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Assessing Provisions and Requirements for the Sustainable Production of Plastics: Towards Achieving SDG 12 from the Consumers' Perspective

Walter Leal Filho [1,2], Jelena Barbir [1,*], Pınar Gökçin Özuyar [3], Enrique Nunez [4], Jose Manuel Diaz-Sarachaga [5], Bertrand Guillaume [6], Rosley Anholon [7], Izabela Simon Rampasso [8], Julia Swart [9], Luis Velazquez [10] and Theam Foo Ng [11]

1 Research and Transfer Centre "Sustainable Development & Climate Change Management" (FTZ-NK), Faculty of Life Sciences, Hamburg University of Applied Sciences, Ulmenliet 20, 21033 Hamburg, Germany
2 Department of Natural Science, Manchester Metropolitan University, Chester Street, Manchester M1 5GD, UK
3 Faculty of Economics, Administrative and Social Sciences, Bahsesehir University, Istanbul 34349, Turkey
4 Management Convening Group, Anisfield School of Business, Ramapo College of New Jersey, Mahwah, NJ 07430, USA
5 GTDS Research Group, Universidad de Oviedo, C/Catedratico Valentin Alvarez s/n, 33006 Oviedo, Spain
6 Interdisciplinary Research on Society-Technology-Environment Interactions (InSyTE), Troyes University of Technology, 10300 Troyes, France
7 Department of Manufacturing Engineering and Materials, University of Campinas, São Paulo 13083-860, Brazil
8 Departamento de Ingeniería Industrial, Universidad Católica del Norte, Antofagasta 0610, Chile
9 Utrecht School of Economics, Utrecht University, Kriekenpitplein 21–22, 3584 EC Utrecht, The Netherlands
10 Industrial Engineering Department, University of Sonora, Blvd Luis Encinas y Rosales S/N, Hermosillo 83000, Mexico
11 Centre for Global Sustainability Studies, Universiti Sains Malaysia, Penang 11800, Malaysia
* Correspondence: jelena.barbir@haw-hamburg.de

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Abstract: Plastics are used widely, and modern civilization would have to behave differently without them. However, plastics pose a threat to sustainable life. This paper focuses on some of the provisions being made for sustainable production to date and focuses on one key sector-plastic manufacturing-where sustainable production patterns are urgently needed. The paper describes the latest trends related to plastic production, its environmental impacts, and how this sector is adjusting its processes in order to meet the current and forthcoming legal requirements and consumer demands. The methodological approach of the study has focused on both a literature review on the one hand and the consumers' perspective obtained via a survey on the other. These two approaches were then crosschecked in order to assess current trends in plastic manufacturing and to understand how consumers see these trends as being consistent with the aims of the UN Sustainable Development Goal 12. The results obtained suggest that a greater engagement of consumers is needed in supporting the efforts to manage plastic more sustainably. Based on its findings, the paper provides useful insights linked to principles and tools for sustainable plastic production and design, and it demonstrates the usefulness and urgency of a sound materials management in order to tackle plastic pollution, one of today's major environmental problems.

Keywords: sustainable production; consumers; SDG 12; plastics

1. Introduction

The idea of sustainable production dates back 30 years when the United Nations Conference on Environment and Development (UNCD) recognized the "unsustainable patterns of consumption and production" as the main reason for the "continued deterioration of the global environment" [1]. Although the idea quickly became mainstream, over the years the definition of sustainable production was placed as a priority on the agendas of all relevant parties-government, academia and the private sector alike.

The definition of sustainable production can stem from that of sustainable consumption as defined at the above-mentioned 1994 Oslo Symposium, which confirmed "the broad international agreement that the matter of changing unsustainable patterns of production and consumption must be tackled on a priority basis" [2,3]. It would then refer to *the design and supply* of "services and related products which respond to basic needs and bring a better quality of life while minimizing the use of natural resources and toxic materials as well as the emissions of waste and pollutants over the life cycle of the service or product so as not to jeopardize the needs of future generations" [2,4]. Later, sustainable production was also defined as "the creation of goods and services using processes and systems that are: non-polluting; conserving of energy and natural resources; economically viable; safe and healthful for workers, communities, and consumers; and, socially and creatively rewarding for all working people" [5]. Of course, as a practical approach to achieving sustainable development, the definition of sustainable production processes may evolve together with the conception of sustainability and may mean different things to different people. Yet there is a gap in research on some overarching concepts. For instance, sustainable production is about continuous, systemic, and multi-level change in industrial systems and processes. Yet, studies on how to foster more eco-efficient production, less environmental degradation from cleaner technologies and further decoupling from ecological impacts in the creation of wealth are needed. Also, further measures are necessary for the implementation of lifecycle thinking and the control of rebound effects (i.e., where growing consumption compensates for technological and efficiency gains). It is against this background that this study has been undertaken. The next section provides an outline of the needs in assessing sustainable production processes. Section 2 presents an overview of the methods used, whereas Section 3 presents the results obtained. These are discussed in Section 4, whereas Section 5 provides some conclusions and describes some future prospects.

Need for Assessing Sustainable Production Processes

Regardless of how one defines sustainable production systems and processes, the public, businesses and governments, have recognized the need for them. In academia, Nash [6] discussed decoupling economic growth from resource use through mandatory quantifiable targets and deadlines across sectors. Haas et al. [7] stressed the importance of assessing the circularity of the global economy's metabolism. Mont and Plepys [8] and Kalmykova et al. [9] showed that while many environmental strategies do not fully address environmental impacts induced by increased consumption, they rely on the improvement of resource productivity and eco-efficiency of processes and products.

Bengtsson et al. [10] re-asserted the seminal distinction from the 1995 "Oslo Roundtable" between two perspectives: one stressing the need to consider overall volumes of consumption and related social, distributional and institutional changes and the other focused on promoting more efficient production methods and products, which contain essential (yet probably not sufficient) elements of a transition. In the framework of the EU's sustainable development policy, Pineiro-Villaverde and García-Álvarez [11] highlighted the role of resource productivity for waste prevention, recycling and an energy/resource-efficient circular economy. Previous studies have included various sectors, e.g., textile [12], energy [13], construction [14] and food [15].

With the introduction of the Sustainable Development Goals of the United Nations, sustainable production is identified as a standalone goal (Goal 12, which calls to "ensure sustainable consumption and production patterns"), and as a central component of many other goals and the accompanying 169 targets agreed in the agenda to help benchmark progress. Analyzing SDG 12, Bengtsson et al. [10] found that in its current conception, SDG 12 mainly relies on what they call the "efficiency" approach, which is centered on sustainable production processes.

As a result of the aforementioned drive for a good definition of sustainable production, relevant assessment methods have also been introduced. Although there is no globally accepted assessment method, tools developed for this purpose are summarized in Table 1.

Table 1. Tools for assessing sustainable production (Source: authors).

Tools	Assessment
Life cycle assessment	Method of defining and quantifying the environmental impact of processes or products. It may be complemented by Life Cost Analysis, which is the assessment of the costs through the lifetime of a given process or product [16]. ISO14041: environmental management-life cycle assessment–lays out the goal and scope definition [17]
Chemical inventory and disclosure	A continuously updated list of the types, sources and quantities of all hazardous and non-hazardous chemicals associated with a product or process [18].
Chemical hazard assessment	Those flammable, toxic, corrosive and reactive chemicals are documented and their potential hazards are analyzed. Also referred to as Material Safety Data Sheets in some countries [19]
Exposure assessment	The determination of the effect of not only chemicals but also physical and biological agents on the receptive mediums, mainly the human body [20,21].
Stakeholder assessment	Stakeholders, such as government and institutions as well as all companies along the supply chain for production, are selected and the opinions of the stakeholders are reviewed [22].
Alternative's assessment	To evaluate and identify environmentally and socially preferable alternatives encompassing production processes, chemicals, materials, products, economic systems (such as transportation systems), and functions, as well as eliminating the need for a current activity or the function of a product [23].
Risk assessment	To assess the risk posed by both external and internal factors to the stability and efficiency of the supply chain [24,25]
Benefit-cost analysis	To assess all associated costs as well as benefits for production in terms of their monetary value equivalent [26]
Ecosystems-services valuation	Assessment of all benefits to humans from nature expressed in four groups: provisioning, such as the production of food and water; regulating, such as the control of climate and disease; supporting, such as nutrient cycles and oxygen production; and cultural, such as spiritual and recreational benefits [27]
Impact assessments	Assessment of the effects of a process or facility on the environment, including biophysical, social, strategic and cumulative assessment activities [28]. Social impact assessments can be part of environmental impact assessments (EIAs) or stand-alone documents.
Footprint analysis	A quantitative measurement describing the appropriation of natural resources by humans, usually measured in units of area or product, and can involve environmental, social, and economic dimensions of the subject [29]
Trade-off and synergy assessments	Assessment of interconnectedness between subjects presented as synergies (positive effects of a target achievement on ecosystem services that would, in turn, allow for obtaining other positive outcomes), or trade-offs (risks taken that may cause potential adverse effects to achieve a positive outcome in lieu of achieving a different positive return) [30]
Multicriteria decision analysis (MCDA)	Determining a preference ordering by scoring among a few available options according to several objectives or criteria identified by relevant stakeholders, followed by employing multicriteria to combine the criteria scores obtained for each option into an overall preference ranking or choice of option [31]
Material/substance flow analysis (MFA)	Systematic assessment of the state and changes of flows and stocks of materials within a system defined in space and time [32]

Bioplastics play an important role when it comes to more sustainable plastic solutions (Figure 1).

Whereas the use of bioplastics has many advantages and they can be part of the circular economy, there are some risks associated with their use. These include the risk of using raw materials which are earmarked for food production, the amount of energy needed to produce and process bioplastic, the problems associated with the biodegrability of some feedstock, and, in the after-use side, the risks associated with micro-plastics deriving from bioplastics. All these elements need to be taken into account and guide current and future decisions on bioplastics use.

Finally, this study aims to assess current plastic manufacturing trends via a literature review and explore how those trends are seen by the consumers through the use of a questionnaire in order to recommend further actions.

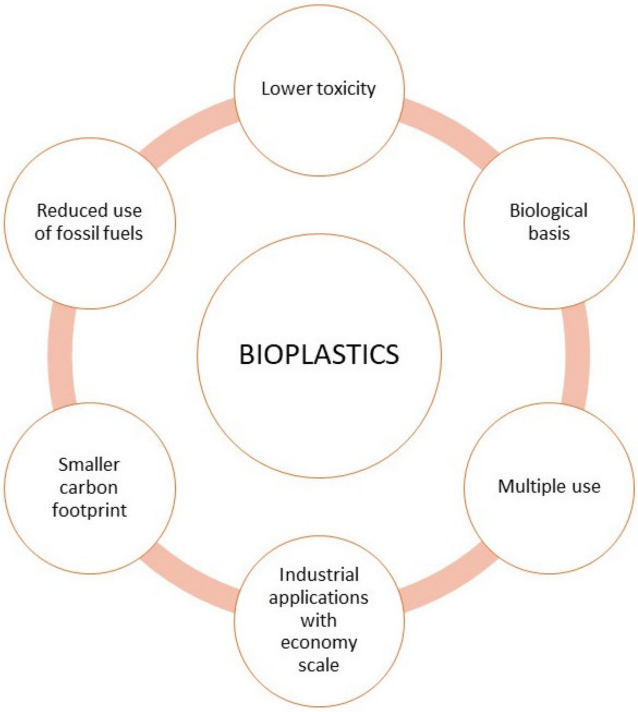

Figure 1. Advantages of bioplastics.

2. Methodology

From a conceptual point of view, the methodological approach proposed in this study consists of determining provisions and requirements for the sustainable production of plastics as part of the statement in SDG 12: Ensure sustainable consumption and production patterns. However, from a practical perspective, the methodology consists of three steps described in Figure 2. In Step 1, trends in manufacturing were characterized through an in-depth literature review. In Step 2, the consumers' perspective on the plastics production trends was assessed. For this purpose, a questionnaire was developed and distributed worldwide to gather insights from consumers to be later compared to those of academia (literature review data). In Step 3, an assessment of the findings is performed, with the results described in Section 3 and discussed in Section 4.

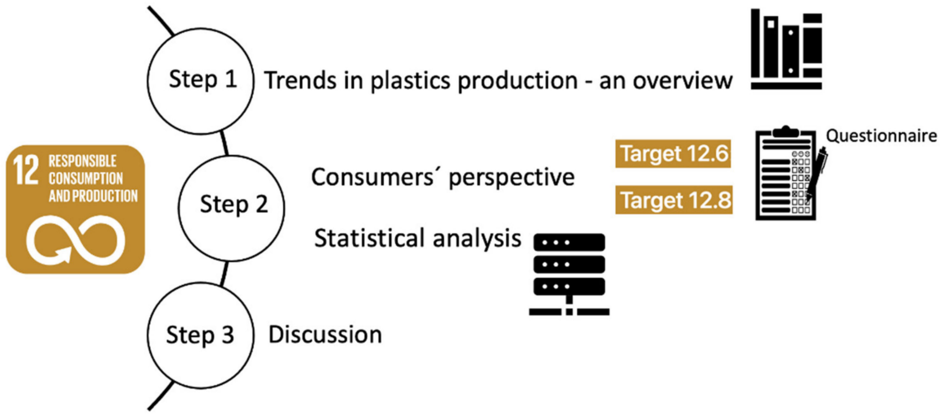

Figure 2. Methodology used in the research (source: authors).

Step 1. Trends in plastics production–an overview.

Some keywords such as "plastics sector", "sustainable production", "negative models of plastics production", "sustainable plastics production processes" and "challenges for creating sustainable plastics" were used to explore contributions related to the plastic industry. Environmental impacts, reduction, re-use, and recycling of plastics were the topics examined in the literature, which served to structure this overview, debate their relevance to the reader's understanding of the theme, and formalize the text.

Step 2. Trends in plastics production–consumers´ perspective.

The SDG 12 marks the road to sustainable development by advocating responsible consumption and production. Hence, both consumers and producers play a major role, which is highlighted by the SDG targets 12.6 and 12.8. While the former promotes the adoption of sustainable practices and the strengthening of corporate sustainability reporting, the latter focuses on providing people with public-relevant information and awareness about sustainable development. Therefore, a questionnaire was designed to appraise insights of individuals associated with conventional plastics and bioplastics in two aspects: (1) knowledge and awareness and (2) usage and attitudes towards them. The questionnaire was introduced to LIME, the survey platform owned by Hamburg University of Applied Sciences, and was previously checked with the university data protection officer. Prior to its distribution, the questionnaire was pretested by 10 experts in the field and the feedback were collected and analysed by the authors, and if relevant, implemented. After undertaking a pre-test, an electronic survey in English was circulated to the international general public involving diverse backgrounds via social and professional networks. In this sense, the sampling can be characterized as non-probabilistic by judgment. Although the findings obtained cannot be generalized, the overview provided can be helpful for exploratory studies [33]. Data were collected from 19 January to 11 May 2021. The survey was structured in three parts: i. Demographic data; ii. Knowledge and awareness about conventional plastics and bioplastics; iii. Usage and attitudes towards conventional plastics and bioplastics. A set of questions was elaborated for each of these three parts. As a result, the questionnaire was constituted of 26 questions (four questions on demography, eight questions on knowledge and awareness, and 14 questions on usage and attitudes). Table 2 summarizes the main content of the questions within these three parts, and all 26 questions are available in Appendix A.

Table 2. Coverage of the survey questions (source: authors).

Demographic Data (i.)	Knowledge and Awareness about Conventional Plastics and Bioplastics (ii.)
Country Gender Age Education	Understanding of what plastics are Concerns about (bio)plastic products

Statistical Treatment of Data

A descriptive statistical analysis of data was collected, including the Pearson chi-squared test, to identify relationships among critical questions.

Step 3. Discussion-Literature review vs. consumers' perception.

The final part of the methodology encompassed a discussion of the findings. The authors contrasted outcomes from the literature review on consumers' perceptions and behaviors towards bio-based products with the findings from the statistical analysis. As the number of articles that analyse consumers' perceptions and behaviour towards bioplastics was not high, a broader literature search based on bio-based products was also considered. The discussion took those articles into account to be compared with the statistical analysis performed. The central findings from this literature relate to the price and attributes of bio-based products and the level of development of the economies. As such, the discussion was focused on these two key aspects.

3. Results

3.1. Trends in Plastics Production—An Overview

Although plastic seems to be the ideal raw material for industrial processes at first glance, its disadvantages regarding sustainability have become evident [34–36]). Pollution stemming from existing models of plastic production poses a global threat to humans and the environment, since most plastics originate from non-renewable petrochemical-based feedstock, including natural gas, crude oil, and natural gas derivatives [37].

Focus on more sustainable plastic production is trending now, and new business models are developing in this direction. A business model for sustainable plastic management requires an industry-wide blueprint that pursues various strategies to prevent, eliminate, or reduce the increasing pollution and health hazards generated by traditional plastics production. Such a holistic response is necessary to manage the constraints and embrace the challenges in meeting the UN's 2030 Agenda [38]. Furthermore, as the "business as usual" approach is no longer possible, plastics producers have adopted principles of a circular economy to emphasize the value of keeping plastic in circulation once it is manufactured, but not without facing process, quality, and societal constraints of manufacturing new material [39,40]. Liu et al. [41] note that the implementation of circular economy practices offers the possibility to reduce emissions generated by the plastic production chain. If coupled with the adoption of Industry4.0 strategies-which include a variety of communication technologies geared toward helping overcome potential manufacturing constraints such as those involving quality, cost, and delivery issues-circular economy principles can assist manufacturers in achieving important sustainable development goals [42,43] and can drive sustainable progress in the plastic industry [44] (Benitez, et al., 2021).

The World Economic Forum [36] argues that new plastics technologies are urgently needed to solve the problem of the resulting plastics waste. As a result, new bioplastics are emerging, but whose benefits vary greatly depending on use. The term "sustainable plastics" encompasses plastics manufactured from different source materials that range from bio-based to biodegradable feedstock. Such plastics are manufactured by recycling and reprocessing used plastic to produce industrial or natural biodegradable polymers. Sustainable plastics have a myriad of applications. For instance, commercially valuable products can be manufactured through a process of chemically recycling plastic from post-consumer apparel [45]. Sustainable plastic also includes biodegradable polymers, which offer the possibility to substitute polypropylene, polyethylene, and polystyrene while reducing greenhouse gas emissions and waste [46]. Nevertheless, polypropylene, polyethylene, and polystyrene are all potentially toxic materials, depending on how they are produced.

The incorporation of bioplastics in the automotive industry promises to decarbonize the sector by allowing the assembly of more fuel-efficient vehicles [47]. Bioplastics can also help reduce occupational risks in the automotive repair and refinishing industry where volatile organic compounds (VOCs) are a serious problem [48,49]. Bioplastics produced industrially are an attractive alternative for plastics producers, because they are comparable in functional performance, but without the associated stigma of being unsustainable [50]. Nevertheless, the higher price of bioplastics is still the main issue when it comes to the transition from fossil fuel-based to bio-based plastics. Additionally, bioplastics have sustainable characteristics usually lacking in conventional plastics, such as less toxicity [51], significantly fewer greenhouse gas emissions [52], and faster biodegradability [53]. According to Green dot Bioplastics [54], the trend is that the market for bioplastics will continue to expand to reach a mature stage by 2030, moving from 2% of bioplastics in the market in 2012 to 40% in 2030.

Efforts related to a more sustainable plastics value chain are currently focused primarily on the recycling of plastic waste [55]. For example, in Europe, single-use plastics (SUP) in particular have been banned in a variety of end-user products, and other measures encouraging the reduction, separation, and recycling of other SUPs are considered by the Directive on the Reduction of the Impact of Certain Plastic Products on the Environment [56]. However, as governments worldwide continue introducing legislation that demands a less polluting plastics chain, including industries that produce raw materials and those that use plastics as input, the trend towards sustainable manufacturing of plastics will grow.

One must remember that the path towards new plastics technologies is ambitious and achievable; however, it is not free of pitfalls. For example, scholars have warned that biodegradable plastics could still harm the environment and human health due to incomplete degradation [57]. Moreover, the shift to intensive agriculture to produce bio-plastics might compromise natural habitats [58]. Therefore, the evolution towards a more sustainable plastic market has to be marginally done, considering that studies have shown that plastic waste may be effectively recycled, improving its environmental performance [59,60]. In addition, the reduction, recyclability, and reuse of plastic along the plastic value chain has the highest potential in reducing greenhouse gas emissions [61].

3.2. Trends in Plastics Manufacturing–Consumers ´ Perception

As previously mentioned, in order to assess the current plastic manufacturing trends, an analysis of the literature and a survey of consumers were performed. After presenting the findings from the literature in the previous section, this section is dedicated to describing the main findings obtained from the survey. Firstly, an analysis of the respondents' profiles is presented. After this, their responses are presented and debated in consideration of the literature on the subject.

3.2.1. Demographical Distribution of Survey Participants

Regarding the respondents' characteristics, it should be noted that the survey included 302 respondents. The sample of this study was diversified and was composed of 64.90% male and 35.10% female respondents worldwide. The countries with the highest percentage were Malaysia (29.47%), the United States (15.89%), the Netherlands (10.93%), Brazil (10.60%), Portugal (7.95%), and Germany (6.95%). Respondents from 23 other countries also participated in this survey, bringing the total to 29 countries. Figure 3 presents all the countries for which at least one respondent participated in the survey, illustrating that the survey comprised individuals from all continents. We used the World Bank income classification to classify countries into the four income groups of "High income", "Upper middle income", "Lower middle income" and "Low income".

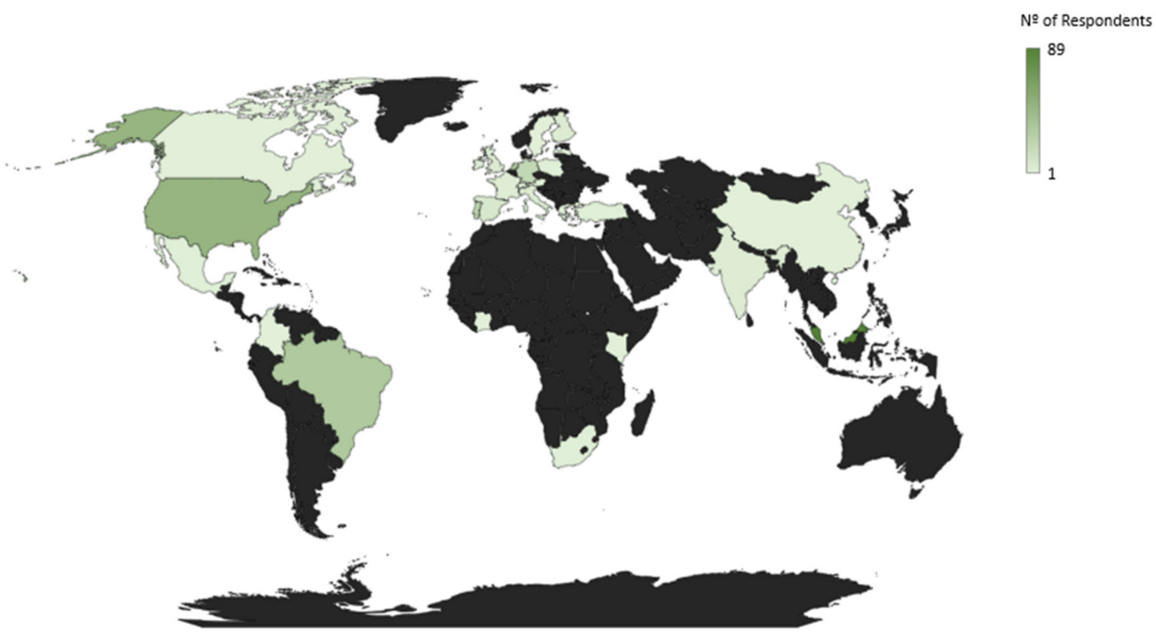

Figure 3. Countries of respondents that participated in the survey.

Table 3 provides the distribution of age and education from the 302 respondents. Regarding the respondents' age, 42.38% of the respondents were between 18 and 25 years, 10.26% between 26 and 35 years, 23.51% between 36 and 45 years, 16.23% between 46 and 59 years, and 7.62% were 60 years of age or more. For education, 45.70% of the respondents have a Bachelor's degree, 19.54% have a Master's degree, 19.54% have a Ph.D. or higher degree, 12.91% completed high school or less, and 2.32% finished trade school. None of the countries in our sample are Low-income countries, and only 2% of the respondents are from Lower Middle-income countries (Côte d'Ivoire, India, and Kenya), while 42.7% are from Upper Middle-income countries and 55.3% are from High-income countries.

Table 3. Frequency of respondents' age groups, education level, and country's development level.

Age	%	**Education**	%	**Development Level**	%
18–25	42.38	High school or less	12.91	Low income	0
26–35	10.26	Bachelor's degree	45.70	Lower-middle income	2.0
36–45	23.51	Trade school	2.32	Upper-middle income	42.7
46–59	16.23	Master's degree	19.54	High income	55.3
60+	7.62	PhD or higher	19.54		

After presenting the details about the sample, their responses regarding knowledge and awareness about plastics are presented and debated in consideration of the literature.

3.2.2. Knowledge and Awareness about Conventional Plastics

Figure 4 shows the respondents' knowledge about conventional plastics by age. Based on the results shown in Figure 4, most of the respondents are aware that conventional plastics can also be referred to as *synthetic polymers* (68.54%) and *synthetic or semi-synthetic materials* (59.60%). Only a small percentage of respondents believe that conventional plastics include *bio-based materials* (18.87%), *polymers based on biological materials including plants and/or plants waste* (15.56%), and *polymers that can biodegrade under certain conditions* (16.56%). This means that conventional plastics are commonly known by the correspondents as synthetic polymers and synthetic/semi-synthetic materials, as compared to the other three categories.

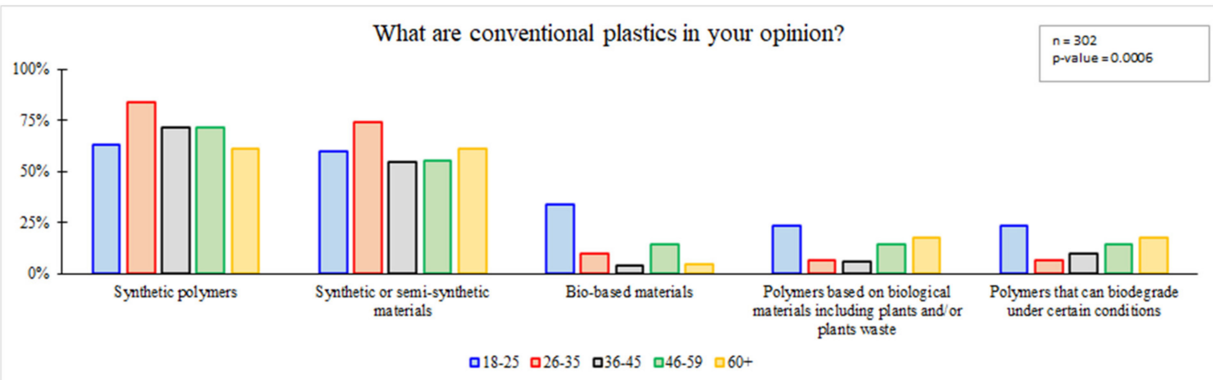

Figure 4. Respondents' knowledge about conventional plastics, by age.

The finding indicates that most of them realize that conventional plastics are made from non-renewable and non-biodegradable resources. Therefore, the majority of the respondents chose categories that are related to synthetic or semi-synthetic resources. In contrast, smaller percentages of respondents chose the latter three categories that are related to non-renewable and non-biodegradable resources. The finding also indicates that the respondent's knowledge level is highly related to the common terms used to describe conventional plastics. Furthermore, the result shows that gender is an indicator of the knowledge level of the correspondents about the five plastics categories. The results indicate that female respondents tend to disagree more often than male respondents with conventional plastic being a synthetic polymer (35.2% against 24.5%) and with conventional plastic being a synthetic or semi-synthetic material (42.3% against 36.8%).

Figure 5 shows the respondents' knowledge about conventional plastics according to country development level. The results in Figure 5 show that the correspondents from the countries of high income and upper middle income have a higher frequency than the countries of lower middle income in the categories of *synthetic polymers* and *synthetic or semi-synthetic materials*. This means that the respondents from countries of high and upper-middle incomes have better knowledge about conventional plastics than the countries of lower-middle income. The finding is aligned with the support and commitments given by the countries of high-income and middle income to reducing carbon footprints.

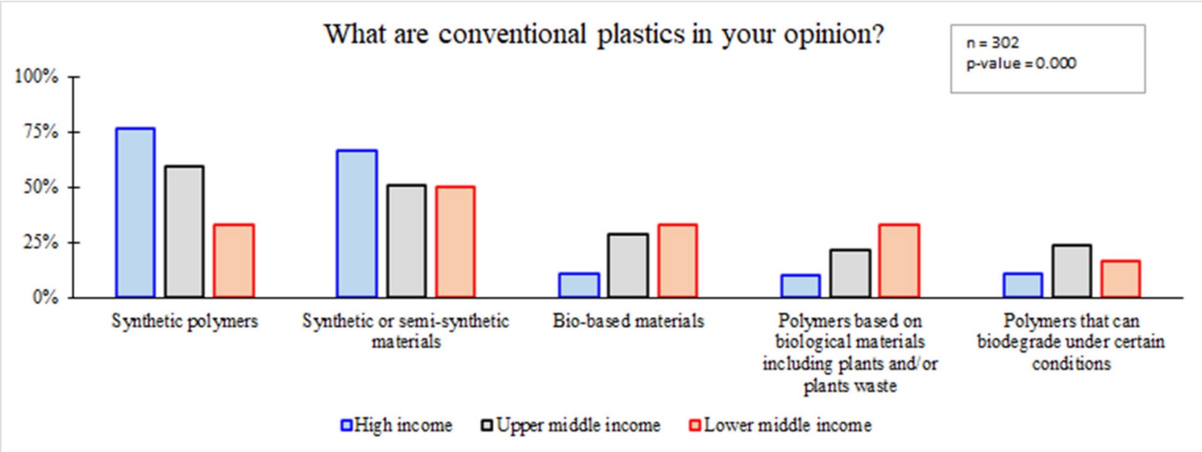

Figure 5. Respondents' knowledge about conventional plastics, by country development level.

Table 4 shows the frequency and percentage of respondents' reasons for concern about conventional plastic according to educational level. Based on the results in Table 4, the percentages of respondents choosing Reason 2 are the highest across different levels of education, followed by Reason 4 as the second most highly chosen reason across different levels of education. The third highly chosen is Reason 1, which is based on the concerns of BPA on human reproduction. Reasons 2 and 4 refer to the concerns about the impact of toxic components and microplastics in conventional plastics on human health. Therefore, the results in Table 4 show that the effects of conventional plastics on human health are the main concern of the correspondents, regardless of their education levels. In other words, human health should become the driving force to increase public awareness of the danger of conventional plastics. The percentage of female correspondents having concern (42%) is higher than male respondents (28%). The total percentage of male correspondents having no concern (47%) and no idea (25%) is higher than female respondents (28% and 30% respectively). Additional results that were obtained regarding health and safety are included in Appendix B (Tables A1–A4).

Figure 6 shows the behavior of the respondents in reducing the use of conventional plastic. The results in the figures show that most of the respondents were ready to adopt more sustainable alternatives to replace conventional alternatives. Instead of eliminating the usage of conventional plastics, 75.5% of them would adopt more sustainable alternatives to replace the daily plastic product, and 43.3% of them would shift to bioplastic alternatives and reduce the usage of the superfluous product that contains or is made of plastics. Some respondents were willing to choose more drastic options, with 61.26% of them willing to buy products without plastic packaging and 59.27% of willing to refuse plastic bags. There was only a small percentage of the respondents who would be willing to wait for better options, accounting for 14.57%. The finding from Figure 6 is that the respondents were willing to change their behavior in the overall usage of conventional plastics. Additional information about bio-based plastics is available in Appendix B (Tables A5 and A6).

Table 4. Frequency and percentage of respondents' reasons for concern about conventional plastic, by educational level. Pearson chi2(16) = 29.1904, *p*-value = 0.023.

No.	Reason	Bachelor's Degree	High School or Less	Master´s Degree	PhD or Higher	Trade School	Total
1	I am concerned about BPA, which mimics the hormone oestrogen and can cause long-term effects on the human body	16	3	2	7	0	28
	%	14.16	8.82	**4.76**	**14.58**	**0**	**11.52**
2	I am concerned about the toxic components in conventional plastic products that can affect human health	62	12	29	19	2	124
	%	54.87	35.29	**69.05**	**39.58**	**33.33**	**51.03**
3	I am concerned, because I do not know how to avoid plastics	12	7	5	3	2	29
	%	10.62	20.59	**11.9**	**6.25**	**33.33**	**11.93**
4	I am concerned, because microplastics have a negative effect on human health	23	12	5	17	2	59
	%	20.35	35.29	**11.9**	**35.42**	**33.33**	**24.28**
5	Other	0	0	1	2	0	3
	%	0	0	2.38	4.17	0	1.23
	Total	113	34	42	48	6	243

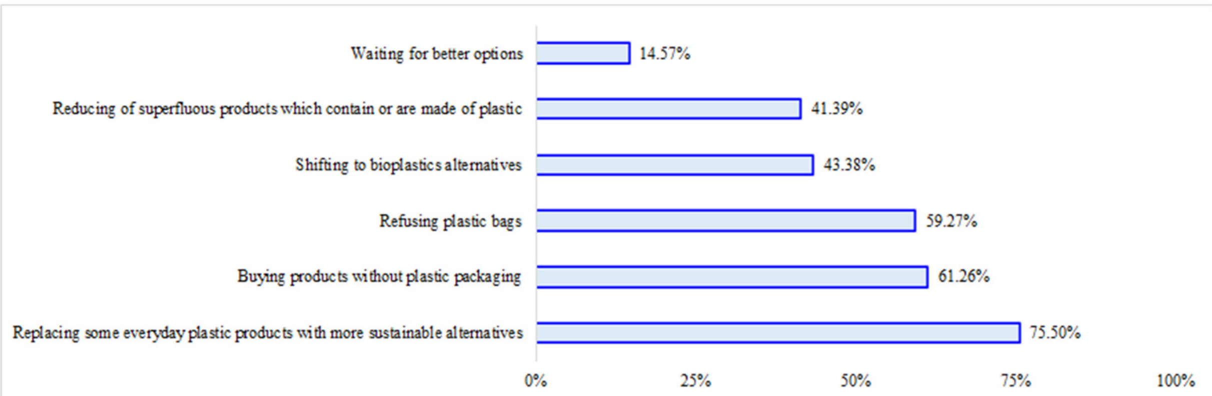

Figure 6. Behaviour to reduce the use of conventional plastics.

3.2.3. Policies to Discourage Conventional Plastic or Encourage Bioplastic

A final intention of the research was to explore the openness that respondents have to different policy measures, such as fees or taxes, subsidies and green labels. Concerning the establishment of a (higher) fee or tax on conventional plastic to encourage its reduction, 71.19% of the respondents considered this a positive measure, while 76.49% favored subsidies for bioplastics. Regarding the relevance of green labels, 81.46% of the respondents feel that they could increase bioplastic product consumption, and 83.11% of the respondents contend that companies should disclose information about the environmental health effects derived from the use of conventional plastics in their products. Regarding government actions, 89.40% of the respondents believe that public procurement practices should incorporate guidelines to promote the consumption of bioplastics.

Figure 7 shows the histogram for the questions related to policies according to gender. A χ^2 (2) test was conducted for each question and gender. With the significance level, $\alpha = 0.05$, we can reject the null hypotheses for all questions except Question 4. Therefore, we can conclude that there were statistically significant differences in gender in answering Questions 1, 2, 3 and 5.

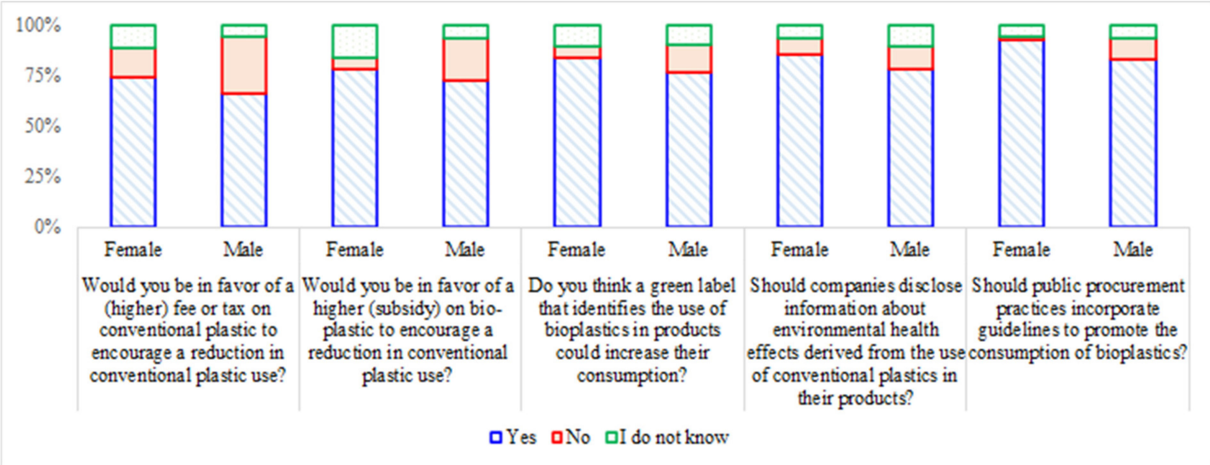

Figure 7. Questions related to policies to encourage consumption of bioplastic/discourage consumption of conventional plastic, by gender. From left to right, the Pearson Chi (2) test for the five survey questions indicated in the graph, and the respective *p*-values are: 9.33, *p*-value = 0.009; 19.3923, *p*-value = 0.000; 7.4243, *p*-value = 0.024; 2.8299, *p*-value = 0.243; 12.4728, *p*-value = 0.002.

For Question 1, $\chi^2(2) = 9.33$, $p < 0.009$: With the significance level, $\alpha = 0.05$, we can reject the null hypothesis and conclude that there are statistically significant differences in gender in answering Question 1, with more females being more favorable of the implementation fee or tax to reduce the usage of conventional plastics. For Question 2, $\chi^2(2) = 19.3923$, $p < 0.000$: With the significance level, $\alpha = 0.05$, we can reject the null hypothesis and conclude that there are statistically significant differences in gender in answering Question 2, with more females being more favorable of implementing a subsidy on bioplastics. For Question 3, $\chi^2(2) = 7.4243$, $p < 0.024$: With the significance level, $\alpha = 0.05$, we can reject the null hypothesis and conclude that there are statistically significant differences in gender in answering Question 3, with more females being more favorable of the implementation of green labels identifying the use of bioplastics in the products. For Question 5, $\chi^2(2) = 12.4728$, $p < 0.002$: With the significance level, $\alpha = 0.05$, we can reject the null hypothesis and conclude that there are statistically significant differences in gender in answering Question 5, with more females being more favorable of public procurement practices incorporating guidelines to promote the consumption of bioplastics. The findings from Questions 1, 2, 3 and 5 indicate that the female correspondents were more likely to be favorable of the implementation of initiatives and policies that encourage the consumption or reduction of conventional plastics and the incremental usage of bioplastics.

Besides the analysis between genders, the relationships between some key questions of the survey were performed to identify possible connections between them. Table 5 shows the joint relative frequencies between Question 19: "Would you be in favour of a higher subsidy on bioplastic to encourage a reduction in conventional plastic use?" and Question 20: "Do you think a green label that identifies the use of bioplastics in products could increase its production?" Nearly 7 in 10 respondents, 68%, were willing to pay a subsidy, or a higher subsidy, and believe that a green label that identifies the use of bioplastics in a product could increase its production. On the other hand, the joint relative frequencies for those who would not pay a subsidy on bioplastics and do not think that green labels that identify bioplastics in products could increase its production is lower, just 5%. Most of the other combinations of answers are negligible. This finding shows that most of those respondents that consider it important for consumers to have access to product information regarding bioplastic aspects are also favourable to subsidies to increase bioplastic product consumption.

Table 5. Joint Relative Frequencies between Question 19 and Question 20.

ITEMS		Question 20		
		Yes (A)	**No (B)**	**I Do Not Know (C)**
Question 19	Yes (A)	0.6821	0.0232	0.0596
	No (B)	0.0464	0.0563	0.0066
	I do not know (C)	0.0861	0.0033	0.0364

Table 6 shows the joint relative frequencies between Question 12: "Do you consciously buy or use bioplastic products?" and Question 18: "Would you be in favor of a (higher) fee or tax on conventional plastic to encourage a reduction in conventional plastic use?". Nearly 4 in 10 respondents, 37.7%, claim that they consciously buy or use bioplastic products and favor paying a (higher) fee or tax on conventional plastic to encourage a reduction in conventional plastic use. However, 22% of those consciously buying or using bioplastic products will not pay a higher fee or tax on conventional plastic. This analysis shows that it is not possible to establish a clear link between these two items.

Table 6. Joint relative frequencies between Question 12 and Question 18.

ITEMS		Question 18		
		Yes (A)	**No (B)**	**I Do Not Know (C)**
Question 12	Yes (A)	0.3775	0.0596	0.0331
	No (B)	0.2252	0.1026	0.0331
	I do not know (C)	0.1093	0.0331	0.0265

Despite this inconclusive result, a link can be made with the study of Martinho et al. [62]. In their research, the authors conducted a survey to analyze the effect of the plastic bag tax implemented in Portugal in 2015. Their result shows that despite the positive effect of the tax to reduce the consumption of plastic bags, it did not increase the consumers' perception of the negative environmental and health effects of plastic. Thus, it suggests that consumers react well to prices regardless of the objective of the tax. In the case of Portugal, the study also shows that respondents see the tax as a source of additional revenue for the State. Convery et al. [63] showed that the introduction of the plastic bags tax was extremely successful in Ireland, as it significantly decreased the consumption of plastic bags, and therefore also of littering, while having low administration costs.

Table 7 shows the joint relative frequencies between Question 2: "Do you have health/safety concerns regarding conventional plastics?" and Question 10, "In your opinion, is there a need to reduce your consumption of conventional plastics?" Around 65% that have health/safety concerns regarding conventional plastics think that there is a need to reduce their consumption of conventional plastics. In contrast, 15% of those claiming to have no health/safety concerns regarding conventional plastics believe that there is a need to reduce their consumption of conventional plastics, showing that health/safety concerns are important reasons for people to reduce their consumption of conventional plastics.

Table 8 shows the joint relative frequencies between Question 2: "Do you have health/safety concerns regarding conventional plastics?" and Question 16: "How much would you be willing to pay on top?". More than 52% of the respondents that claim to have health/safety concerns regarding conventional plastics would accept to pay up to

25% more for bioplastic products, also corroborating the argument regarding the relevance of health/safety concerns on consumers' purchasing decisions.

Table 7. Joint relative frequencies between Question 2 and Question 10.

ITEMS		Question 10		
		Yes (A)	**No (B)**	**I Do Not Know (C)**
Question 2	Yes (A)	0.6523	0.0066	0.0132
	No (B)	0.1556	0.0331	0.0066
	I do not know (C)	0.1225	0.0033	0.0066

Table 8. Joint relative frequencies between Question 2 and Question 16.

ITEMS		Question 16				
		Up to 10% (A)	**Between 10–25% (B)**	**Between 25–40% (C)**	**More than 40% (D)**	**Other (E)**
Question 2	Yes (A)	0.2887	0.2337	0.0756	0.0103	0.0275
	No (B)	0.0825	0.0584	0.0069	0.0069	0.0137
	I do not know (C)	0.0241	0.0584	0.0172	0.0034	0.0034

4. Discussion

Research on the consumers' perceptions of and behaviors towards bio-based products and production processes is still scarce. This research follows a broader strand in the literature that studies consumer behavior towards environmental-friendly products, by exploring factors linked to the quality of the products, beliefs, pricing and emotional and moral dimensions. Kihlberg & Risvik [64] conducted a survey to analyze the consumption of organic bread in Sweden and found that despite the consumers' belief that the consumption of organic bread should increase, and feeling that organic bread is more tasteful, they were unwilling to pay a higher price for organic food in general. This finding is in line with similar research in the literature focusing on consumer behavior towards organic and bio-food (see e.g., [65–68]). Aertsens et al. [66], Shafie & Rennie [67], Marian et al. [68], and Aschemann-Witzel & Zielke [65] found that higher prices associated with organic and bio-food are a barrier to consuming these products. Additionally, these studies also show that the consumers' knowledge and awareness of the health and environmental benefits of organic food consumption is fundamental to increasing the purchase of these goods. Consumers make a combined consideration of different product attributes to decide on their purchases, where price is one of the most important attributes. Rizzo et al. [69], for example, find that health concerns are the major factor behind the individual's purchase of organic olive oil. Similarly, Massey et al. [70] identify health concerns as the main reason for their willingness to pay a higher price for organic products. Other reasons are environmental concerns and quality/taste. The findings are in line with the literature, pointing out that health is a key concern with respect to conventional plastic [71].

For the specific case of consumer behavior towards bioplastics, a few researchers have analyzed the factors behind the consumers' purchase of bioplastics [72–74]. Klein et al. [72] conducted a survey among German citizens, and based on their findings, they argue that communication and information are necessary to spur bioplastic consumption. Zwicker et al. [74] analyze the consumer attitudes to both conventional and bio-plastics and indicate that a higher willingness to pay for bioplastics could be the result of a negative attitude towards conventional plastic, instead of a positive attitude towards bioplastics. These researchers focus mainly on the attributes leading consumers to opt for bioplastics. We add to these studies by analyzing consumer knowledge and understanding of conventional plastics and bioplastics and their relationship to their purchasing decisions and policy views. Another contribution of the research is to analyze the individual's acceptance of a higher price on conventional plastic to discourage their consumption of them and the increased demand for bioplastics as a response to lower the price. The findings indicate that respondents are willing to pay a fee or tax on conventional plastic. However, a larger fraction of respondents is in favor of a subsidy on bioplastics.

A tax or fee on conventional plastic or a subsidy on bioplastics are two potential policy responses to decrease the consumption of conventional plastic and/or increase the consumption of bioplastics. Another policy response we investigated is the relevance of green labels that differentiate bioplastics from conventional plastic. This would be particularly necessary when consumers feel that the lack of information refrains them from changing their consumption behavior towards more sustainable products. The literature is still scarce in this respect. A few exceptions are Martinho et al. [62] and Convery et al. [63]. We find that green labels are seen by respondents as a positive tool to increase bioplastic product consumption. Aligned with this, respondents also feel that companies should disclose information about the environmental health effects derived from the use of conventional plastics in their products. Additionally, the government should also play an important role in promoting less plastic. Respondents believe that public procurement practices should incorporate guidelines to promote the consumption of bioplastics.

Finally, the finding indicates that respondents from high and upper-middle-income countries have more knowledge about conventional plastic. This finding can be linked with the strong commitment of the governments of some of these countries, demonstrated through policies such as the implementation of Extended Producer Responsibility (EPR) by EU members [75,76] and the ban on single-use plastics (SUP) [56], which are crucial in ensuring the responsibilities are shared amongst brand owners, manufactures, producers and consumers. By having the appropriate policies in place from production to consumption, producers and consumers receive consistent information about the concerns of conventional plastics. Countries presenting strong commitments to reducing carbon footprints will implement initiatives and policies that educate their citizens to become knowledgeable consumers in plastic usage.

Focusing on low-middle-income countries, the low level of awareness about conventional practices should be a topic of debate. An illustrative example of this can be verified when China banned the import of plastic waste [77]. Instead of solving the problem, the waste started to be sent to low-middle-income countries, such as Vietnam and Laos [78,79]. In this sense, the problem persisted globally. Therefore, more efforts should be implemented to attract the participation of countries of low-middle incomes in reducing the production and consumption of conventional plastics as well as the import of plastic waste. In addition, as evidenced by Brodin et al. [50], these countries need to realize that bioplastics are viable alternatives to conventional plastics and can generate promising revenue, without the associated stigma of being unsustainable.

5. Conclusions

This paper assessed current trends in plastic production by emphasizing how consumers perceive and respond to these trends. From a theoretical perspective, researchers adopt various tools for assessing sustainable production. Plastics are often single-use, resulting in a large amount of waste and an inefficient use of resources. Although more limited to responses from Europe and America, the paper showed that there is an increasing political change towards less polluting plastics and measures to reduce plastic use, but also that within the industrial sector itself there have been important signs of a movement towards a more circular economy with less plastic waste. From a circular economy perspective, an important improvement has been the advancement of sustainable plastic, that is, bio-based and biodegradable feedstock-based plastic or simply bioplastics. Bioplastics have been shown to be less toxic and to result in fewer greenhouse gas emissions. Nevertheless, the literature also points out that similar to conventional plastic, bioplastics are still associated with unsustainable consumption. Therefore, the paper intended to investigate this further by conducting a qualitative analysis.

The analysis of consumers' perspectives emphasized their knowledge and awareness and their usage and attitudes towards plastics. We analysed the relationship between these characteristics and the demographic data from the respondents. An international online survey was conducted from 19 January–11 May 2021. The findings indicate that the majority of the respondents understand what conventional plastics are. Despite female respondents disagreeing more often than male respondents with the survey alternative that conventional plastics are synthetic polymers and with the survey alternative that conventional plastics are semi-synthetic materials, the female respondents are more concerned about plastic use and are also more willing to accept policy measures to stimulate the consumption of bioplastics instead of conventional plastic (e.g., favouring an increase in the price of conventional plastic). These findings suggest that, from the consumers' perspective, for change to take place it is essential that consumers become aware of the detrimental impact of plastic. It is less important to understand the composition and distinction in the material properties of plastic and/or bioplastics.

Similar to the gender differences, the results also show that respondents from wealthier countries are more aware of what conventional plastics and bioplastics are. No statistically significant differences were found concerning the educational level. Therefore, we argued that the differences between the development level of the countries could be a result of targeted information campaigns in developed countries, which are, in general, more engaged with sustainability practices than in developing nations.

This paper has some limitations. Firstly, the bibliographic research focused on the plastic industry and used terms associated with plastic production, without a specific focus on its environmental impacts. Secondly, the survey, which constituted of 26 questions, was aimed at an assessment of consumers´ levels of information and attitudes and not at the perspectives of producers. Finally, the study period did not allow for comparisons among years.

However, despite these limitations, the paper -and especially the survey with 302 respondents from 32 countries- provides a contribution to the literature by assessing the provisions and requirements for the sustainable production of plastics and by building a profile of the ways plastic consumption is perceived, and hence contributing to efforts to pursue SDG12 from the perspective of consumers.

Regarding future prospects, this paper indicates that there is significant willingness to accept policy measures to stimulate the consumption of bioplastics and decrease the consumption of conventional plastic, both in developed and developing countries. One of the main reasons identified is the respondents' concern with the health and safety effects linked with conventional plastic. Thus, the research indicates that countries should move forward towards the implementation of further policy measures that may lead to a decrease in the use of conventional plastic and stimulate the use of bio-based alternatives. The use of green labels can be an important tool, since consumers usually feel that the lack of information keeps them away from adopting more sustainable consumption practices. Further research should be undertaken to analyse country-specific measures to reduce the use of conventional plastic, bearing in mind a country-specific context.

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Appendix A. Questions from the Questionnaire

Demographic Data

1. Gender:
- ☐ Male
- ☐ Female
- ☐ Othe
2. Country of residence:
3. Age group (years):
- ☐ 18–25
- ☐ 26–35
- ☐ 36–45
- ☐ 46–59
- ☐ 60+
4. Highest degree or level of education:
- ☐ High school or less
- ☐ Trade school
- ☐ Bachelor 's degree
- ☐ Master 's degree
- ☐ PhD or higher

Knowledge Level

5. What are conventional plastics in your opinion?
- ☐ Synthetic polymers
- ☐ Synthetic or semi-synthetic materials
- ☐ Bio-based materials
- ☐ Polymers based on biological materials including plants and/or plants waste
- ☐ Polymers that can biodegrade under certain conditions
- ☐ Other:
6. Do you have health/safety concerns regarding conventional plastics?
- ☐ Yes
- ☐ No
- ☐ I do not know
7. Which statement fits the best?
- ☐ I am concerned about the toxic components in conventional plastic products that can
- ☐ affect human health
- ☐ I am concerned about the BPA, which mimics hormone oestrogen and can cause
- ☐ Long term effects on the human body
- ☐ I am concerned, because I do not know how to avoid plastics
- ☐ I am concerned, because microplastics have negative effect on human health
- ☐ Other:
8. Do you have environmental related concerns regarding conventional plastics?
- ☐ Yes
- ☐ No
- ☐ I do not know

9. Which statement fits the best?
- ☐ I am concerned about the toxic components in conventional plastic products which
- ☐ end up in land and contaminate the soil
- ☐ I am concerned about the toxic components in conventional plastic products which
- ☐ end up in rivers, lakes and the ocean
- ☐ I am concerned about plastic intoxicating animals and harming their health
- ☐ I am concerned about our dependency on oil
- ☐ Other:

10. What are bioplastics in your opinion?
- ☐ Polymers based on bio-waste
- ☐ Bio-based materials
- ☐ Materials which are bio-based and/or biodegradable
- ☐ Polymers based on biological materials including plants and/or plants waste
- ☐ Polymers that can biodegrade under certain conditions
- ☐ Other:

11. Do you have health/safety concerns regarding bioplastics?
- ☐ Yes
- ☐ No
- ☐ I do not know

12. Which statement fits the best?
- ☐ I am concerned about the more toxic components compared to those in conventional plastic products
- ☐ I am concerned because information about bioplastics for general public is scarce
- ☐ I am concerned because long term studies are not available yet
- ☐ I am concerned because the degradation of bio-based plastics result in tiny plastic
- ☐ pieces that have similar characteristics and effects on health as regular micro plastic
- ☐ Other:

Usage and Attitudes towards plastics and bioplastics

13. How often do you use conventional plastics?
- ☐ Daily-I use plastic products or plastic packaging everyday
- ☐ Occasionally-I have been trying to avoid plastic products and packaging
- ☐ Rarely-I do not use much plastic products or packaging

14. In your opinion, is there a need to reduce your consumption of conventional plastics?
- ☐ Yes
- ☐ No
- ☐ I do not know

15. How could you reduce your consumption of conventional plastics?
- ☐ Replace some everyday plastic products with more sustainable alternatives
- ☐ Buy products without plastic packaging
- ☐ Refuse plastic bags
- ☐ Shift to bioplastics alternatives
- ☐ Reduce my consumption of superfluous products which contain or are made of
- ☐ plastic
- ☐ I am waiting to have better options available

16. Do you consciously buy or use bioplastics products?
- ☐ Yes
- ☐ No
- ☐ I do not know

17. If you do buy use bioplastic products, how often do you use them?
- ☐ Daily-I use bioplastic products or bioplastic packing everyday
- ☐ Occasionally-I do not always have access to bioplastics as a substitute for
- ☐ conventional plastics
- ☐ Rarely-I do not use much bioplastic products or packaging

18. What is the main reason that keep you from buying and using bioplastic products more frequently?
- ☐ High cost
- ☐ Low quality
- ☐ Design
- ☐ Limited availability
- ☐ Limited awareness
- ☐ Lack of information about the products
- ☐ Health concerns
- ☐ Environmental concerns
- ☐ I do not know

19. Would you buy a bio-based and biodegradable product if it has good quality and design, is safer for humans and environment, but is more expensive than comparable products?
- ☐ Yes
- ☐ No
- ☐ I do not know

20. How much would you be willing to pay on top?
- ☐ Up to 10%
- ☐ Between 10% and 25%
- ☐ Between 25% and 40%
- ☐ More than 40%
- ☐ Other:

21. What would encourage you to use bioplastics more frequently?
- ☐ More targeted information about the products
- ☐ Lower price
- ☐ Increased availability
- ☐ Better quality
- ☐ More products

22. Would you be in favour of a (higher) fee or tax on conventional plastic to encourage a reduction in conventional plastic use?
- ☐ Yes
- ☐ No
- ☐ I do not know

23. Would you be in favour a higher (subsidy) on bioplastic to encourage a reduction in conventional plastic use?
- ☐ Yes
- ☐ No
- ☐ I do not know

24. Do you think a green label that identifies the use of bioplastics in products could increase their consumption?
- ☐ Yes
- ☐ No
- ☐ I do not know

25. Should companies disclose information about environmental health effects derived from the use of conventional plastics in their products?
- ☐ Yes
- ☐ No
- ☐ I do not know

26. Should public procurement practices incorporate guidelines to promote the consumption of bioplastics?
- ☐ Yes
- ☐ No
- ☐ I do not know

Appendix B. Additional Results

Healthy and safety concerns regarding conventional plastics.

Table A1. Do you have health/safety concerns regarding conventional plastics? By gender. Frequency and percentage.

	Female	Male	Total
I do not know	30 15.31	10 9.43	40 13.25
No	27 13.78	32 30.19	59 19.54
Yes	139 70.92	64 60.38	203 67.22
Total	196 100	106 100	302 100

Pearson chi2(2) = 12.4144, *p*-value = 0.002.

Table A2. Do you have health/safety concerns regarding conventional plastics? By age group. Frequency and percentage.

	18–25	26–35	36–45	46–59	60+	Total
I do not know	29 22.66	2 6.45	3 4.23	4 8.16	2 8.7	40 13.25
No	24 18.75	7 22.58	14 19.72	8 16.33	6 26.09	59 19.54
Yes	75 58.59	22 70.97	54 76.06	37 75.51	15 65.22	203 67.22
Total	128 100	31 100	71 100	49 100	23 100	302 100

Pearson chi2(2) = 19.089, *p*-value = 0.014.

Table A3. Do you have health/safety concerns regarding conventional plastics? By highest degree or level of education. Frequency and percentage.

	Bachelor	High School or Less	Master's Degree	PhD or Higher	Trade School	Total
I do not know	28 20.29	7 17.95	2 3.39	2 3.39	1 14.29	40 13.25
No	25 18.12	5 12.82	17 28.81	11 18.64	1 14.29	59 19.54
Yes	85 61.59	27 69.23	40 67.8	46 77.97	5 71.43	203 67.22
Total	138 100	39 100	59 100	59 100	7 100	302 100

Pearson chi2(8) = 19.9541, *p*-value = 0.011.

Table A4. Do you have health/safety concerns regarding bioplastics?

	High Income	Upper Middle Income	Lower Middle Income	Total
Yes	47 28.14	61 47.29	4 66.67	112 37.09
No	67 40.12	36 27.91	2 33.33	105 34.77
I do not know	53 31.74	32 24.81	0 0	85 28.15
Total	167 100	129 100	6 100	302 100

Pearson chi2(4) = 14.7268, *p*-value = 0.005.

Table A5. Would you buy bio-based and biodegradable product if it has good quality and design, is safer for humans and environment, but is more expensive than comparable products? By country development level.

	High Income	Upper Middle Income	Lower Middle Income	Total
Yes	144 86.23	96 74.42	4 66.67	244 80.79
No	10 5.99	16 12.40	0 0	26 8.61
I do not know	13 7.78	17 13.18	2 33.33	32 10.60
Total	167 100	129 100	6 100	302 100

Pearson chi2(4) = 10.3985, *p*-value = 0.034.

Table A6. Would you buy bio-based and biodegradable product if it has good quality and design, is safer for humans and environment, but is more expensive than comparable products? By gender.

	Female	Male	Total
Yes	166 84.69	78 73.58	244 80.79
No	11 5.61	15 14.15	26 8.61
I do not know	19 9.69	13 12.26	32 10.60
Total	196 100	100	302 100

Pearson chi2(2) = 7.3057, *p*-value = 0.026.

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