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Efficiency of consumer behaviour and digital ecosystem in the generation of the plastic waste toward the circular economy

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Abstract

A circular economy can help reduce the impact of plastic waste using reaction, resilient, and digital approaches. In addition, it can facilitate reducing plastic consumption. In this regard, consumer behaviour and digitalization are deemed to be two main factors that play major roles in the implementation of a circular economy of plastic waste. The idea of this paper is to understand the relevance of consumer behaviour and digital ecosystem efficiency on plastic waste at the country level. Hence, the efficiency of eight European countries in the generation of plastic waste was analysed using international databases and the statistical method of receiver operation characteristic (ROC). For this purpose, the dependent actual state variables were defined as plastic waste generations, and the independent test variables were defined as digital ecosystem and consumer behaviour factors. ROC plots for the determination of the area under the curve (AUC) indices were produced between the mentioned state and test variables. The results revealed that consumer behaviour increases the higher generation of plastic waste (AUC > 0.6), indicating that consumer behaviours have high effectiveness on the generation of plastic waste in European countries. Furthermore, the results indicated that the digital ecosystem has a controlling role in the generation of plastic waste in the study area (AUC < 0.5), indicating the digital ecosystem factors associated with the low generation of plastic waste. The overall consumer behaviour in the selected European countries showed an unskilled role regarding the higher generation of plastic waste, while the digital ecosystem context showed a mitigating role in decreasing plastic pollution. The confirmation of the research hypotheses leads to some managerial propositions for the circular economy of plastic waste in the area of consumer behaviour and digitalization. The results propose an elaborated framework, including a reduction in waste generation, recycling in waste circulation, recovery in waste valorization, and efficiency in resource consumption by the digitalization of design technology and education in consumer behaviour for the circular management of plastic waste.

Keywords: Plastic Waste, Circular Economy, Consumer Behaviour, Digital Ecosystem, European Countries, Receiver Operation Characteristic (ROC)

1. Introduction

Plastic materials, which are used in food packaging (Dey et al., 2021; Kitz et al., 2022) and drug delivery (Hogan and Mikos, 2020; Aoki and Saito, 2020), among other applications, become waste due to irrational production, inappropriate disposal at landfills, and inadequate recycling management (Kumar et al., 2021). Minimizing plastic waste is extremely important, as a large quantity of plastic waste is buried or forgotten by the linear economy (Burlakovs et al., 2019). In EU countries, recent statistics revealed more than 16 million tons of plastic waste per annum, with a recycling rate of 42.4% (approximately 6.9 million tons) on average (Eurostat, 2019). In 2017, the European Council, European Parliament, and European Commission agreed to set a new target for plastic recycling at a rate of 50% by 2025, to be increased to 55% by 2030 (Jang et al., 2020). The circular economy facilitates the reduction of plastic consumption by substituting plastics for other materials, avoiding unnecessary packaging, or using alternatives and green logistics in global supply chains (Zhang and Zhao, 2012). Hence, the study needs to conduct the research findings through the circular economy function.

The European Commission identifies plastic waste as a key priority in its action plan for the circular economy (EC, 2015; 2019). In the context of circular economy plans, the reduction of the impact of plastic waste on the environment is a very important topic. Simultaneously, increasing plastic consumption is accompanied by severe environmental problems (Beaumont et al., 2019; Jambeck et al., 2018; Wright and Kelly, 2017). An increasing amount of plastic portion of the total waste through the consumption process of commodities is one of the leading causes of the waste management problem (Schmid and Rhein, 2018).

As mentioned in the literature, the circular economy can help reduce the impact of plastic waste using reaction, resilient, and digital approaches (see Kumar et al., 2021). What is missing in the current literature is the lack of information about consumer behaviours, leading to entrepreneurial strategies to reduce plastic consumption and plastic waste generation (see Latinopoulos et al., 2018). In the same way, the effectiveness of some innovative methods, such as digital ecosystems, should be investigated in the circular economy of plastic waste to reduce waste generation at the country level. Hence, consumer behaviour and digitalization are two main factors that play major roles in the implementation of a circular economy of plastic waste (e.g., Sijtsema et al., 2020; Grdic et al., 2020).

This study is needed to determine the efficient or non-efficient status of European countries in the generation of plastic waste. This study is original in addressing the status of eight European countries in the generation of plastic waste, performing a sensitivity analysis of consumer behaviour and digital ecosystem efficiency on plastic waste. Consideration of the possible role of consumer behaviour and the digital ecosystem in reducing plastic waste generation is very rare in previous studies. Furthermore, the novelty of the present study depends on the application of the plots of the receiver operation characteristic (ROC) method (as defined by Gonçalves et al., 2014; Yang and Berdine, 2017) to analyse the relevance of consumer behaviour and digital ecosystem efficiency in plastic waste. This study's research questions (RQs) are as follows:

RQ1: How can we explain the effective relation of consumer behaviour with the generation of plastic waste in selected EU countries?

RQ2: How can we explain the role of the digital ecosystem in controlling plastic waste in selected EU countries?

This study aims to analyse the sensitivity of consumer behaviour and digital ecosystem efficiency to the generation of plastic waste in some European countries. This aim can be achieved by assessing ethical behaviour (acceptable international norms of behaviour) and principles of social responsibility (responsibility for impacts of each decision or action on society and the environment). In this regard, social responsibility supports consumer behaviour regarding the waste reduction hierarchy, including source reduction, reuse, recycling, reprocessing, waste treatment, and disposal (ISO-26000, 2010). Moreover, the research also expressed the role of innovative technology in decreasing plastic waste (see Syberg et al., 2021). In this regard, the forensic engineering of advanced polymeric materials (FEAPM) could be considered to manage plastic waste, especially in the packaging industry (Musioł et al., 2011; Musioł et al., 2017). For example, in the production phase, biodegradation and oxo-biodegradation are innovative approaches to removing plastic and polymer solid particles in the environment using chemical reactions (Musioł et al., 2017; Sikorska et al., 2020). However, the relations between plastic structure, properties, and behaviour can be processed before, during, and after practical applications (Rydz et al., 2015; Musioł et al., 2016).

2. Literature and hypothesis development

2.1. Circular economy and plastic waste

The circular economy of plastic waste (predominantly classified as technical materials) is a new business model that leads to sustainable development using new designs to reuse and recycle at the end of the plastic life cycle (Ghisellini et al., 2015). At the 'end-of-life' of plastics, waste should be viewed in four different forms – wasted resource, wasted life cycle, wasted capacity, and waste embedded value – to create an economic opportunity for the business ecosystem and prevent plastic from reaching the end of its life and being exposed to the natural ecosystem (Galafassi et al., 2019; Kumar et al. 2021). By reducing waste generation, finding alternative disposal methods, and finding resilient, circular, digital, and low-carbon economic models, the circular economy can help reduce the impact of plastic pollution (Kumar et al., 2021). One significant way to achieve this in the circular economy of plastic waste depends on consumer behaviour to reduce plastic packaging and reuse plastic material for secondary usage (Chen and Tan, 2021). Hence, all plastic products in the EU market should be reusable or recyclable in a cost-effective way by 2030 (Foschi and Bonoli, 2019).

2.2. Circular economy and consumer behaviour

This section initially involves an empirical examination of influential factors of consumer behaviours (defined as the first set of independent variables), which can directly influence plastic waste (dependent variables of total and per capita plastic waste in this study). This initial part of the research model, which is assumed for hypothesis development, is shown in Fig. 1. Consumption behaviour is globally recognized as an element, leading to unsustainable development (De Bernardi and Tirabeni, 2018), and a consumer's environmental responsibility is the intention of a person to act toward remediation of environmental problems not as an individual user with economic interests but as a responsible citizen having concerns about society's social and environmental wellbeing (Pawaskar et al., 2018). Consumer demands for plastic materials are for short-term and single-use plastic for immediate disposal after use, resulting in notable amounts of plastic waste and pollution (Jang et al., 2020). Several scholars have investigated consumer intentions regarding plastic pollution by measuring the level of environmental awareness and linking it to specific behaviours (e.g., Latinopoulos et al., 2018; Rhein and Schmid, 2020). Cooperating with digitalization, consumers could access other behaviours to reduce plastic consumption (Labrecque et al., 2013; Sparks et al., 2013). In addition, consumers can customize products, track their orders, and influence public opinion of offerings to change plastic waste generation (Young et al., 2017; Tunn et al., 2020).

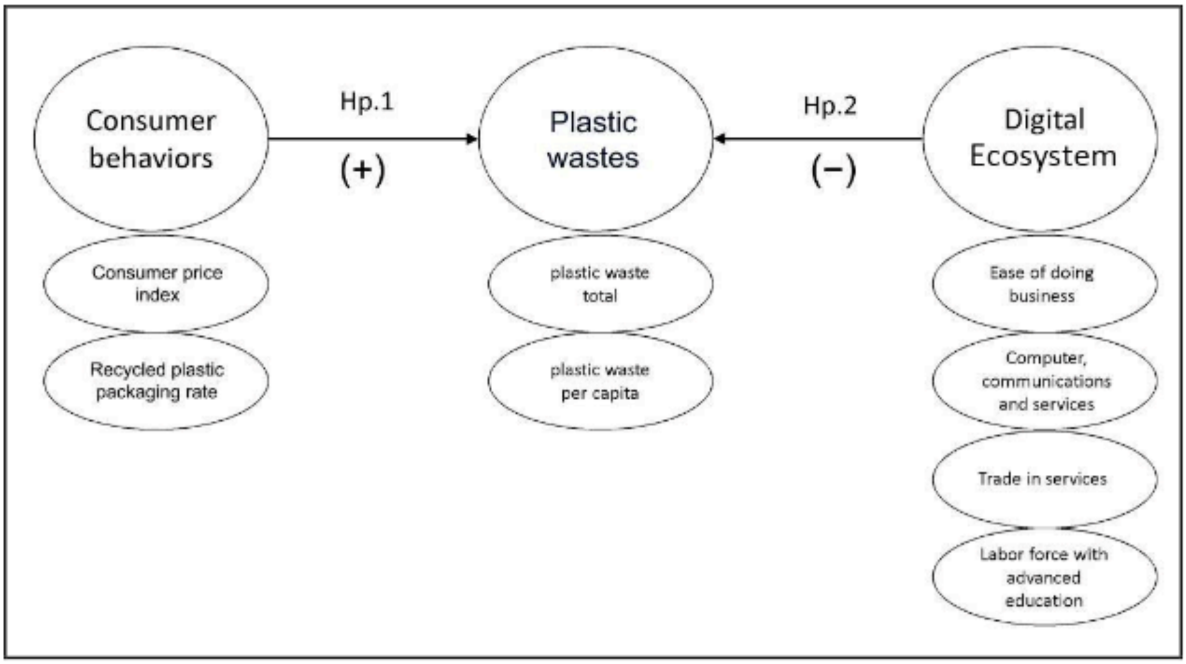

Fig. 1: Research model for hypothesis development

2.3. Circular economy and digital ecosystem

This section investigates the possible performance of digital ecosystem factors (defined as the second set of independent variables), which can alter the generation of plastic waste. The second part of the research model is represented in Fig. 1. Although consumer behaviour plays a major role in the implementation of a circular economy (Sijtsema et al., 2020), the concept of a circular economy encompasses systemic changes based on innovation and digitalization (Domenech and Walkowiak, 2019; Grdic et al., 2020). The long-term efficiency of this circular economy of plastic waste must be accompanied by digital and technological innovations (Horvath et al., 2018). A digital ecosystem can define the factors of sustainability, which can be assumed to be the motor of evolution in each sector of the economy (Filipiak et al., 2020).

The digital ecosystem supports the ability of organizations' operational processes and procedures to have supreme functions (Susanto et al., 2021). For instance, organizations can integrate digital technologies to develop a digital ecosystem in the supply chain of manufacturing (Margherita and Braccini, 2021). Hence, a digital ecosystem, defined as a distributed, adaptive socio-technical system with the properties of sustainability, can modify the consumption of plastic and reduce waste (Suuronen et al., 2022). A digital ecosystem for digital customers, users, and agents can create new social values in the environment (Sussan and Acs, 2017).

2.4. Hypothesis development

The main research gap is the complex and paradoxical role of consumer behaviour in decreasing or increasing plastic pollution. In addition, plastic pollution can be modified by external factors, such as digital ecosystems, where digitalization has enabled the creation of new platforms (Tiwana et al., 2010) and infrastructures (Elia et al., 2020) in each production process. According to previous works, consumer behaviour has a significant link with the generation of waste, and subsequent recovery can be affected using technological waste management (Nemat et al., 2022). In addition, digital technologies and platforms are considered vital enablers of a circular economy of plastic waste and pollution (Oyinlola et al., 2022). Overall, the circular economy's targets in the context of plastic waste can help reduce the generation of plastic and its threat to the environment (Khan et al., 2019). Accelerating the development of a circular economy around plastic materials will be significant in decreasing the impact of plastic waste on the environment (Sakthipriya, 2022).

Now, the following two essential hypotheses can be retained:

Hp. 1: The high efficiency of consumer behaviours is related to the high generation of plastic waste in the study area.

Hp. 2: The high efficiency of digital ecosystems can be associated with the low generation of plastic waste in the study area.

To cope with such hypotheses, it is necessary to understand the efficiency of some independent variables that influence the generation of plastic waste. Performance analysis of efficiency in the generation of plastic waste is one of the main contributions of our research to improving the circular economy of plastic waste. Regarding efficiency, consumer behaviour could influence the better management of plastic production in terms of lower waste, higher rates of recycling and recovery, and improved economic growth (Robaina et al.,
2020). From this technical viewpoint, efficiency is defined as the ability of a system (such as a digital ecosystem or consumption behaviour) to operate close to its production or optimized function (Deprins et al., 2006).

3. Methodology

3.1. Study area

Case studies from European countries were selected based on two screening steps within the searches of the available databases. In the first step, countries that had a total generated quantity of waste above 100 million tons per year, according to the EURO-STAT database in
2018, were chosen. In the second step, the remaining countries with a population rate above
10 million inhabitants, according to the WORLD-BANK database in 2018, were selected. The reason for these screenings includes the confidence level of total waste generation and the population at 85–

90%. Ultimately, eight countries, France, Germany, Italy, Netherlands, Poland, Spain, Sweden, and the UK, were selected as the case studies using the aforementioned screening steps (Table 1). In Table 1, the total population and total generated waste (million tons) are presented for the selected countries. On this basis, highest amount of total waste generated belongs to Germany and France, with 405 and 642 million tons, respectively, in 2018.

Table 1: The summarized profile of the eight selected European countries (2018)

Country name	Population (million inhabitants)	Total waste (million tons)
France	66.97	342.39
Germany	82.91	405.52
Italy	60.42	172.51
Netherlands	17.23	145.24
Poland	37.97	175.14
Spain	46.80	127.98
Sweden	10.18	138.67
UK	66.46	282.21

3.2. Data collection

In the context of the analysis of efficiency in the circular economy of plastic waste, there is no standard of theoretical efficiency to be used as a reference (Robaina et al., 2020). Hence, our paper attempts to present a quantitative approach to solving the research questions using the relevant international databases and statistical method of ROC at the country level of the selected European countries. In this regard, the dependent actual state variables are defined as the plastic waste parameters, and the independent test variables are defined as digital ecosystem factors and consumer behaviour factors (i.e., consumer price index and plastic packaging rate). The given indicators were selected based on the waste process output and affecting variables that emerged from the economics literature (e.g., Samuelson and Nordhaus, 2004; Robaina et al., 2020).

The following two dependent indicators, [1] total generation of plastic waste and [2] plastic category of waste per capita, which were process outputs of plastic waste noted by Robaina et al., (2020), were extracted from environmental statistics and accounts of the European Commission (EURO-STAT) via https://appsso.eurostat.ec.europa.eu. In addition, to define the affecting variables in the process outputs, two sets of independent variables were assumed. The first set of independent variables of consumer behaviour indices was assumed based on the indicators exhibiting the official behaviour of consumers (Cavallo and Rigobon,

2016), such as [3] the consumer price index and [4] recycled plastic packaging, which were considered based on the aforementioned Eurostat database. Furthermore, the second set of

independent factors was related to a framework of the digital ecosystem with the four elements of digital infrastructure governance, digital user citizenship, digital entrepreneurship, and digital marketplace, as noted by Ács et al., (2014), Stam (2015), and Sussan and Acs (2017). On this basis, four indicators were obtained that emerged from global databases, based on their relevancy and proper linking with the four elements of digital ecosystems (e.g., Sussan and Acs, 2017): [5] ease of doing business, [6] computer services, communications services, and other services, [7] trade in services, and [8] labour force with advanced education was assumed based on the WORLD-BANK development indicators in
2018 via https://databank.worldbank.org (Tables 2 and 3). In these tables, the raw values of all eight indicators obtained are shown based on their categories. Meanwhile, the obtained variables were controlled using originated sources to obtain reliable data corresponding to the research subjects of plastic waste, consumer behaviour, and the digital ecosystem.

Table 2: The raw values of five obtained indicators for defining plastic pollution and consumer behaviours

Country name	Plastic pollution		Consumer behaviours	
	Total plastic waste (million tons/year)	Plastic waste per capita (kilos)	Consumer price index (2010 = 100)	Recycled plastic packaging rate (%)
France	3.01	44.89	109	26.9
Germany	6.64	80.04	111	46.4
Italy	3.54	58.64	110	43.4
Netherlands	1.24	71.94	113	52.0
Poland	1.30	34.33	112	35.7
Spain	1.81	38.75	110	50.7
Sweden	0.31	30.11	109	50.0
UK	6.31	94.99	118	43.8

Table 3: The raw values of four obtained indicators for defining moderator and mediator categories

Country name	Digital ecosystems			
	Ease of doing business score (0–100)	Computer, communications (% of exports)	Trade in services (% of GDP)	Labour force adv. education (% of workers)
France	76.78	55.52	20.66	76.55
Germany	79.35	49.11	18.20	73.44
Italy	73.04	42.70	11.93	74.65
Netherlands	76.10	67.38	42.73	80.59
Poland	76.93	50.21	19.24	80.38
Spain	77.70	45.95	16.72	80.12
Sweden	82.02	57.22	26.18	83.57
UK	83.55	49.71	23.49	83.94

3.3. ROC method

As several fields have contributed independently to the development of ROC analysis, many concepts and techniques are known under different names in different communities (Gonçalves et al., 2014). A ROC curve plots the true positive rate (sensitivity) against the false positive rate (1 – specificity) for all possible cut-off values, and a general definition of the ROC method can be found in Bandos et al., (2005). The x-axis of the independent variable (test variable) is specificity, and the y-axis of the dependent variable (state variable) is sensitivity for the model test. Each point in the ROC space is a discrimination cut-off value of the test (Yang and Berdine, 2017).

When the state and test variables are known, a confusion matrix is needed to produce the ROC plot as a contingency table to describe the performance of a classification system (Yang and Berdine, 2017). In our study, the dependent actual state variables are defined as the plastic waste parameters, and the independent test variables are defined as digital ecosystem and consumer behaviour factors. In the confusion matrix of the research, four conditions can be defined below (Yang and Berdine, 2017): [1] True-positive (TP) or perfect sensitivity, which truly measures the presence of the positive actual state, corresponds to high values of test variables. [2] False-negative (FN), which falsely measures the absence of a positive actual state, corresponds to low values of test variables. [3] False-positive (FP), which falsely measures the presence of a positive actual state, corresponds to high values of test variables. [4] True-negative (TN) or specificity, which truly measures the absence of a positive actual state, corresponds to low values of test variables. A better distribution is expected to have both higher sensitivity and specificity (Table 4). Based on this table, the positive (= 1) actual states of total and per capita plastic waste are categorized as values > 3 tons/year and > 50 kilos, respectively. Contrarily, the negative (= 0) actual states of total and per capita plastic waste are categorized as values < 3 tons/year and < 50 kilos, respectively. In addition, the positive and negative classes for test variables are categorized as high (> 50% from total data) and low (< 50% from total data) values, respectively.

Table 4: Confusion matrix of the study

Conditions		Test variable values (Consumer behaviours/digital ecosystem)	
		Positive values (High: > 50%)	Negative values (Low: < 50%)
Actual state (plastic waste)	Positive (= 1) (total > 3 million tons) (per capita > 50 kilos)	True positive (TP) (perfect sensitivity)	False negative (FN)
	Negative (= 0) (total < 3 million tons) (per capita < 50 kilos)	False positive (FP)	True negative (TN) (perfect specificity)

3.4. AUC index

Considering the ROC plots, the area under the curve (AUC) is the most commonly used index (Hanley and McNeil 1982). In the last decade, the AUC index has been accepted as the standard measure for assessing the accuracy of distribution and discrimination models (Lobo et al., 2008; Jiménez-Valverde, 2012). This represents the probability of a test with average specificity toward sensitivity values of the ROC plots. According to Table 5, the acceptable, excellent, and outstanding discriminating values for the test variable should indicate an AUC > 0.6, whereas poor and random chance are indicated by an AUC < 0.6 (Lasko et al., 2005). A better discrimination of the model in the ROC plot depends on the values above the diagonal line connecting the (0, 0) and the (1, 1) points (Yang and Berdine, 2017). In this research, the AUC indices between dependent and independent variables are analysed to represent the sensitive and efficient relationships between them through the examination of the hypotheses.

Table 5: Determination of discriminations for AUC values

No.	AUC index	Determination
1	≤ 0.5	No discrimination and randomly
2	0.5–0.6	Poor discrimination
3	0.6–0.7	Acceptable discrimination
4	0.7–0.8	Excellent discrimination
5	≥ 0.8	Outstanding discrimination

4. Results

4.1. Relationship between the generation of plastic waste and consumer behaviour

In the first step, the ROC plots for the determination of AUC indices between the generation of plastic waste and consumer behaviours were produced, as shown in Figs. 2 and 3. In Fig.2, the ROC plots of the sensitivity test were analysed between the state variable of "total generation of the plastic waste" and the test variables of "consumer price index" and "recycled plastic packaging rate". In addition, the sensitivity test of the ROC plots was analysed between the state variable of "per capita generation of plastic waste" and test variables of "consumer price index" and "recycled plastic packaging rate", as shown in Fig.3. The AUC indices of these plots were calculated as 0.400, 0.625, 0.667, and 0.844, with a mean value of 0.634. According to the determination of discrimination for AUC values given in Table 5, the discrimination of the test model is acceptable. This means that overall consumer behaviour showed an unskilled role regarding the higher generation of plastic waste in the selected European countries. In other words, there is a gap in defining the mitigating role of innovative methods to decrease plastic pollution. The results suggest that this controlling role can be considered in the digital ecosystem context.

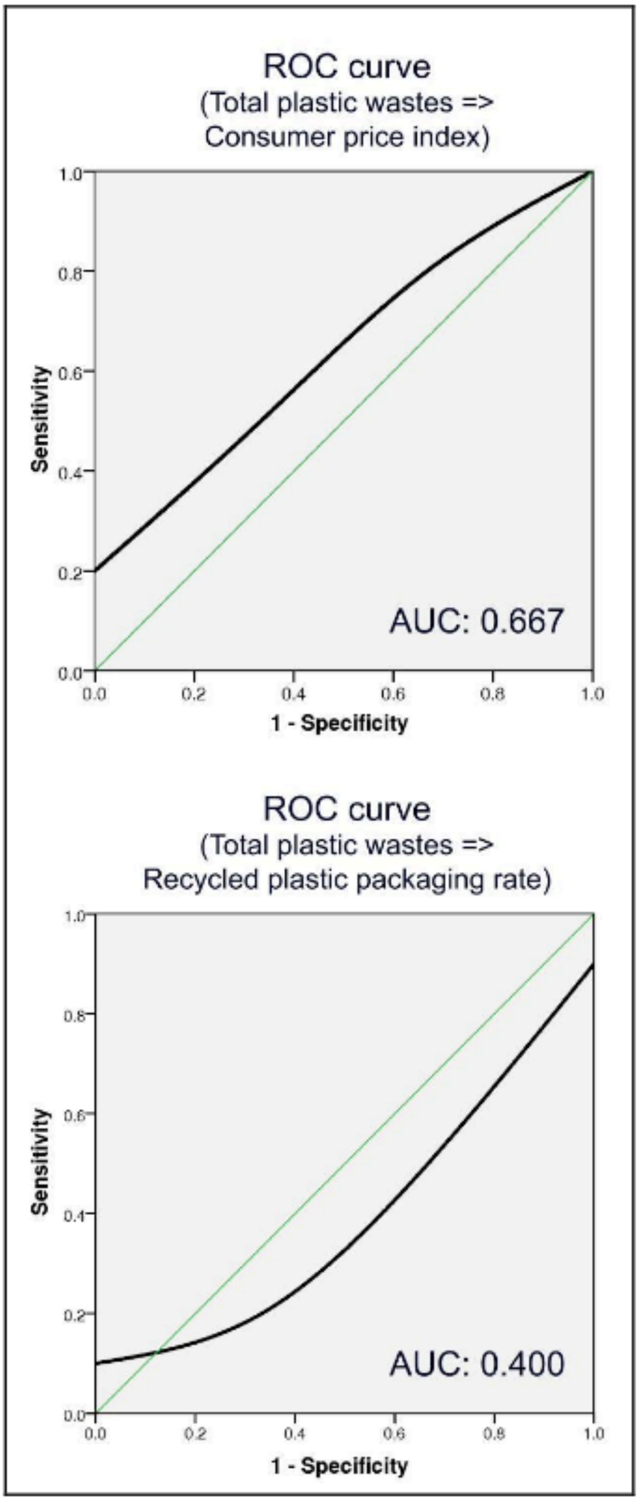

Fig. 2: ROC plots for sensitivity analysis between total plastic waste and consumer behaviours

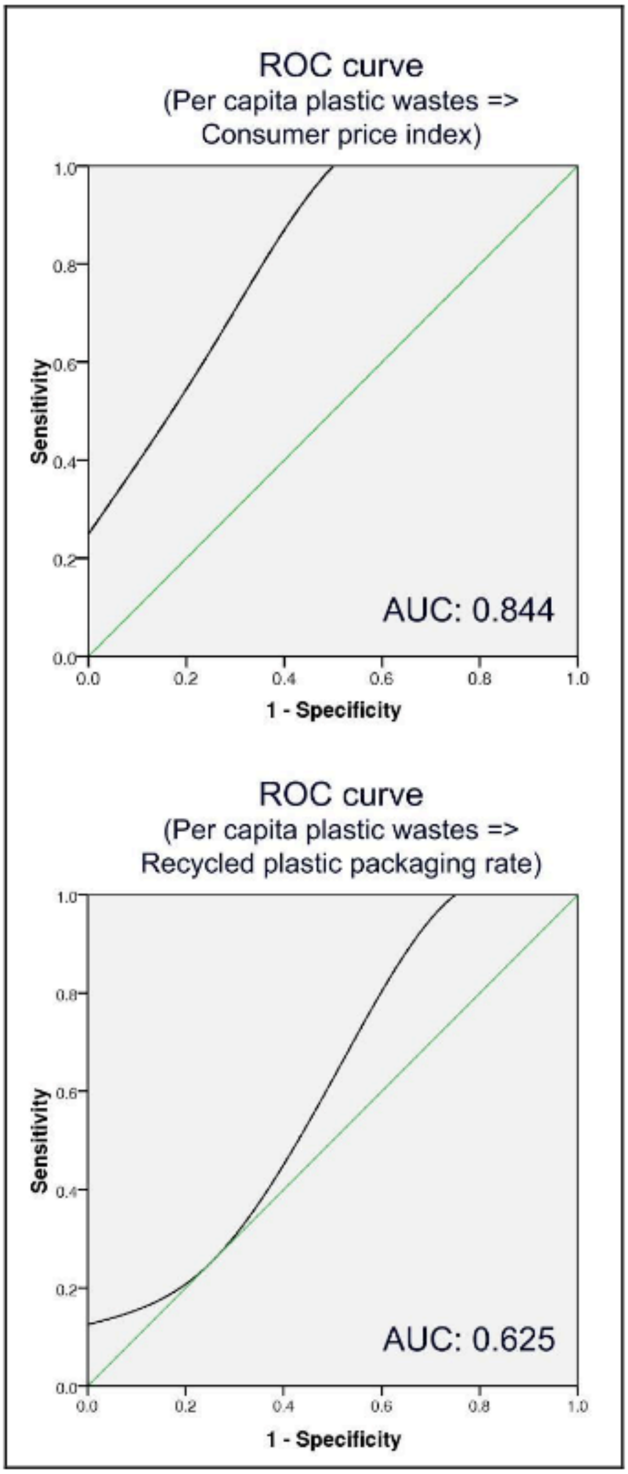

Fig. 3: ROC plots for sensitivity analysis between per capita plastic waste and consumer behaviours

4.2. Relations between the generation of plastic waste and the digital ecosystem

In Figs. 4 and 5, the ROC plots between state variables of plastic waste and test variables of “ease of doing business”, “computer, communications, and other services”, “trade in services”, and “labour force with advanced education" were analysed to explore the efficiency of the digital ecosystem in the mitigation of plastic pollution. Based on the ROC plots for the analysis of efficient relations between the state variables of plastic waste and test variables of digital ecosystem factors, the AUC indices were calculated as ranging from 0.250 to 0.500 (i.e., AUC $\leq$ 0.5), revealing random conditions and no discrimination. Hence, the paper can conclude that digital ecosystem factors have a controlling role in the generation of plastic waste in the selected European countries.

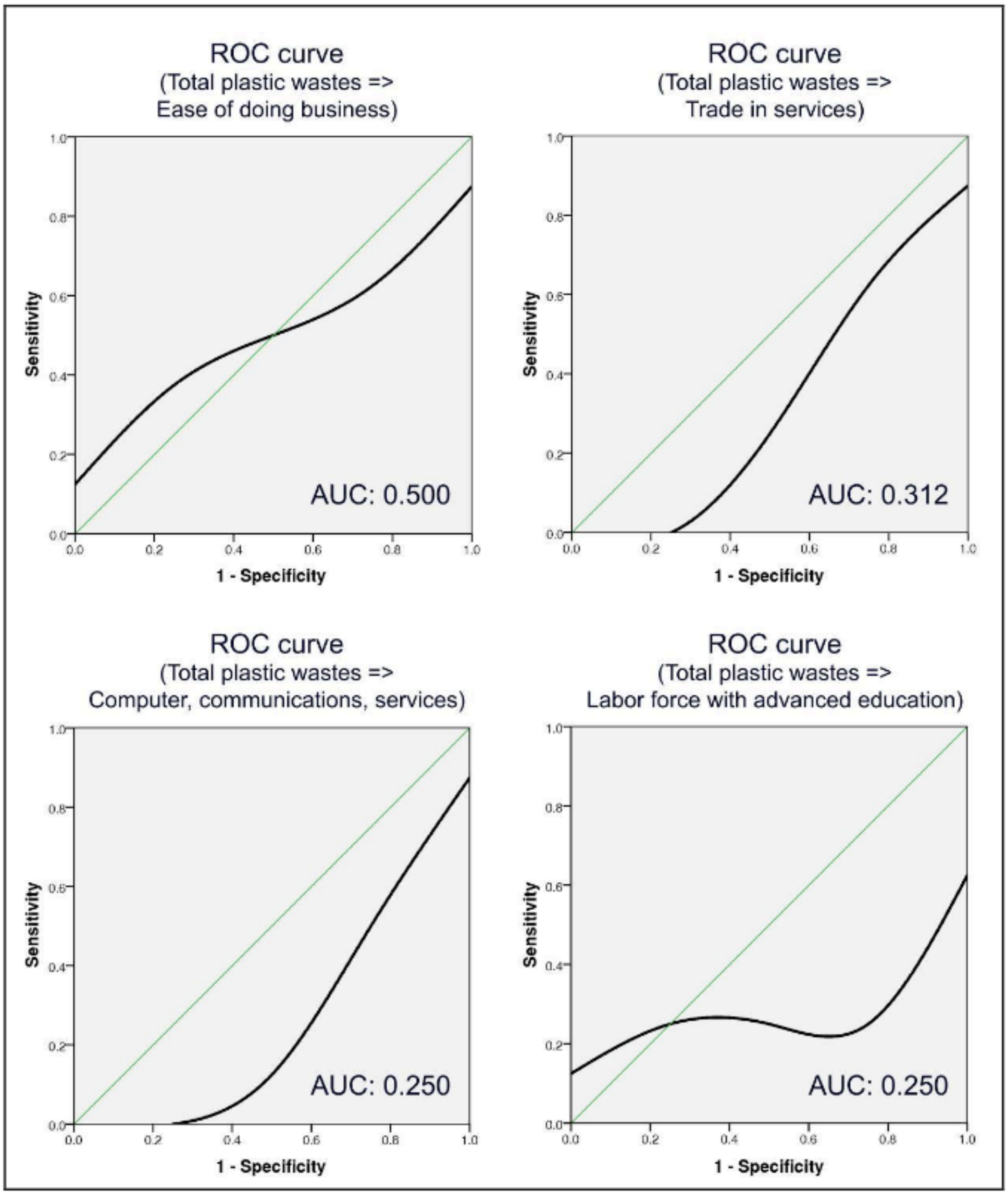

Fig. 4: ROC plots for sensitivity analysis between total plastic waste and digital ecosystem factors

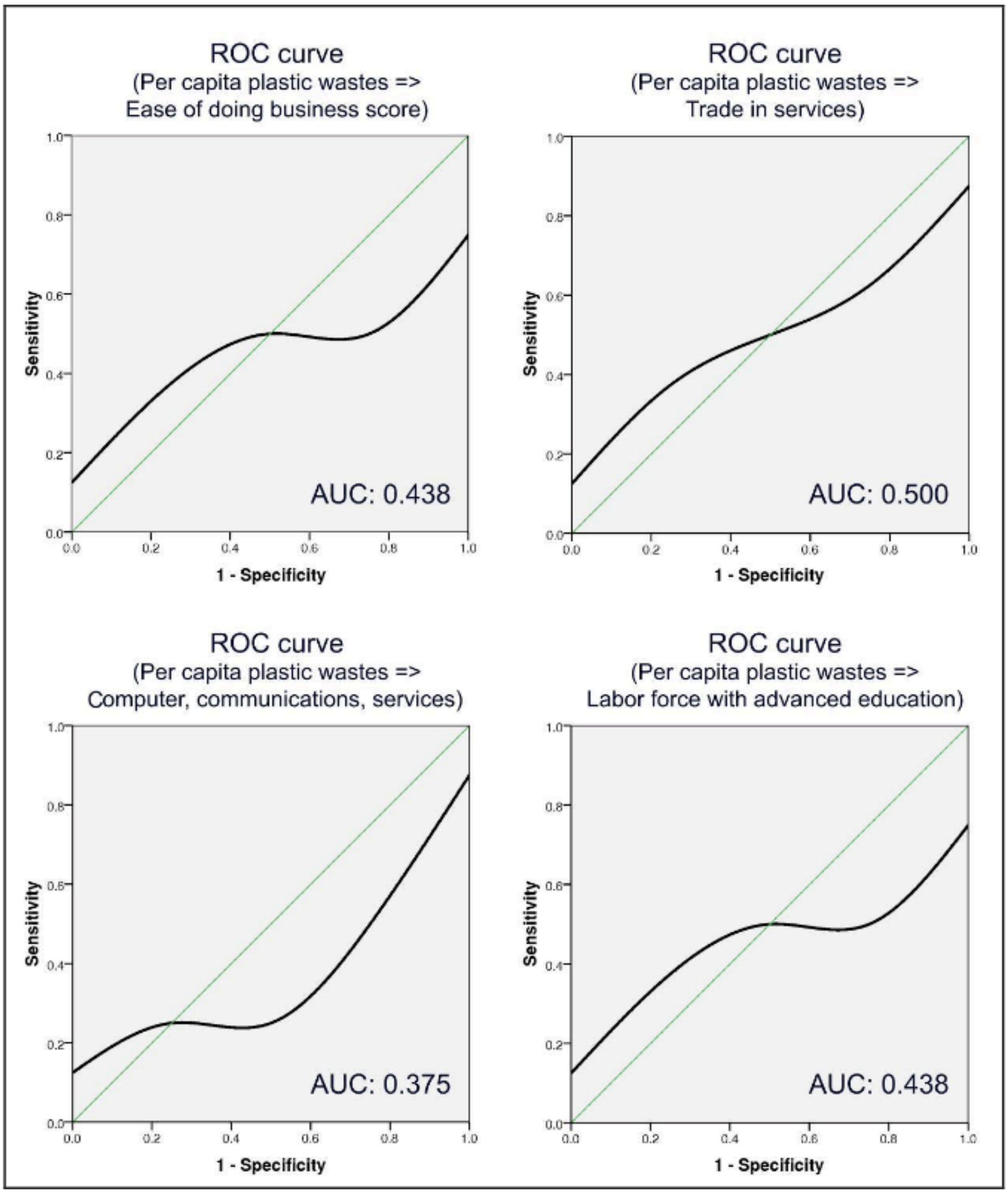

Fig. 5: ROC plots for sensitivity analysis between per capita plastic waste and digital ecosystem factors

4.3. Test of the hypotheses

The results revealed that both factors of consumer behaviour depend on the higher generation of plastic waste in the study area due to their average AUC index of ROC plots above 0.6. On this basis, the first hypothesis (Hp. 1) can be accepted, claiming that consumer behaviours have a high effectiveness on the high generation of plastic waste in European countries. Furthermore, the results indicate that the digital ecosystem factors have a controlling role in the generation of plastic waste in the study area due to their average AUC index of ROC plots below 0.5. Hence, the second hypothesis (Hp. 2) can be accepted, claiming that the high efficiency of digital ecosystems is associated with the low generation of plastic waste and the high recycling rate in European countries. The overall s revealed that consumer behaviours have induced the high volume of plastic waste in the countries as positive actors. Hence, the need to moderate the impact of digital ecosystems in the generation of plastic waste is a significant issue. The present paper can suggest the enhancement of digital ecosystems and applications in consumption processes to decrease plastic waste and reduce environmental pollution. This is consistent with recent findings that advanced recycling technology with innovations, such as digital ecosystems, is urgently needed for the environmentally sound management of plastic waste in service of a circular economy (Jang et al., 2020).

5. Discussion

According to the key considerations for the circular economy and business models developed and outlined by Richardson (2008) and Geissdoerfer et al., (2020), some managerial propositions were suggested for the circular economy of plastic waste, depending on consumer education rationalizing behaviours and also digital technology in the design of the plastic outcomes. These propositions were gained from interactions between the dematerializing strategy of the circular economy and the value creation–delivery element of the business models.

Overall, it can be observed that the digitalized production system could not achieve adequate efficiency in uneducated consumer behaviour in recent studies (e.g., Bressanelli et al., 2018; Ingemarsdotter et al., 2019). Hence, in accordance with the findings interpreted by Tunn et al., (2022), this research anticipated that a well-informed consumer attitude could contribute to the digitalization of plastic outcomes through technological designs and applications. Recycling-based design is a clever potential solution for the sustainable valorization and circulation of materials such as plastic particles (Ragaert et al., 2020). Subsequently, in a circular economy, consumer behaviour will play a strong role in enhancing the reuse and recycling of plastic and generated waste (Mehta et al., 2022). This fact indicates that subjective norms, awareness, and education in the circular plastic waste system are major effective factors in consumer behaviour and reuse/recycling intention (Khan et al., 2019). According to Morseletto (2020), a circular economy can encompass a wider range of strategies than recycling and recovery (e.g., reusing or refurbishing) and more possible solutions beyond efficiency (e.g., Reike et al., 2018; Tukker, 2015).

New propositions can also provide new feedback models among already proposed models and frameworks to strengthen a circular economy of plastic waste, as shown in Fig. 6. The proposed model presented in this figure elaborates existing targets in the circular economy, including a reduction in waste generation, recycling in waste circulation, recovery in waste valorization, and efficiency in resource consumption through the circular management of plastic waste using digitalization in design technology and education in consumer behaviour. More identification of the model is discussed below:

I. Reduction in waste generation in the absolute term under the circular definition (a zero-waste approach) is based on the concept of eliminating waste sources and emissions as much as possible (Murray et al., 2017; Morseletto, 2020).

II. The term “recycling” refers to the mechanical reuse of plastic waste, and the term “recovery” refers to the thermal conversion of plastic waste into electrical power, fuels, and chemicals (Khoo, 2019).

III. Concerning efficiency in resource consumption, the key point of circular management is keeping a plastic resource within the economy when it can be used again, creating more value added (e.g., Di Maio et al., 2017; Robaina et al., 2020).

IV. A circular economy is a way to propose solutions to changing consumer behaviour (e.g., Daae et al., 2019; Chizaryfard et al., 2021) regarding waste management using communication and education tools. Wagner (2017) noted that local governments are increasingly adopting a variety of measures to reduce plastic waste, such as consumer education (Horvath et al., 2018).

V. Digitalization is a catalyst of circularity in CBMs (Chiaroni et al., 2021), which can change design and consumption by exploiting digital technologies (De Bernardi and Tirabeni, 2018). Furthermore, in the field of plastic waste, the standardization of design could increase circularity using digital technologies (Mehta et al., 2022).

VI. Overall, the circularity model of this research suggests that education for improving consumption behaviour in addition to digital technology for implementing circularity at the design level of plastic production can reduce plastic waste by enhancing recycling rates. The application of circularity in plastic waste can ensure economic growth in addition to reducing environmental degradation (Grdic et al., 2020).

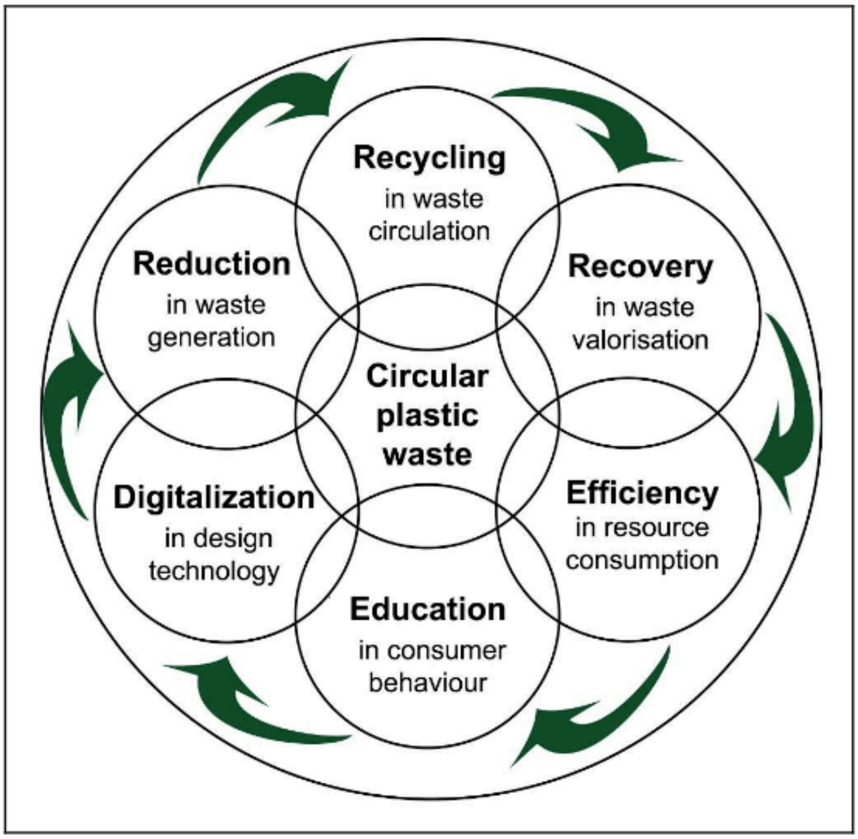

Fig. 6: Framework of circular economy in plastic waste management

6. Theoretical and managerial implications

The implications of the present paper depended theoretically on four categories: circular economy, consumer behaviour, digital ecosystem, and plastic waste. The major results of the current paper also support the previous research of other scholars. First, the relationship between consumer behaviour and plastic waste is consistent with recent research results (e.g., Khan et al., 2019) that tried to understand the consumer's attitude regarding plastic waste. Our findings respond to this research call by indicating that educating consumers regarding reusing and recycling is important in meeting an efficient target in the reduction of plastic waste generation. Second, the relationship between digital ecosystems and plastic waste supports the results of the previous research (e.g., Oyinlola et al., 2022), which indicated the role of digital innovation as a potential contributor to circular plastic. Hence, the paper's findings contribute to this research stream by proposing a broad use of digital technologies for implementing circularity at the design level of plastic production, recycling, recovery, and reduction of plastic waste generation. Third, the mentioned relationships contributing to a circular economy, verified by existing research (e.g., Chiaroni et al., 2021 and Tunn et al., 2020), are reporting a better perception of digitalization and consumer behaviour in the circular economy concept. In this vein, our results can also try to accelerate the transition to a circular economy through an elaborated framework (efficiency in resource consumption, digitalization in design technology, education in consumer behaviour, reduction in waste generation, recycling in waste circulation, and recovery in waste valorization).

The managerial implications emphasized education for improved consumption behaviour in addition to the design of technology and digitalization to reduce plastic waste by enhancing recycling rates. This research was done based on some general indicators to examine the success of consumer behaviour and digital ecosystems as possible proxies in the circular economy of plastic waste. At the country level, decision-makers in the energy sector can prepare digital infrastructures to increase the education level of consumer behaviours, as well as to reduce the generation of plastic waste in the consumption process. For instance, an extension of current knowledge regarding recycling and recovery loops in the circular economy of plastic production, consumption, waste, new norms, and new value added should be planned and modelled through local and national companies.

7. Conclusions

The main aim of the present study was to analyse the sensitivity of consumer behaviour and digital ecosystem efficiency to the generation of plastic waste in some European countries. The results revealed that consumer behaviour increases the higher generation of plastic waste (AUC > 0.6) and that the digital ecosystem has a decreasing role in the generation of the plastic waste in the study area (AUC < 0.5), confirming both research hypotheses. This means that consumer behaviours have induced the high volume of plastic waste in the studied countries as positive actors and that there is a significant need to moderate the impact of digital ecosystems in the generation of plastic waste. The propositions for the circular economy of plastic waste can reveal the effects of consumer behaviour and the digital ecosystem on plastic waste management. These propositions are based on interactions between the dematerializing strategy of the circular economy and the value creation–delivery element of the business model. Our results also proposed an elaborated framework (efficiency, digitalization, education, reduction, recycling, and recovery) to accelerate the transition to a circular economy of plastic waste.

The main limitations of the present study may be related to model construction and data preparation. One of the limitations depends on the availability of data, which is limited to the annual scale at the national level. Hence, future studies should be repeated using local data in detailed periods. The research method, focused on the ROC plots in the sensitivity analysis, can be examined in the different research to obtain trustworthiness or restrictions compared with other statistical methods. Another limitation of the research is the circular economy's restraints in the area of plastic waste. In this regard, the paper was not solely about digitalization, consumption, and waste management through the circular economy. Hence, further research could provide standardized aspects to measure consumption behaviour and digitalization factors in the circular economy of plastic waste. A recommendation for future research is to assume the norms of ethical behaviour and principles of social responsibility in each given study area regarding the sustainability and efficiency of consumer behaviour in the management of plastic waste. In this regard, quantitative indices for efficiency analysis can be compared through several time intervals. Ultimately, future research could focus on novel sustainable approaches to forensic engineering of advanced polymeric materials (FEAPM) to control plastic waste generation from production to consumption processes.

References

Ács, Z.J., Autio, E., Szerb, L., 2014. National systems of entrepreneurship: measurement issues and policy implications. Res. Pol. 43, 476–494.

Aoki, K., Saito, N., 2020. Biodegradable polymers as drug delivery systems for bone regeneration. Pharmaceutics 12, 95.

Bandos, A.I., Rockette, H.E., Gur, D., 2005. A conditional nonparametric test for comparing two areas under the ROC curves from a paired design. Acad. Radiol. 12, 291–297.

Beaumont, N.J., Aanesen, M., Austen, M.C., Börger, T., Clark, J.R., Cole, M., Hooper, T., Lindeque, P.K., Pascoe, C., Wyles, K.J., 2019. Global ecological, social and economic impacts of marine plastic. Mar. Poll. Bull. 142, 189–195.

Bressanelli, G., Adrodegari, F., Perona, M., Saccani, N., 2018. Exploring how usage- focused business models enable circular economy through digital technologies. Sustainability 10, 639.

Burlakovs, J., Kriipsalu, M., Porshnov, D., Jani, Y., Ozols, V., Pehme, K.M., Rudovica, V., Grinfelde, I., Pilecka, J., Gaile, Z.V., Turkadze, T., Hogland, W., Klavins, M., 2019. Gateway of landfilled plastic waste towards circular economy in Europe. Separations 6, 25.

Cavallo, A., Rigobon, R., 2016. The billion prices project: using online prices for measurement and research. J. Econ. Perspect. 30, 151–178.

Chen, Z., Tan, A., 2021. Exploring the circular supply chain to reduce plastic waste in
Singapore. Log Forum 17, 271–286.

Chiaroni, D., Del Vecchio, P., Peck, D., Urbinati, A., Vrontis, D., 2021. Digital technologies in the business model transition towards a circular economy. Resour. Conserv. Recycl. 168, 105286.

Chizaryfard, A., Trucco, P., Nuur, C., 2021. The transformation to a circular economy:framing an evolutionary view. J. Evol. Econ. 31, 475–504.

Daae, J., Chamberlin, L., Boks, C., 2019. Dimensions of behaviour change in the context of designing for a circular economy. Des. J. 21, 521–541.

De Bernardi, P., Tirabeni, L., 2018. Alternative food networks: sustainable business models for anti-consumption food cultures, Brit. Food J. 120, 1776–1791.

Deprins, D., Simar, L., Tulkens, H., 2006. Measuring labor-efficiency in post offices. In: Tulkens H (Ed.) Public Goods, Environmental Externalities and Fiscal Competition. Chap. 13, 285–309.

Dey, A., Dhumal, C.V., Sengupta, P., Kumar, A., Pramanik, N.K., Alam, T., 2021.
Challenges and possible solutions to mitigate the problems of single-use plastics used for packaging food items: a review. J. Food Sci. Technol. 58, 3251–3269.

Di Maio, F., Rem, P.C., Baldé, K., Polder, M., 2017. Measuring resource efficiency and circular economy: a market value approach. Resour. Conserv. Recycl. 122, 163–171. Domenech, T.,

Bahn-Walkowiak, B., 2019. Transition towards a resource efficient circular economy in Europe: policy lessons from the EU and the member states. Ecol. Econ. 155, 7–19.
EC, 2015. Closing the loop – an EU action plan for the circular economy. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52015DC0614. Accessed 2022.
EC, 2019. Press release – circular economy package report: questions & answers. http://europa.eu/rapid/press-release_MEMO-19–1481_en.htm. Accessed 2022.
Elia, G., Margherita, A., Passiante, G., 2020. Digital entrepreneurship ecosystem: how digital technologies and collective intelligence are reshaping the entrepreneurial process. Technol. Forecast. Soc. Change 150, 119791.
Eurostat, 2019. Packaging waste statistics. https://appsso.eurostat.ec.europa.eu. Accessed 2022.
Filipiak, B.Z., Dylewski, M., Kalinowski, M., 2020. Economic development trends in the EU tourism industry, towards the digitalization process and sustainability. Qual. Quant. https://doi.org/10.1007/s11135–020–01056–9.
Galafassi, S., Nizzetto, L., Volta, P., 2019. Plastic sources: a survey across scientific and grey literature for their inventory and relative contribution to microplastics pollution in natural environments, with an emphasis on surface water. Sci. Total Environ. 693,
Geissdoerfer, M., Pieroni, M.P.P., Pigosso, D.C.A., Soufani, K., 2020. Circular business models: a review. J. Clean. Prod. 277, 123741.
Ghisellini, P., Cialani, C., Ulgiati, S., 2015. A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. J. Clean. Prod. 114, 11–32.
Gonçalves, L., Subtil, A., Oliveira, M.R., Bermudez, P.D.Z., 2014. ROC curve estimation: an overview. REVSTAT – Stat. J. 12, 1–20.
Grdic, Z.S., Nizic, M.K., Rudan, E., 2020. Circular economy concept in the context of economic development in EU countries. Sustainability 12, 3060.
Hogan, K.J., Mikos, A.G., 2020. Biodegradable thermoresponsive polymers: applications in drug delivery and tissue engineering. Polymer 211, 123063.
Horvath, B., Mallinguh, E., Fogarassy, C., 2018. Designing business solutions for plastic waste management to enhance circular transitions in Kenya. Sustainability 10, 1664. Ingemarsdotter, E., Jamsin, E., Kortuem, G., Balkenende, R., 2019. Circular strategies enabled by the internet of things – a framework and analysis of current practice. Sustainability 11, 5689.
ISO-26000, 2010. International standard: guidance on social responsibility (106 pp). Switzerland. http://www.iso.org. Accessed 2022.
Jambeck, J., Hardesty, B.D., Brooks, A.L., Friend, T., Teleki, K., Fabres, J., Beaudoin, Y., Bamba, A., Francis, J., Ribbink, A.J., 2018. Challenges and emerging solutions to the land-based plastic waste issue in Africa. Policy 96, 256–263.
Jang, Y.C., Lee, G., Kwon, Y., Lim, J., Jeong, J., 2020. Recycling and management practices of plastic packaging waste towards a circular economy in South Korea. Resour. Conserv. Recycl. 158, 104798.
Jiménez-Valverde, A., 2012. Insights into the area under the receiver operating characteristic curve (AUC) as a discrimination measure in species distribution modeling. Glob. Ecol. Biogeogr. 21, 498–507.
Khan, A., Ahmed, W., Najmi, A., 2019. Understanding consumers' behaviour intentions towards dealing with the plastic waste: perspective of a developing country. Resour. Conserv. Recycl. 142, 49–58.
Khoo, H.H., 2019. LCA of plastic waste recovery into recycled materials, energy and fuels in Singapore. Resour. Conserv. Recycl. 145, 67–77.
Kitz, R., Walker, T., Charlebois, S., Music, J., 2022. Food packaging during the COVID-19 pandemic: consumer perceptions. Int. J. Consum. Stud. 46, 434–448.
Kumar, R., Verma, A., Shome, A., Sinha, R., Sinha, S., Jha, P.K., Kumar, R., Kumar, P., Shubham, M., Das, S., Sharma, P., Prasad, V., 2021. Impacts of plastic pollution on ecosystem services,

sustainable development goals, and need to focus on circular economy and policy interventions. Sustainability 13, 9963.
Labrecque, L.I., vor dem Esche, J., Mathwick, C., Novak, T.P., Hofacker, C.F., 2013. Consumer power: evolution in the digital age. J. Inter. Market 27, 257–269.
Lasko, T.A., Bhagwat, J.G., Zou, K.H., Ohno-Machado, L., 2005. The use of receiver operating characteristic curves in biomedical informatics. J. Biomed. Inform. 38, 404–415.
Latinopoulos, D., Mentis, C., Bithas, K., 2018. The impact of a public information campaign on preferences for marine environmental protection, the case of plastic waste. Mar. Pollut. Bull. 131, 151–162.
Lobo, J.M., Jiménez-Valverde, A., Real, R., 2008 AUC: a misleading measure of the performance of predictive distribution models. Glob. Ecol. Biogeogr. 17, 145–151. Margherita, G., Braccini, M., 2021. Examining the development of a digital ecosystem in an Industry 4.0 context: a sociotechnical perspective. SN Bus. Econ. 1, 89.
Mehta, N., Cunningham, E., Doherty, M., Sainsbury, P., Bolaji, I., Nejad, B.F., Smyth, B.M., 2022. Using regional material flow analysis and geospatial mapping to support the transition to a circular economy for plastics. Resour. Conserv. Recycl. 179, 106085.
Morseletto, P., 2020. Targets for a circular economy. Resour. Conserv. Recycl. 153, 104553.
Murray, A., Skene, K., Haynes, K., 2017. The circular economy: an interdisciplinary exploration of the concept and application in a global context. J. Bus. Ethics. 140, 369–380.
Musioł, M., Rydz, J., Janeczek, H., Radecka, I., Jiang, G., Kowalczuk, M., 2017. Forensic engineering of advanced polymeric materials Part IV: Case study of oxo-biodegradable polyethylene commercial bag – aging in biotic and abiotic environment. Waste Manag.64, 20–27.
Musioł, M., Rydz, J., Sikorska, W., Rychter, P., Kowalczuk, M., 2011. A preliminary study of the degradation of selected commercial packaging materials in compost and aqueous environments. Pol. J. Chem. Technol. 13, 55–57.
Musioł, M., Sikorska, W., Adamus, G., Janeczek, H., Richert, J., Malinowski, R., Jiang, G., Kowalczuk, M., 2016. Forensic engineering of advanced polymeric materials. Part III – Biodegradation of thermoformed rigid PLA packaging under industrial composting conditions. Waste Manag. 52, 69–76.
Nemat, B., Razzaghi, M., Bolton, K., Rousta, K., 2022. Design affordance of plastic food packaging for consumer sorting behaviour. Resour. Conserv. Recycl. 177, 105949.
Oyinlola, M., Schröder, P., Whitehead, T., Kolade, O., Wakunuma, K., Sharifi, S., Rawn, B., Odumuyiwa, V., Lendelvo, S., Brighty, G., Tijani, B., Jaiyeola, T., Lindunda, L., Mtonga, R., Abolfathi, S., 2022. Digital innovations for transitioning to circular plastic value chains in Africa. Africa J. Manag. 8, 83–108.
Pawaskar, U.S., Raut, P.D., Gardas, B.B., 2018. Assessment of consumer behaviour towards environmental responsibility: a structural equations modeling approach. Bus. Strategy Environ. 27, 560–571.
Ragaert, K., Huysveld, S., Vyncke, G., Hubo, S., Veelaert, L., Dewulf, J., Bois, E.D., 2020.Design from recycling: a complex mixed plastic waste case study. Resour. Conserv. Recycl. 155, 104646.
Rhein, S., Schmid, M., 2020. Consumers' awareness of plastic packaging: more than just environmental concerns. Resour. Conserv. Recycl. 162, 105063.
Richardson, J., 2008. The business model: an integrative framework for strategy execution. Strat. Change 17, 133–144.
Robaina, M., Murillo, K., Rocha, E., Villar, J., 2020. Circular economy in plastic waste –efficiency analysis of European countries. Sci. Total Environ. 730, 139038.
Rydz, J., Wolna-Stypka, K., Admus, G., Janeczek, H., Musioł, M., Sobota, M., Marcinkowski, A., Krzan, A., Kowalczuk, M., 2015. Forensic engineering of advanced polymeric materials. Part

1 – Degradation studies of polylactide blends with atactic poly[(rs,)-3-hydroxybutyrate] in paraffin. Chem. Biochem. Eng. Q. 29, 247–259.
Sakthipriya, N., 2022. Plastic waste management: a road map to achieve circular economy and recent innovations in pyrolysis. Sci. Total Environ. 809, 151160.
Samuelson, P., Nordhaus, W., 2004. Economics. 18th ed. McGraw Hill Professional. Schmid, M., Rhein, S., 2018. Potential substitutions and design strategies to address the flood of plastics. Kunststoffflut 98, 877–883.
Sijtsema, S.J., Snoek, H.M., de Haaster-Winter, M.A., Dagevos, H., 2020. Let's talk about circular economy: a qualitative exploration of consumer perceptions. Sustainability 12, 286.
Sikorska, W., Zięba, M., Musioł, M., Kowalczuk, M., Janeczek, H., Chaber, P., Masiuchok, O., Demchenko, V., Talanyuk, V., Iurzhenko, M., Puskas, J.E., Adamus, G., 2020. Forensic engineering of advanced polymeric materials – Part VII: Degradation of biopolymer welded joints. Polymers 12, 1167.
Sparks, B.A., Perkins, H.E., Buckley, R., 2013. Online travel reviews as persuasive communication: the effects of content type, source, and certification logos on consumer behaviour. Tour. Manag. 39, 1–9.
Stam, E., 2015. Entrepreneurial ecosystems and regional policy: a sympathetic critique. Eur. Plan. Stud. 23, 1759–1769.
Susanto, H., Fang Yie, L., Mohiddin, F., Rahman Setiawan, A.A., Haghi, P.K., Setiana, D., 2021. Revealing social media phenomenon in time of COVID-19 pandemic for boosting start-up businesses through digital ecosystem. Appl. Syst. Innov. 4, 6.
Sussan, F., Acs, Z.J., 2017. The digital entrepreneurial ecosystem. Small Bus. Econ. 49, 55–73.
Suuronen, S., Ukko, J., Eskola, R., Semken, S., Rantanen, H., 2022. A systematic literature review for digital business ecosystems in the manufacturing industry: prerequisites, challenges, and benefits. CIRP J. Manuf. Sci. Technol. 37, 414–426.
Syberg, K., Nielsen, M.B., Clausen, L.P.W., van Calster, G., van Wezel, A., Rochman, C., Koelmans, A.A., Cronin, R., Pahl, S., Hansen, S.F., 2021. Regulation of plastic from a circular economy perspective. Curr. Opin. Green Sustain. 29, 100462.
Tiwana, A., Konsynski, B., Bush, A.A., 2010. Platform evolution: coevolution of platform architecture, governance, and environmental dynamics. Inf. Syst. Res. 21, 675–687.
Tunn, V.S.C., van den Hende, E.A., Bocken, N.M.P., Schoormans, J.P.L., 2020. Digitalised product-service systems: effects on consumers' attitudes and experiences. Resour. Conserv. Recycl. 162, 105045.
Wagner, T.P., 2017. Reducing single-use plastic shopping bags in the USA. Waste Manag. 70, 3–12.
Wright, S.L., Kelly, F.J., 2017. Plastic and human health: a micro issue? Environ. Sci. Technol. 51, 6634–6647.
Yang, S., Berdine, G., 2017. The receiver operating characteristic (ROC) curve. Southwest Respir. Crit. Care Chron. 5, 34–36.
Young, W., Russell, S.V., Robinson, C.A., Barkemeyer, R., 2017. Can social media be a toolfor reducing consumers' food waste? A behaviour change experiment by a UK retailer. Resour. Conserv. Recyc. 117, 195–203.
Zhang, G., Zhao, Z., 2012. Green packaging management of logistics enterprises. Phys.Procedia 24, 900–905.