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Social Innovations for Improving Compostable Packaging Waste Management in CE: A Multi-Solution Perspective

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Abstract: Compostable packaging is one of the innovative alternatives to conventional packaging. This is also an opportunity in view of the current energy crisis and rising oil prices, firstly, because compostable packaging is produced only from renewable resources, and secondly, it can feed both the composting process and biogas plants. According to the CE principles, it is vital to effectively close product life cycles. Therefore, this paper is aimed at expounding the triggering role of social innovations co-created by stakeholders for improving compostable packaging waste management in accordance with the CE concept. The research procedure consisted of four integrated research phases. A qualitive study was undertaken by conducting 29 in-depth interviews and 3 Social Innovation Labs, engaging 67 bio-packaging market stakeholders, which are national and international companies (e.g., manufacturing, distributing), institutions and other organisations from the social, public and private sectors. The results show that one of the key problems for the development of the CE compostable packaging market is the low level of compostable waste packaging management. Its detailed analysis showed that this problem is associated with several barriers and their numerous causes. According to stakeholders, this can be effectively minimised by applying three social innovations that when combined stimulate all elements of waste management, moving it to a higher level of development.

Keywords: circular economy; organic recycling; packaging life cycle; waste management; social innovation; composting; plastic pollution

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1. Introduction

Presently, a remarkable increase in global pollution with plastic waste can be observed. This serious problem directly affects ecosystems, destabilising their homeostasis and consequently endangering biotic and non-biotic components. Water systems, which receive about 10 million tons of waste annually, are especially endangered. It is estimated that 80% of all litter in saltwater is plastic [1] (pp. 6–7). Plastic waste mechanically interferes with the steady functioning of living systems (e.g., aquatic animals become entangled in waste). Furthermore, extremely dangerous, degraded plastic persists in the environment in the form of toxic microplastics, entering into the food chain and negatively impacting human health and safety [2,3].

Due to huge plastic pollution, which is currently one of the greatest environmental challenges, it is necessary to properly plan and implement multidimensional actions of a preventive and mitigating nature, on national, regional and sectoral levels [4]. Such an approach requires a strong commitment of different groups of stakeholders, i.e., government institutions, public administration bodies, market participants and research units.

Therefore, a key systemic response to the problems of waste production and excessive exploitation of raw materials has been developed in recent years, which is the concept of the circular economy (CE). It is understood as a regenerative model based on eliminating waste and pollution, circulating products and materials (at their highest value) and on the abandonment of the take–make–waste linear processes. Consequently, the life of materials and products is extended, thus reducing the amount of generated waste as well as reducing the demand for raw materials [5,6]. CE integrates the idea of 'closing the loop' and waste management, whereas the life cycle approach is increasingly important in waste management, as it involves the implementation of various routes at the end of product life [7]. Thus, when treating waste as a value resource and turning waste management into resource management, various CE principles need to be implemented to effectively manage and close product life cycles [8,9]. For example, recycle, recover (energy), re-mine and repurpose represent the value retention options according to the downcycling rule [10]. At the same time, the design of new products should be compatible with the possibilities of waste management, which is understood as 'the collection, transport, recovery (including sorting), and disposal of waste, including the supervision of such operations and the aftercare of disposal sites, and including actions taken as a dealer or broker' [11]. Mainly, it should fit into the biological and technical cycles of used materials [12] (p. 26).

The problem with pollution of the natural environment with plastics is closely related to the accelerating exploitation of non-renewable resources in order to meet the needs of a growing population and consumer society. It is predicted that the use of plastics as well as the amount of plastic waste (with half of all plastic waste being landfilled and less than a fifth recycled) is projected to almost triple by 2060 [4]. Reducing this speed requires the involvement of many industries, especially the packaging industry, which is the main source of plastic waste in the European Union [13] (p. 2). In particular, plastic packaging is largely produced for food products [14] (s. 26). Therefore, food packaging supply chains are looking for new environmentally friendly packaging solutions [15,16]. Consequently, in recent years, the potential of bio-based biodegradable packaging, including compostable packaging, has gradually been recognised as the ecological alternative to conventional packaging [17]. Implementation of compostable packaging is perceived as better for the environment, mainly because the use of crude oil can be reduced, limiting the dependence of the packaging market on this raw material, and thus the shift to renewable raw materials [18]. Additionally, materials derived from bio-based polymers (also called bioplastics) have a lower raw material CO_2-emission footprint from planting and harvesting versus fossil fuel extraction [19]. Today, there are three main generations of bio-based biodegradable polymers that can be used for compostable packaging production, depending on the type of source, which can be: edible crops, non-agricultural sources (such as wood and lignocellulosic biomass) or engineered crops (such as algae and urban waste feedstocks) [20]. It is predicted that in 2025, the share of biodegradable packaging will amount to 10%, with the overall share of plastic packaging at 37.5% [21], and the market of biopolymers is anticipated to increase to a value of USD 16.8 billion by 2022 [22]. In the face of this increase, it is becoming crucial to properly plan and implement waste management processes for this kind of emerging product innovations in order to ensure their circularity. Closing the loop of compostable packaging is especially important in relation to the innovative usability potential. Mainly, a key value retention option for organic waste disposal is organic recycling, both aerobic and anaerobic (waste-to-energy) [23,24]. According to the EN 13,432 standard [25], compostable packaging is packaging that will biodegrade to at least 90% within 6 months. The product of the composting process (aerobic recycling) is compost that is safe for health and the natural environment and can be used in agriculture. On the other hand, anaerobic recycling of biowaste is an important source of biogas for energy purposes, mainly heat and electricity [26] as well as a source of digestate [27]. In this sense, the significant potential of compostable packaging is recognised [28,29].

The development of the compostable packaging market is especially stimulated by legal regulations [11,30], the growing ecological awareness of consumers [31,32] and emerg-

ing material innovations [20]. Although the compostable packaging market is still young, it will develop fast in the coming years. Therefore, it is the last moment to design waste management processes that will efficiently deal with the growing compostable load of packaging waste, while using the potential of organic recycling of this packaging [33] and preventing the contamination of other waste streams with compostable packaging waste [34,35].

A recent study shows that one of the key problems hindering the development of the compostable packaging market according to the CE principles is the low level of compostable waste packaging management, which is related to several barriers and reasons for their occurrence [36]. This article is a continuation of that research, as it is aimed at expounding the triggering role of social innovations co-created by stakeholders for compostable packaging waste management in accordance with the CE concept. The study contributes to the research conducted to date, because at present, there is no framework to apply the multi-solution perspective for improving waste management by closing the compostable packaging lifecycle with organic recycling. In this way, it especially enriches the literature on waste management, waste-to-energy, special waste streams, bio-packaging and the circular economy. This paper consists of five sections. At the beginning, the research procedure is described, including the research phases and methods used. The next section is based on the results of the qualitative study and provides an insight into understanding the need for changes in compostable packaging waste management in a multi-solution perspective. The results of the study include an analysis of the recognised problem, 'the low level of development of compostable packaging waste management', identification of the hard and soft elements of efficient waste management, as well as the description of key solutions (social innovations) aimed at the elimination of the analysed problem. Then, in light of previous studies, the solutions are discussed in terms of their integrated potential to improve various elements of compostable packaging waste management in CE.

2. Materials and Methods

This paper presents the research results concerning waste management achieved during a two-year international project focused on developing compostable food packaging. The project is a platform for stakeholders' communication and cooperation in the food bio-packaging market to create and implement social innovations. It covers four phases and selected methods, that determined the study for waste management in compostable packaging (Figure 1). To investigate problems and identify solutions the authors used an in-depth interview (IDI) method [37] and panel discussion workshops organised as Social Innovation Labs (SILs) [38]. The research was conducted in close cooperation with bio-packaging market stakeholders.

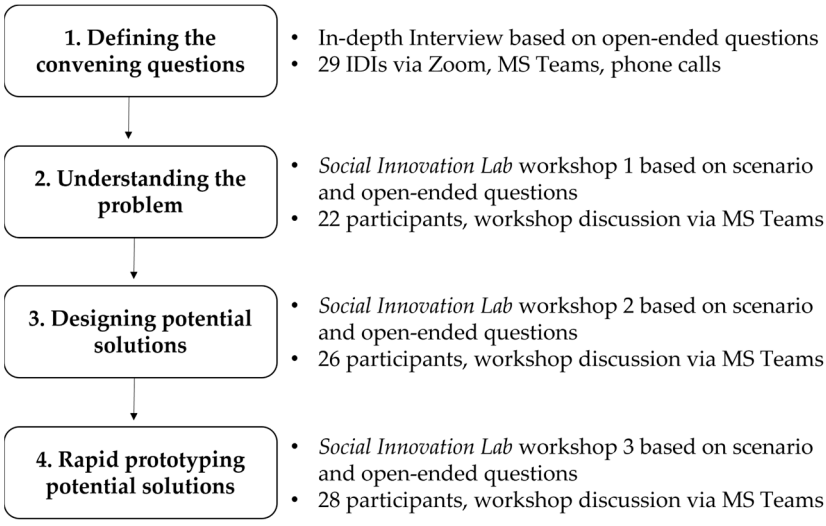

Figure 1. Characteristics of the research phases and methods. Source: own elaboration.

The first research stage was aimed at identifying key activators, drivers and barriers to the large-scale introduction of food bio-packaging (including compostable packaging) on the market. It was focused on bio-packaging supply chain management and the life cycle management, considering the CE principles, with strong focus on bio-waste management.

The starting point for the first research phase was a review of the literature on the circular economy, supply chains of bio-packaging (including compostable packaging) and waste management. The literature review was followed by IDIs with market stakeholders' representatives conducted face-to-face or via MS Teams, Zoom, and phone calls. Interviews lasted 60–90 min. They were based on open-ended questions and focused on the identification of key activators, drivers, and barriers to the development of the bio-packaging market in Poland, from the perspective of waste management. One of the identified barriers was the lack of efficient compostable waste management that would support the implementation of the CE principles effectively. Based on the market diagnosis, key recommendations were formulated to support the development of the food bio-packaging market considering waste management and CE principles.

The data collected during the first research phase served as an input for the analytical work in the second research phase. It was focused on in-depth analysis and understanding of the main problems and barriers to the development of food bio-packaging supply chains (including compostable packaging) in Poland from the perspective of waste management, in accordance with the CE principles. At this stage, the *Social Innovation Lab* workshop 1 with representatives of market stakeholders was conducted. During this workshop, a diagnosis of the problems and barriers throughout the entire life cycle of bio-packaging was conducted. The workshop resulted in a list of problems and barriers and their causes for the development of bio-packaging supply chains in Poland, according to the CE principles from the perspective of waste management. The list was the starting point for the implementation of the third research phase.

The third research stage was aimed at identifying potential solutions to overcoming the barriers in managing the supply chains of bio-packaging and waste management. A panel discussion during the Social Innovation Lab workshop 2 was conducted using open-ended questions to organise the discussion and dedicated templates to collect potential solutions. The workshop was attended by a total of 26 representatives of bio-packaging supply chain stakeholders using MS Teams. Panel participants proposed a total of 53 solutions, 10 of which were related to the low level of compostable packaging waste management development. Due to the multitude of potential solutions, three social innovations highlighted by workshop participants as the most urgent for eliminating the identified problems and barriers were selected for the next, fourth stage of the project. The greatest potential for rapid prototyping was shown by a national strategy for the compostable packaging market development, industry organisation and a multi-sided B2B platform. As part of the project's third stage, team members also conducted analyses of the global market in search of innovative solutions used in the bio-packaging market. The review allowed for the identification of good practices for waste management that were taken as benchmarks in prototyping social innovation.

The fourth stage of the research aimed at developing the three above-mentioned solutions for the compostable packaging market development. The workshop was attended on-line by a total of 28 representatives of bio-packaging supply chain stakeholders via MS Teams. The discussion was conducted using a list of open-ended questions and a tool in the form of diagrams, based on the Canvas scheme, dedicated to each of the three solutions. These diagrams were used to define: the goals, benefits and activities or functionalities, as well as the necessary resources, participants and the leader, and their relationships or risks for the functioning of a given solution. Intensive dialogue with representatives of stakeholders in the fourth stage of the project allowed for the development of assumptions for the implementation of these three solutions in the area of WM. In the fourth research phase, in addition to prototyping solutions, the identification and analysis of foreign best practices was also conducted. The project team explored solutions for stimulating the

market, including waste management as a key determinant of closing the life cycle of compostable packaging and implementing the CE rules.

Summarising, in-depth interviews and the Social Innovation Labs allowed for identification and analysis of the barriers to compostable waste management and prototype solutions stimulating its development. The four research phases contribute to building a platform of bio-packaging market stakeholders (including compostable packaging) and gathering representatives of the following stakeholders: suppliers of raw materials and bioplastics, packaging manufacturers, packaging distributors, business customers, food manufacturers, consumers, waste management entities, organisations for standardisation and certification, research and development institutions, universities, public administration institutions and non-governmental entities.

3. Research Results

3.1. Problem under the Empirical Study

As a result of the diagnosis of the bio-packaging market in the first stage of the research project, it was revealed that bioplastics are a large family of different materials with different properties and applications [39]. In order to select the best sector of bioplastic packaging in terms of the lowest impact on the natural environment and compliance with the CE principles, the research was focused on bio-based biodegradable packaging, including compostable packaging. It was recognised that compostable packaging forms an important segment of the food packaging market for the future due to the use of organic recycling, both aerobic and anaerobic, to close its life cycle. However, the analysis of empirical data, collected during in-depth interviews with stakeholder representatives, on the conditions for bio-based biodegradable packaging supply chains and market development identified a serious problem regarding the low level of development of compostable packaging waste management. Furthermore, based on the research findings, key barriers determining this problem were recognised, as mentioned in Table 1.

Table 1. Barriers determining the problem of the low level of development of compostable packaging waste management.

Problem: The Low Level of Development of Compostable Packaging Waste Management			
Barriers Determining the Problem			
Barrier 1	**Barrier 2**	**Barrier 3**	**Barrier 4**
Lack of uniform and transparent regulations regarding the planning and organisation of compostable packaging circularity	Insufficient communication between the private and public sectors regarding the possibilities of increasing the use of compostable food packaging	Poorly developed management system for compostable packaging waste	Lack of sufficient financial incentives to support activities for the benefit of compostable packaging circularity at the level of local government units

Source: own elaboration based on the SIL workshop 2 results.

The problem of the low level of development of compostable packaging waste management is primarily based on the lack of coherent and transparent regulations supporting the planning and organisation of a closed bio-waste cycle, including compostable packaging waste, on a countrywide scale. The stakeholder representatives also recognised a poorly developed management system for compostable waste and insufficient communication between the private and public sectors as key barriers. The problem is aggravated by the lack of sufficient incentives to support activities and investments of private and public entities for the benefit of compostable packaging circularity. The identification of the barriers sheds light on the potential soft and hard elements of composting packaging waste management. For the more accurate identification and systematisation of such elements, it is worth continuing the analysis based on the results of the second stage of the research.

3.2. Elements Required for Waste Management

At the second stage of the research project, the main causes of the above-mentioned problem and barriers were identified. Figure 2 presents an original diagram supplemented by stakeholder representatives in the progress of the first *Social Innovation Lab* workshop. The diagram relates to the problem–barriers–causes triad highlighting the connections.

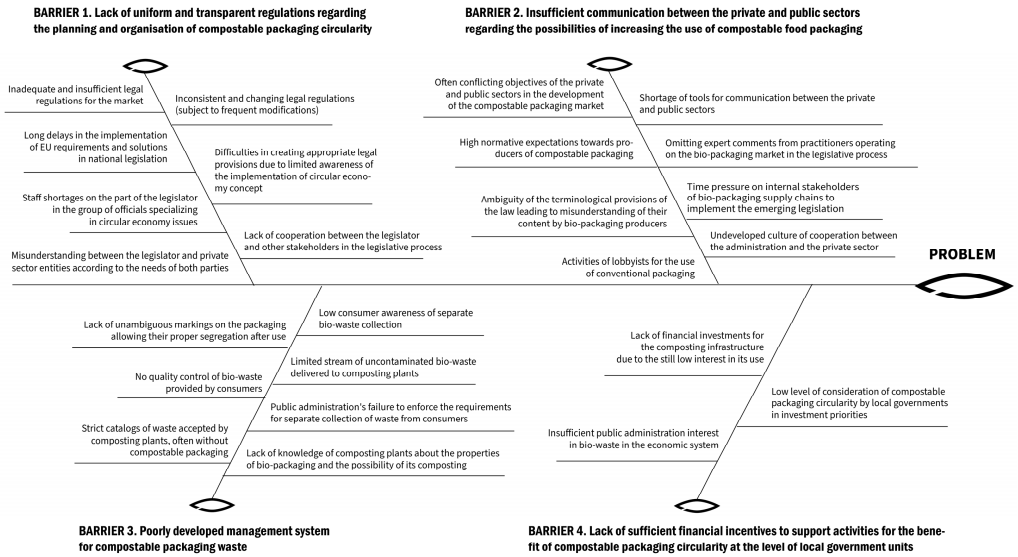

Figure 2. Diagram of the problem–barriers–causes triad. Source: own elaboration based on the SIL workshop 2 results.

Barrier 1 is mainly caused by the lack of synchronisation of regulations between the EU, national and local government levels, as well as the lack of communication between the legislator and other stakeholders. The key reason for barrier 2 is the lack of a dialogue culture and cooperation between stakeholders of the compostable packaging market on the one hand, and a strong lobbying for the use of conventional plastic packaging on the other hand. The basis for barrier 3 is the lack of a systemic solution for compostable packaging to collect, process and close its lifecycle in the most environmentally friendly way. The main causes in this regard are as follows: low consumer awareness of bio-waste collection, contamination of bio-waste, insufficient knowledge of composting or biogas plants regarding the properties of this type of packaging. The fundamental cause of barrier 4 is the lack of a developed local policy providing financial and investment incentives to increase the circularity of bio-waste, including compostable packaging waste.

On the one hand, the revealed causes help to better understand the essence of the problem and barriers, on the other hand, they contribute to a more accurate recognition of desirable elements of compostable packaging waste management. The identified components were systemised into two groups as presented in Table 2.

Table 2. The fundamental elements of compostable packaging waste management.

No.	Physical and Technical Elements	Managerial and Behavioural Elements
1.	Principles and methods of planning, organising and controlling	Management methods
2.	Organisational structure	Power and leadership
3.	Workflow and activity structure	Knowledge and experience
4.	Methods and tools for information and communication flows	Awareness and responsibility
5.	Physical flows infrastructure	Culture and attitude to collaboration

Source: own elaboration based on the SIL workshop 1 results.

The group of physical and technical elements includes 'hard factors' and is related especially to principles, methods, structures, tools and infrastructure. Altogether, public

administration's failure to enforce the requirements for separate collection of waste from consumers, no quality control of bio-waste provided by consumers, inconsistent, changing, and inadequate and insufficient legal regulations for the market result in the need to implement principles and methods of planning, organising and controlling the packaging circular economy at strategic, and tactical and operational levels in the public and private spheres. Moreover, in the public sector, there is the potential to design the appropriate organisational structure between the EU, national, regional and local administrative entities. Such a structure can determine the appropriate levels of strategic document development and project implementation. Its application can be a remedy for long delays in the implementation of EU requirements and solutions in national legislation. Identification of the insufficient scope of joint work and cooperation between representatives of the public and private sectors proves the necessity to make efforts to share competences and tasks in a systemised workflow and activity structure between stakeholders. This component simultaneously addresses the need to enhance streams of uncontaminated bio-waste and extend catalogues categories of bio-waste, including compostable packaging. Depending on the type of processes, activities and its outputs, the workflow and activity structure is different, especially at the last stage of the compostable packaging lifecycle, namely at the bio-waste management phase. In the case of the composting process managed in composting plants on an industrial scale, compost as a product can be used in agriculture sectors. Another option is anaerobic digestion of bio-waste being a source of biogas that is considered as a renewable energy source used in various industrial sectors. Both types of outputs from compostable packaging waste management are desirable in the context of circularity and sustainability. Additionally, biogas is gaining more and more attention in energy transition. At the same time, it is desired to ensure methods and tools for information and communication flows in the system. This development may eliminate the lack of unambiguous markings on the packaging allowing for proper segregation after use, improving tools for communication between the private and public sectors, and eliminating misunderstanding between the legislator and private sector entities according to the needs of both parties. Finally, the development of physical flows infrastructure is critical. The need for higher interest and financial support for investments in the infrastructure is also postulated. Effective and successful exploitation of the above-mentioned physical and technical components requires synergy with managerial and behavioural elements called 'soft factors'. Firstly, the recognition of high normative expectations towards producers of compostable packaging highlights the dominant role of regulations as a mechanism stimulating the activities of the market entities. There is a need to implement new management methods—not only reactive, but also proactive to market needs. Moreover, time pressure on internal stakeholders of bio-packaging supply chains to implement the emerging legislation, activities of lobbyists for the use of conventional packaging, as well as often conflicting objectives of the private and public sectors in the development of the compostable packaging market revealed the need to transform the power and leadership structure in the system. The following causes: low consumer awareness of separate bio-waste collection, the low level of consideration of compostable packaging circularity by local governments in investment priorities, insufficient public administration interest in bio-waste in the economic system, difficulties in creating appropriate legal provisions due to limited awareness of the implementation of the CE concept, determine the next required element of the system, which is awareness and responsibility of stakeholders. Furthermore, the lack of knowledge of composting plants regarding the properties of bio-packaging and the possibility of its composting, omitting expert comments from practitioners operating on the bio-packaging market in the legislative process, ambiguity of the terminological provisions of the law leading to misunderstanding of their content by bio-packaging producers, and staff shortages on the part of the legislator in the group of officials specialising in CE issues draw attention to the need to advance knowledge and experience in the field of compostable packaging. Culture and attitude to collaboration play an important role in their advancement. The importance of the last proposed component is raised by two causes, namely: undeveloped culture of

cooperation between the administration and the private sector, and a lack of cooperation between the legislator and other stakeholders in the legislative process.

The first *Social Innovation Lab* stakeholder discussion allowed us to distinguish elements of compostable packaging waste management as well as revealed the necessity for integration. Therefore, the next research task was to identify essential solutions for integrated waste management in a holistic approach covering waste generation, characterisation, collection, separation, treatment, and final disposal.

3.3. Solutions for Improving Waste Management

The second *Social Innovation Lab* workshop at the third research stage was concentrated on designing potential solutions to the problem of the low level of development of compostable packaging waste management. Particular attention was paid to overcoming the barrier of the lack of uniform and transparent regulations regarding planning and organising the circularity of compostable packaging, recognised by stakeholders as the most important among those listed in Table 1. Stakeholder representatives generated ideas for the following social innovations:

- Designing a strategy for the domestic compostable market development and operational documents for its implementation.
- Establishment of an association of bioplastics processors (and/or producers of compostable packaging).
- Education of all society generations based on unanimous and coherent communication.
- Creation of a law of appropriate quality.
- Increasing the awareness and qualifications of specialists who create legal regulations influencing the increase in the share of compostable packaging in the food packaging market.
- Taking into consideration the opinions of business practitioners when developing legal regulations.
- Open dialogue between the world of science, business and public administration.
- Conducting research and development projects in cooperation between scientific and business units.
- Development of optional solutions as part of bottom-up initiatives of stakeholders of compostable packaging supply chains (e.g., certification).
- Conducting a life cycle assessment of various packaging, including compostable packaging.

The presented list of social innovations reflects a multi-solution perspective. The designed solutions are characterised by various levels of urgency and implementation difficulties. Taking into consideration the greatest importance and priority outlined by stakeholders as well as close interdependencies between solutions, the following three social innovations were considered in order to integrate identified elements and improve compostable packaging waste management in line with the CE principles, namely:

- National strategy for the compostable packaging market development;
- Industry organisation;
- Multi-sided B2B platform.

The chosen three solutions were prototyped during the *Social Innovation Lab* workshop 3 at the fourth stage of the research. In the prototype strategy, stakeholder representatives defined a vision for the development of an innovative and competitive compostable packaging market as an integrated system involving stakeholders through their roles and responsibilities in value chains, fulfilling the CE principles and providing access to information for customers. The content of the strategy should cover the following areas: (1) innovations, (2) regulations, (3) finance and (4) education. In turn, the most important tasks of the industry organisation include (1) integration of stakeholders of the compostable packaging market, (2) monitoring of regulatory changes and lobbying activities at the EU level, (3) providing up-to-date and reliable information on changes in legal regulations, (4) cooperation with other entities, (5) setting strategic directions for the compostable packaging market development, (6) disseminating information, and (7) education in the fields

of compostable packaging and waste management. Among the most desirable features of a multi-sided B2B platform, stakeholder representatives indicated the following functions: (1) educational, (2) communication, (3) informative, (4) innovative, and (5) relational. Stakeholders in the country, in which the prototypes of social innovations are to be introduced, may benefit from the examples of foreign practices presented in Table 3.

Table 3. Examples of social innovations from foreign markets.

No.	Social Innovation	Example of Foreign Practice	Characteristic
1.	National strategy for compostable packaging market development	National Compostable Packaging Strategy in Australia	It covers three main areas: packaging development supported by education and counteracting greenwashing, building a compostable packaging collection system, and activities related to the composting process development.
2.	Industry organisation	Consorzio Italiano Compostatori in Italy	It is engaged in a wide range of activities to enhance biological treatment (composting and anaerobic digestion) of separated bio-waste, green waste and other organic waste feedstock to obtain organic fertilisers, biogas and biomethane and advanced biofuel.
3.	Multi-sided B2B platform	Compost Connect platform in Australia	It helps to increase access to organic recycling services for compostable packaging (industrial composting) in line with the CE principles.

Source: [40–42].

The next section discusses the significance of key social innovations in stimulating the development and integration of the above-mentioned elements of compostable packaging waste management in light of the CE concept.

4. Discussion

Compostable packaging is a more valuable packaging for the natural environment than conventional plastic, mainly because it is made of renewable raw materials. Their use in the economy is in line with the principles of the circular economy. Firstly, increasing the use of compostable packaging reduces the demand for fossil based raw materials in line with the 'reduce' principle. Secondly, their specificity allows for the recovery and reintroduction of resources into the environment through organic recycling, in accordance with the 'recycle' principle. In this perspective, compostable packaging waste is treated as a resource. When it is used for producing compost, it enriches the natural environment. These are the two key advantages of composting packaging over conventional packaging.

The life cycle of composting packaging includes the following stages: crop cultivation, harvesting and resource extraction; raw materials processing; packaging manufacturing; combining products and packaging; distribution; consumer purchase; consumption/use; post-purchase evaluation; packaging disposal or reusing; bio-waste materials collection and recovery; organic recycling [43]. The multitude of stages means that internal and external stakeholders of the supply chain are involved in the life cycle of composting packaging. This means that minimising the impact on the natural environment depends on the needs, goals and activities of many public and private entities as well as their effective cooperation. Consequently, the management of the packaging life cycle is difficult and requires coordination. As a result, it is important to design and implement instruments to support supply chain stakeholders. According to the assumptions of CE, the production and use of compostable packaging in the economy is important, but the essence is to close the loop. This could be achieved by using compostable packaging as waste-to-energy and as a source of producing compost introduced into the environment. The path to

completing the biological life cycle [44] of compostable packaging is multiplex because it depends on well-organised waste management consisting of three stages. Among them are waste collection, transport and processing, including sorting of compost waste [45], while involving multiple stakeholders in the supply chain. In order to effectively close the life cycle of compostable packaging, it becomes necessary to design and implement instruments stimulating the activities of all stakeholders that have an impact on compostable packaging waste management.

Searching for the best solutions based on SIL methodology, it was made possible to select three key social innovations supporting the improvement of the composting packaging market, including in the area of waste management in CE. These solutions involve: a national strategy for the compostable packaging market development, industry organisation, and a multi-sided B2B platform. There are dependences and feedback loops between the three solutions. Strategy and the process of its development stimulates stakeholder cooperation. The result may be the creation of an organisation or industry platform. An industry organisation or technological platform can become a bottom-up mechanism for creating a strategy in cooperation with the public administration. Indicated solutions perform various functions (e.g., integrational, educational, organisational, legislative, financial), which reinforce and complement each other. Together, they constitute a triangle of priority innovative solutions stimulating the composting packaging market in accordance with the CE rules. They all provide diverse material and non-material resources from the public, private and social sectors. Each of them individually have their own values, but together, they determine the highest effects for market development. This means that the implementation of the multi-solution perspective seems to be a comprehensive approach to stimulating the development of the necessary resources that can supply and optimise the effects of the circular economy of packaging composting. Although there are no studies in the literature on the subject showing precisely how each of these three dedicated solutions could support improving compostable packaging waste management in CE, the authors of previous studies refer to the role of some of the fundamental soft and hard elements that need to be strengthened in order to build appropriate compostable packaging waste management. The presented considerations discuss the IDI and SIL results against the previous studies.

4.1. National Strategy as a Roadmap for Compostable Packaging Waste Management

Integrating the needs, goals and activities in the area of waste management requires a holistic approach that can be provided by the strategic document. National strategy for the compostable packaging market development is regarded by research participants as the umbrella for various issues related to the compostable packaging life cycle. Above all, it enables the implementation of principles and methods of planning, organising and controlling the life cycle packaging management at strategic, tactical and operational levels in the public and private fields. It is a forward-looking plan that sets market vision, strategic objectives, and a road map of activities and resources supporting the compostable packaging market acceleration according to the CE principles. It is a signpost for strategic and operational plans developed at the regional and local level. According to the SIL workshop participants, it should cover four pillars: innovations, regulations, finances, and education. This kind of strategy is based on a multi-level and multi-dimensional approach, because both internal and external stakeholders of the compostable packaging supply chain participate in its development, e.g., governmental entities, industry organisations, as well as enterprises and waste management companies [41]. The parallel involvement of the public and private sector in the design of the strategy provides an opportunity to establish a sustainable and trust-based culture and attitude to collaboration. According to the previous research, this type of document should create opportunities for integration and strengthen relationships between stakeholders, including national, regional, and local government administration [46]. Joint discussion and the consensus achieved in the works on the strategy between the stakeholders constitute a potential for effective and efficient

cooperation in the legislative process. Increasing the integration and flexibility of legal regulations at all levels of packaging waste management enables the achievement of the set objectives [46]. According to the project stakeholders, the strategy should systematise and adopt the definition of compostable packaging, in line with the provisions of law and applicable standards, and define the rules for the functioning of the compostable packaging market, in particular, the management of compostable packaging waste, including compostable marking, segregation, as well as ways of organic recycling (both aerobic and anaerobic). Through such an informational function, strategy development stimulates the methods and tools for information and communication flows. Based on the results of the discussion panels, a national strategy for compostable packaging market development is a kind of manifesto of the awareness and responsibility. The strategy is also intended to deepen the knowledge and experience of stakeholders in the field of the circular economy of compostable packaging. According to the research participants, the effect of the information and educational content, dedicated especially to business and individual customers, could be the reduction of the greenwashing phenomenon, which disrupts the process of recognition, segregation and, consequently, closes the life cycle of compostable packaging. It was confirmed by other authors that increasing awareness of unethical practices increases customer caution with their purchasing decisions [47]. Stakeholders have stated that planned educational activities should target the whole society and use traditional and innovative channels and methods. Moreover, according to Fargnoli et al., the new trend such as customers' environmental awareness pushes companies to put on the market an ever-larger range of green products [48], which includes compostable packaging. Diverse tools make it possible to reach the largest group of recipients of the X, Y and Z generations. For example, it is recommended to introduce teaching content on compostable packaging waste management in kindergartens and schools. According to the previous studies, environmental education provides an impulse to embed the principles of waste segregation and builds a positive attitude of a young society towards environmental protection [49]. Mobile applications [50] and social networking sites [51] can be used to disseminate knowledge regarding compostable packaging waste segregation and home composting. In order to optimise waste management processes, it becomes important to support civic initiatives in both the financial and administrative areas [52]. Education should be strongly supported by public campaigns that encourage society to collect and segregate waste correctly as well as to prevent food waste [50,53]. Following the SIL results, educational activities aimed at strengthening the environmental responsibility of enterprises should include issues related to legal regulations, certification, industrial composting, available innovations (product, process and technological), as well as sources of financing compostable packaging waste management. The last but equally important group for education activities should be employees of public institutions, who have a key influence on the creation of landscape for the compostable packaging market development. The organisational structure of waste management consists of various units, including waste collection companies, recycling companies, composting and biogas plants. The conducted research revealed that their proper functioning is ensured by coherent and understandable legal regulations, communication, as well as physical flows in infrastructure. This is in a line with past studies. Composting processes are of great importance because their environmental advantage over incineration and landfilling is recommended [53]. Moreover, the infrastructure adjusted to the needs of the compostable packaging life cycle management provides an opportunity for optimal management of waste streams and obtaining high-quality compost [54]. Innovative infrastructure should include the stage of waste segregation at the source. An example is the development and investment in intelligent bins and containers for waste segregation, in residential, pre-industrial, and public areas [55]. Consequently, the proposed solution in the form of a national strategy should create opportunities for investments in technologically advanced infrastructure of compostable packaging waste management as well as identify potential sources of financing.

An example of foreign social innovation is the National Compostable Packaging Strategy in Australia, listed in Table 3 [40]. It is aimed at determining a coherent and strategic development of the certified compostable packaging market directions (for compliance with the requirements of national standards). Moreover, this strategy indicates the necessary actions to ensure the appropriate use and recycling processes following the implementation of the principles of CE. This correct approach to life cycle compostable packaging management emphasises eco-design as well as recycling stages valuable for the environment and society in closing the loop. Consumer behaviour has been seen as an important starting point not only to managing the compostable packaging waste stream but also to preventing the contamination of others. Consequently, the valuable role of household education and information sharing on the differences between biodegradable and compostable packaging, its proper selection, and segregation have been emphasised. To assure effective use and recovery of compostable packaging, engagement and closer collaboration between packaging manufacturers, brand owners, and organics recyclers have been essential. Implementation of the principles of CE has been made possible via common collaboration of all supply chain stakeholders in terms of using, inter alia, labels on brand owners' packaging for correct disposal, certified compostable packaging, local government information activities, state and territorial government education programs (e.g., 'South Australia's Which Bin?'; 'National Consumer Education Campaign Check It! Before You Chuck'; 'Compost for Soils'), and clear instructions for local governments and residents on the collected waste and compostable packaging, created by entities dealing with organic recycling. Moreover, the Australian strategy underlines the state and territory governments' roles in ensuring the compliance of compostable packaging to feedstock with existing and future legislation, the infrastructure for sorting and processing following the CE postulates, and finally, the local council's activities.

The strategy has an active impact on the future shape of compostable packaging waste management. The overriding and sectoral document sets directions, goals and actions to reduce barriers and problems hampering the sustainable and circular development of compostable packaging waste management. The strategy coordinates and stimulates the behaviour of stakeholders with often enough limited resources, including financial. The content of the strategy is designed coherently to national circumstances. Therefore, partnership cooperation between the stakeholders of compostable packaging waste management becomes important. On the one hand, the strategy can stimulate the initiation of the organization and platform. On the other hand, it may be the result of cooperation within these solutions. Regardless of the path of creating a national strategy, it is important that it is not only a document, but a responsibly implemented policy.

4.2. Industry Organisation as an Entity Associating Stakeholders of Compostable Packaging Waste Management

Sustainable waste management requires the participation and collaboration of all stakeholders, such as waste producers, waste disposal entities, public authorities, corporations, educational entities, NGOs, and funding institutions [56]. Further, the involvement of the public, private, and social sectors enables the transition to a circular economy [57,58]. Therefore, an industry organisation aimed at associating market stakeholders is the second solution enhancing the improvement of compostable packaging waste management and stimulating the hard and soft elements presented in Table 2. Based on the project research results, integrating various stakeholders in the compostable packaging supply chain should strengthen the culture and attitude to collaboration between them. For example, the Australasian Bioplastics Association successfully unites various government administrations, ecological recyclers, composting plants, industry groups, NGOs, brand owners, and processors [59]. Research participants noted that the industry organisation, acting as a representative for the industry, should join a legislative process and in cooperation with the public administration in the country and the European Union, stimulate the packaging waste management improvement at the strategic and operational level. In

this way, the organisation would lobby the creation of a favourable legal and economic framework, which will consequently support the compostable packaging life cycle management in accordance with the CE principles, through building an appropriate physical flows infrastructure, workflow and activity structure, development of innovations, and through increasing the financing of waste management. The involvement of the industry organisation in enhancing circular waste management and active participation in the development of strategic documents and regulations builds power and leadership in packaging waste management processes. Industry organisation may also strengthen the designing principles and methods of planning, organising and controlling compostable packaging waste management [35]. An example of the association successfully representing the interests of the bioplastics industry in Europe is European Bioplastics [60]. According to the research results, gathering various business stakeholders in one place also allows for the strengthening of the knowledge and experience exchange. The knowledge exchange requires linking environmental research, business practice and policy [61]. Therefore, the prototyped industry organisation should be strongly focused on conducting research and development activities for the improvement of waste management. By bringing together various stakeholders, there should be a place for the exchange of reliable information, expertise, and bio-based biodegradable innovations as well as for the implementation of research projects in the field of compostable packaging life cycle management according to the CE principles. The effect of such cooperation would especially be the improvement of physical flows infrastructure as well as the workflow and activity structure. In this way also, an industry organisation may efficiently match companies that produce compostable materials and packaging, companies collecting compostable packaging wastes, composting plants and biogas plants, as well as compost users in one place. Moreover, by developing, collecting, and promoting the best waste management practices, it is advisable to support the implementation of new management methods supporting the eco-designing, identification, marking, collection, segregation, collection, and processing of compostable packaging. Finally, the synergy effect in the form of many benefits for waste management improvement will also be a source of increasing awareness and responsibility of industry organisation members.

An interesting foreign industry organisation is the Italian Composting and Biogas Association (it. C.I.C Consorzio Italiano Compostatori), listed in Table 3. It deals with the issues of composting and biogas production [41]. Its mission is 'to promote biowaste recycling and prevention, enhance compost quality and the market, organise technical training for the composting sector, and support government in improving biowaste recycling'. Based on the cooperation of various participants, e.g., public and private compost producers, local authorities, machinery and equipment constructors, and research institutes organisation, it is engaged in a wide range of activities on a national and international level. The organisation certifies industrial compost according to its certification scheme called 'Compostable CIC'. It helps citizens to recognise and use bio-based biodegradable shoppers and bags and other compostable products. The association's technical staff continuously control the quality of the organic waste collected in Italy, yearly providing about 850 composition analyses from more than 550 Italian municipalities. Moreover, the role of the organisation is to enhance biological treatment (composting and anaerobic digestion) of source-separated bio waste, green waste, and other organic waste, to obtain organic fertilisers, biogas, and biomethane, an advanced biofuel. The association is an active member of many other organisations on national and international levels aimed at improving compostable packaging waste management.

4.3. Multi-Sided B2B Platform as a Digital Tool Integrating Waste Management Entities and Processes

The literature review results indicate that the role of digital technologies in waste management is under discussion [62,63]. However, there is a lack of research studies directly connecting multi-sided platforms with compostable packaging waste management

in CE. The entities and processes integration could be supported by digital tools, such as multi-sided B2B platforms, currently seen in the literature and business practices as powerful business models [64–66]. Properly designed, implemented, and then executed solutions positively influence the hard and soft waste management elements in the compostable packaging area. Multi-sided B2B platforms are surely valuable knowledge based on CE regulations, financing sources, packaging properties, supply chain business processes, technologies, and innovations. Waste-to-energy infrastructure and technologies are still perceived as innovations, even if the issue of energy and waste management is under discussion [67]. Consequently, the proposed solution systemises workflow and activity structure. The multi-sided B2B platform should also help solve problems in the field of a low-awareness society regarding bio-packaging or separate waste collection to prepare the special waste stream, which is also essential for the B2B cooperation contributing to meeting compostable packaging waste management challenges. In this context, the solution should reinforce proper waste transport; transfer and recycling, both aerobic and anaerobic, economical material; and waste-to-energy management. The use of bio-waste and rational nutritional management are essential in CE. According to the research participants, its role is to support such soft elements as knowledge and experience, awareness, and responsibility. The multi-sided B2B platform is a type of tool for information and communication regarding the physical flow's infrastructure. It is based on the exchange of information between platform participants in any most convenient and flexible way (e.g., via chat, forum, virtual rooms), where respondents would like to share comments, recommendations, knowledge and experience. As a result, it includes in one place market information such as industry news; information about market participants and their business activities; goods and services offered, preferable with transparency; open access; and reliability information reassurance. Moreover, it was confirmed by other authors that sharing globally distributed and transferred knowledge by market experts, specialist companies, users, R&D laboratories, and universities [68] (culture and attitude to collaboration) could stimulate various types of innovation (product, process, marketing, and organisational ones) because the digital platforms tend to attract complementary innovators [69] and potentially support commercialisation.

An example of good foreign practice is the digital platform 'Compost Connect' integrating organisations from Australia and New Zealand, e.g., packaging manufacturers, food services and the organic waste industry entities [42]. The main actions aim to divert organic waste from landfill and transform these materials into high-value organic compost. This process not only reduces the impact of waste in landfill but also cleans waste streams. As a result, it ensures the recovery and reuse of inorganic materials such as recyclables. The platform also supports the prevention of greenwashing, promotes certified products, communicates with platform users and the local community, as well as matching production and distribution organisation composting. Membership of the Compost Club allows business organisations to obtain the newest sectorial information. In line with CE, the platform supports supply assurance of compostable special waste streams by the possibility of finding an approved distributor of certified compostable food packaging and buying compost indirectly from the special compost partners list. According to the data, Compost Club Members have made an impact by composting their food waste and compostable packaging in 4680 tons of waste diverted from landfill, 3276 tons of compost created, and 2387 tons of carbon avoided and sequestered [42]. The entity contributes to increasing access to organic recycling, i.e., industrial composting, including compostable packaging, closing the loop in accordance with the CE rules. The Compost Connect proves that this type of social innovation allows for matching supply and demand to achieve compostable packaging circularity [42]. The Australian platform supports closing the loop. There is also a huge need for effective relationship building between participants in a wider variety of areas, including the development of regulations and standards, the sharing of recommendations and problems to solve, as well as cooperation in achieving external financing and founding to the benefit of compostable packaging circularity. Standardising bio-waste

in terms of its use as secondary raw materials and creating tools for controlling the final product from recycling could minimise the use of primary raw materials. Strengthening co-operation in supply chains between international industry organisations, clusters, research institutions, and companies, as well as between representatives of the private sector and public sector entities can improve compostable packaging waste management. Therefore, the multi-sided platforms reinforce creating a complex ecosystem of relations [70] through the entire product life cycle [71] according to the concept of CE. They enable the effective integration of stakeholders, e.g., waste generation sites with companies collecting waste and composting plants. In conclusion, the compostable packaging waste management improvement in CE will be possible if the proposed solution provides its participants with the appropriate functionalities: educational, communication, informative, innovative, and relational.

4.4. Comprehensive Support of Compostable Packaging Waste Management through a Multi-Solution Perspective in CE

The fundamental elements (soft and hard elements) of compostable packaging waste management could be exploited effectively and successfully by preferably implementing the three described social innovations, as presented in Figure 3.

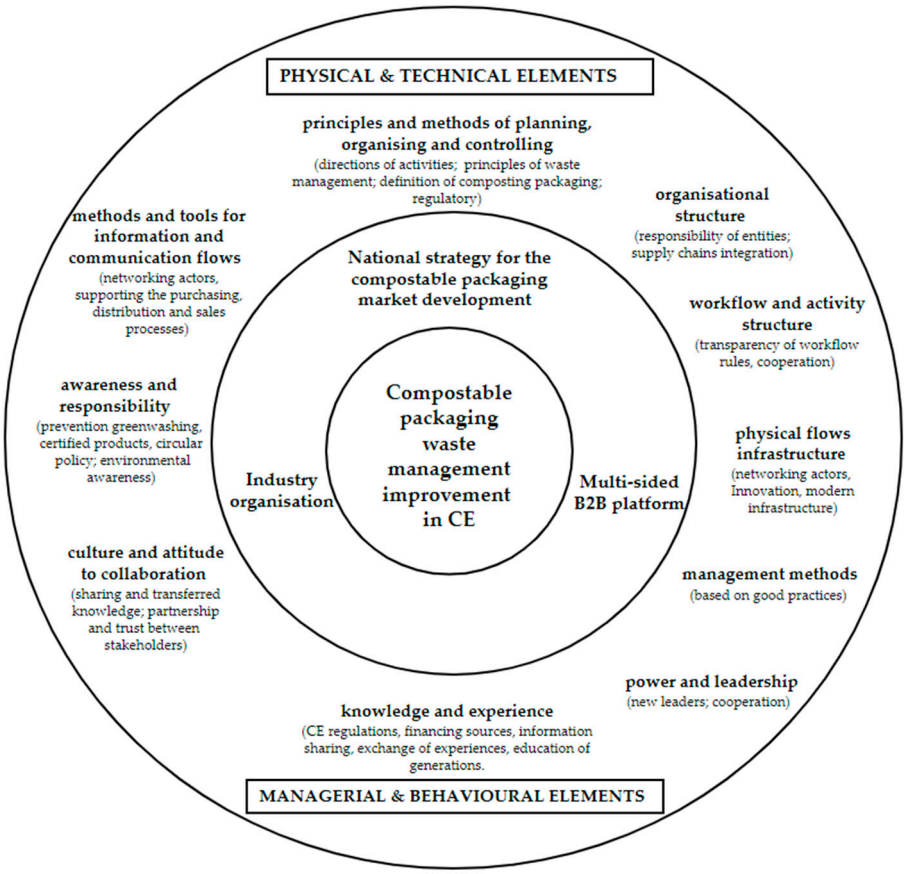

Figure 3. Multi-solution perspectives for improving compostable packaging waste management in CE. Source: own elaboration based on the SIL workshop results and literature review.

There are connections and dependencies between three innovative solutions. The national strategy for the compostable packaging market development could be understood as an instrument supporting the creation of an industrial organisation and a multi-sided B2B platform. Moreover, legal, financial, and organisational conditions could be regulated to meet the development of cooperation between stakeholders in compostable packaging waste management. The essence of the strategy is to integrate goals and activities in the area

of waste management. An industrial organisation could be the stimulus to start work on a strategy for compostable packaging. The active participation and engagement of entities may constitute an important voice in shaping the waste management policy. Cooperation with government authorities may contribute to the creation of a strategic document, setting the directions and goals for the development of the compostable packaging market and waste management. This industrial organisation could also be the starting point for the creation of a muti-sided platform, as an expression of trust and cooperation between market stakeholders. As a result, the multi-sided platform could also support the development of industrial organisation to realise national strategy directions. Finally, the three proposed social innovations could be implemented separately, but together, they should bring synergy effects in moving to a higher level of compostable waste management in accordance with the CE concept. The results depend on the level of advancement in relationships between participants of compostable packaging supply chains seen in motivation and engagement to close the compostable packaging life cycle.

5. Conclusions

The results of the study show that eliminating barriers that cause the problem of the low level of development of compostable packaging waste management is possible through the application of a multi-solution perspective. Namely, the simultaneous implementation of all three prototyped social innovations is an approach of increased value and benefits resulting from the obtained synergy effect. The multi-perspective approach effectively stimulates all the hard and soft elements of waste management and focuses on the circular economy concept by closing the compostable packaging life cycle through organic recycling, both aerobic (source of compost for agriculture) and anaerobic (waste to energy). However, to address all the recognised barriers, the strategy for the compostable packaging market development, industry organisation, and a multi-sided B2B platform need to be carefully designed and enriched by foreign good practices. Thus, all complement each other when improving compostable packaging waste management in CE.

As a first implication of the presented study, the need for further interdisciplinary research should be indicated to improve waste management in CE. It is possible to explore such research fields and disciplines as: engineering and technology, agriculture, social sciences, and natural sciences. Research results revealed that social innovations adequately address the necessity of problem solving, overcoming barriers, and designing solutions. Furthermore, the transformation of waste management for circularity requires strategic planning, stakeholder engagement, and the application of modern technologies. The discussion presents the impact of the three solutions on waste management and identifies interdependencies between them. From a practical point of view, it demonstrates the need for a holistic approach to the waste management policy and system in a country. Finally, it is also recommended to exploit solutions developed in different countries as good practices.

The research was conducted among the sixty-seven stakeholders of the bio-packaging market in one country, which can be seen as a limitation. However, its value is important for other countries, as the global compostable packaging market is gradually developing. The implemented quantitative methods are recommended for further research. Mainly, IDIs and SILs provide an opportunity for a detailed study of the issues in the still young market, where only a small number of participants operate. Further investigation should be directed towards the improvement of packaging properties and specifications in order to adapt to the current conditions and possibilities of waste management processes in other countries. In addition, an unexplored area is the search for the use of compostable packaging in other sectors of the economy.

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Abbreviations

B2B	Business to Business
CE	Circular Economy
EU	European Union
IDI	In-depth Interview
NGOs	Non-Governmental Organizations
R&D	Research and Development
SILs	Social Innovation Labs

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