific kg of CO_2 per kilometer according to the means of transport. In particular, passenger cars are considered for customers’ movements (i.e., 0.16 kg of CO_2 per km) while trucks for logistics flows (i.e., 0.67 kg of CO_2 per km) (ISPRA 2022), as suggested by the involved company. For customers location has been considered an average distance from the store, as well as for the washing and refurbishment centers. Production plants, distributors and stores are instead located according to the data input, and real kilometers are calculated using GIS functionalities.

4 RESULTS

The proposed model has been applied to compare a traditional buying supply chain with a renting one. In both scenarios, a single production plan located in Tuscany (Italy) supplies the regional distributors. According to the region, each provincial store is supplied by the regional distributor. Same initial and security stock levels, as well as reorder points, have been set for stores, distributors and production facility respectively, to compare scenarios having the same conditions. A washing and refurbishment center has been located with an average distance of 15 km from each store. As anticipated, vehicle movements are triggered by customers' orders and automatic reorders launched when stocks reach the reorder point. Travelled kilometers are traced by GIS and used to calculate CO_2 emissions related to transportations, as described in the previous section. Similarly, number of buying and renting orders are logged respectively in the traditional and collaborative business models to calculate CO_2 emissions related to production, utilization, and washing and refurbishment.
The purpose of the conducted scenario analysis is to compare environmental impacts for the modelled traditional and renting supply chains, starting from the same configuration and parameters. The output of scenario analysis in terms of kilometers and number of orders is resumed in Table 1.

Table 1: Output of Scenario Analysis (kilometers and number of orders).

	Buying	Renting
Production Plant – Distributor	26,592 km	9,145 km
Distributor – Store	59,489 km	17,676 km
Customer – Store	1,110,900 km	2,221,800 km
Number of production orders	40,000	6,000
Number of buying / renting orders	18,515	18,515

As expected, travelled kilometers from production plant to regional distributors and from those to provincial stores for buying model are strongly higher than renting model. At the end of the rental service, indeed, the rented fashion item is taken back to the store, increasing the related stocks and reducing, at the same time, the need for replenishment and, consequently, the number of production orders in the production plant. As the number of buying and renting orders is the same, the kilometers travelled by customers to and from stores for the rental service doubled the traditional business model ones, because customers need to come back to the store to return rented items. The two business models have been compared considering different article types to investigate if moving from one to another changes the overall environmental impact. Considering data from the "Second Hand Effect 2020" report by the Swedish IVL Institute, three article types have been included in the scenario analysis according to their low, intermediate and high level of CO_2 emissions per item in the production stage: t-shirts (2 kg of CO_2 per item), shoes (19 kg of CO_2 per item) and jeans (33.4 kg of CO_2 per item). The output of scenario analyses in terms of environmental impacts per t-shirts, shoes and jeans are resumed in Table 2, Table 3 and Table 4 respectively.

Table 2: Output of Scenario Analysis (environmental impacts per t-shirts).

	Buying	Renting
Production Plant – Distributor	17,817 kg of CO_2	6,127 kg of CO_2
Distributor – Store	14,277 kg of CO_2	4,242 kg of CO_2
Customer – Store	177,744 kg of CO_2	355,488 kg of CO_2
Store – Washing and Refurbishment Center	0 kg of CO_2	8,640 kg of CO_2
Production	80,000 kg of CO_2	12,000 kg of CO_2
Utilization	1,185 kg of CO_2	0 kg of CO_2
Washing and Refurbishment	0 kg of CO_2	592 kg of CO_2
Total	291,023 kg of CO_2	387,090 kg of CO_2

Table 3: Output of Scenario Analysis (environmental impacts per shoes).

	Buying	Renting
Production Plant – Distributor	17,817 kg of CO_2	6,127 kg of CO_2
Distributor – Store	14,277 kg of CO_2	4,242 kg of CO_2
Customer – Store	177,744 kg of CO_2	355,488 kg of CO_2
Store – Washing and Refurbishment Center	0 kg of CO_2	8,640 kg of CO_2
Production	760,000 kg of CO_2	114,000 kg of CO_2
Utilization	1,185 kg of CO_2	0 kg of CO_2
Washing and Refurbishment	0 kg of CO_2	592 kg of CO_2
Total	971,023 kg of CO_2	489,090 kg of CO_2

Table 4: Output of Scenario Analysis (environmental impacts per jeans).

	Buying	Renting
Production Plant – Distributor	17,817 kg of CO_2	6,127 kg of CO_2
Distributor – Store	14,277 kg of CO_2	4,242 kg of CO_2
Customer – Store	177,744 kg of CO_2	355,488 kg of CO_2
Store – Washing and Refurbishment Center	0 kg of CO_2	8,640 kg of CO_2
Production	1,336,000 kg of CO_2	200,400 kg of CO_2
Utilization	1,185 kg of CO_2	0 kg of CO_2
Washing and Refurbishment	0 kg of CO_2	592 kg of CO_2
Total	1,547,023 kg of CO_2	575,490 kg of CO_2

Previous tables show the average value of the outputs resulting running 10 times each scenario. The performed two-sample-t-test results in a p-value lower than 0.005, demonstrating that two scenarios are significantly different. Results highlight that the most sustainable business model between buying and renting cannot be fully predicted. Considering the analyzed less impacting article type (i.e., t-shirts), fashion renting results more impacting in terms of CO_2 emissions due to the high incidence of transportations. On the other hand, scenario analyses for shoes and jeans show higher environmental impacts for the buying model, due to the incidence of production. Looking only at the emissions related to transportations (i.e., rows from first to fourth in previous tables), the renting model overcome the traditional one due to the travelled distance for customer-store and store-refurbishment center (i.e., 209,838 kg of CO_2 for buying and 374,497 kg of CO_2 for renting), despite the travelled distance for production plant-distributor and distributor-store are higher for the buying model.

5 CONCLUSION

To address the recent concern about considering or not collaborative consumption, like fashion renting, more sustainable than traditional models, the present work proposes a hybrid simulation model to assess environmental impacts along the supply chain. DES, ABM and GIS have been integrated to assess CO_2 emissions along different stages of the fashion supply chain, such as production, use, washing and refurbishment, and transportation. Even if two contributions can be found in literature about the application of simulation in fashion renting, none of them refers to the assessment of environmental impacts moving from traditional to sharing models, making the present work relevant for academics.

The results of the scenario analyses conducted through the proposed simulation model demonstrate also the managerial implications of this work, as different supply chain configurations and parameters can be easily changed to assess the less impacting network and policies from an environmental point of view. For instance, presented results show the outcomes of two opposite approaches (i.e., 100% buying and 100% renting), but the model supports also the assessment of hybrid strategies that include mixed order types. Quantifying environmental impacts of fashion industry through the supply chain stages, indeed, allows to identify the potentially most impacting nodes, supporting decision-makers to focus and prioritize intervention points. Useful guidelines can be therefore provided not only for researchers but also fashion industry actors. The main innovative contribution of the research is that the comparative emissions for renting and buying options strictly depends on the fashion item type, as they greatly vary due to the different contributions of production, washing and transportation to the lifecycle emissions.

The presented method can be potentially applied as starting point for future research. For instance, different type of fashion items can be contemporarily included to better represent the variability of customers' choices, as well as other product categories (e.g., luxury clothing) or different rental behaviors (e.g., frequent or occasional renters). This kind of integration are easy to implement due to the data-driven approach followed in the model development. More in details, new product categories or more than one item type to manage only require to update the dataset with related CO_2 emissions per supply chain stage and the probability distribution to generate related purchase or rental orders in the "source" block. The definition of a specific probability distribution represents also the integration needed to model both frequent and occasional renters, who rent or not another item when returning one respectively.

As future developments, the proposed simulation model can also be integrated to consider the online distribution and return flows, due to the increasing spread of digital channels (e.g., e-commerce) strictly interconnected with physical ones (e.g., pick-up point in store for web orders). Similarly, C2C models can be investigated and modelled, as well as different business models, such as the second-hand. Following the approach used for the buying and renting options, the new business models will need to be analyzed in order to identify potential new nodes and flows to model. After completing the models, they can be integrated by updating the dataset with the new locations or average distances of the nodes, as well as the details of the flow sequences. For example, the second-hand business model will use the same nodes as the original model (i.e., production facilities, distribution centers and stores), but the production flow will vary for the rental in terms of washing and refurbishment processes and return. Considering the GIS application, the "Road Traffic Library" of AnyLogic® can be used as future steps to simulate physical movements of vehicles on the road, in order to consider also the negative impact of traffic on CO_2 emissions.

Finally, interactions among customers can be included as future step, as customers' behaviors are naturally influenced by external feedback, making this aspect relevant for its recent application in the fashion industry (Lee and Huang 2020; Becker-Leifhold 2018). For instance, reviews and Word Of Mouth (WOM) are able to push or criticize rental services, especially for those who have never tried it before. Due to the influence of customer-to-customer interactions on the transition from purchasing to renting, the proposed application of agent-based simulation could be therefore integrated to include the impact of WOM on consumer rental decision, as implemented by Fani et al. (2022). Within the model, it can be implemented in the ABM state chart, considering WOM able to increase or decrease the proportion of rental orders according to positive or negative comments respectively.

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