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Features of Sustainability-Oriented Innovations: A Content Analysis of Patent Abstracts

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Abstract: This article aims to identify the features of sustainability-oriented innovation starting from the content analysis of patent abstracts. An automatic tool was developed capable of finding the keywords, or groups of keywords, related to the 169 targets of sustainable development goals (SDGs). Once the patents deemed useful for pursuing SDGs were selected through the tool, they were analyzed to obtain information on their features in terms of breadth, scope, novelty, openness, prior art and scientific base. Among the most significant results, it is found that a larger number of applicants, suggesting the adoption of "open innovation" strategies, contributes to sustainability orientation. Moreover, patent originality contributes to the probability of pursuing sustainable objectives, especially related to environmental issues. On the contrary, claims are inversely correlated with the attitude to pursue SDGs, i.e., the larger number of areas in which a patent claims to intervene, the lower the probability that such innovation is sustainable. The results obtained by adopting a quantitative approach are in line with suggestions proposed by the literature and, so far, only supported by logical arguments or case studies. The potential of the tool developed, applied to the field of innovation and sustainability, is demonstrated as significant.

Keywords: sustainable development goals; SDG innovation; patent; content analysis; text analysis; sustainable development; sustainable innovation

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1. Introduction

The objectives of the UN 2030 Agenda represent a priority of Western governments [1]. In the context of academic research, the interest in sustainable development goals (SDGs) has grown enormously, as demonstrated by the increasing number of publications since 2015. Sustainability is considered a motherlode of organizational and technological innovations and a precious source of them [2]. The relationship between sustainability and innovation is studied in various areas: business start-up [3], design of new products [4], production processes [5], cultural initiatives [6] or development of services [7]. In other works [8–11], innovation and SDGs have proven to be closely linked in the business environment, starting from patent development [12,13], using open or frugal innovation [14,15] and reverse innovation [16]. Analyzing the SDGs, sustainability seems to be favored by product and process innovation [17,18]. In the industrial field, such considerations led to the development of "eco-innovation" [19], which, through what is called "eco-efficiency" [20], contributes to the realization of Industry 4.0 [21]. Yet, some authors are critical on the statement, according to which technological and industrial innovation contributes to sustainable development without considering key issues, such as planned obsolescence [22–24].

Indeed, despite the topic raised a debate, there is still difficulty in finding parameters capable of quantitatively measuring the impact of innovation on SDGs, especially at the firm level. Some sustainability-related factors in the business environment are regulated by the law and featured by quantitative measurability: it is the case for the quality of exhaust gases, the use of water, the regularity of employment contracts and all the economic data reported in financial statements [25]. However, other factors are featured by a non-quantitative nature and regulation is still lacking [26]: this is the case for the resilience of those living in situations of vulnerability, the strengthening of international cooperation or the concepts of freedom and quality of education. Specific sustainable objectives are included in the 2030 Agenda for Sustainable Development, but many of these do not have quantitative indicators which can be employed at the firm level. Given the difficulty in quantifying a company's attitude in pursuing SDGs, a gap in the literature is found as to the quantitative measurement of the features of SDG-oriented innovation.

For this reason, the innovative element of this work from the methodological point of view is the combined use of (1) textual information of patent abstract to detect sustainability-oriented innovation and (2) patent data to define the features of innovation in terms of breadth, scope, novelty, openness, prior art and scientific base. This provides a quantitative methodology for analyzing sustainability-oriented innovation. The study contributes to literature on sustainability-oriented innovation by identifying the features of patents, which can be related to the achievement of SDGs using a quantitative approach. In particular, the research question is: "What are the features of sustainability-oriented innovation in terms of patent quality and do these features significantly differ from those of non-sustainability oriented one?" The answer to such a question will provide a guideline to companies that want to pursue SDGs as part of their social responsibility governance without losing their capability of producing valuable innovation.

The work is based on the context analysis of patent abstracts. Indeed, the literature widely recognized that it is possible to extract useful information from patent data to provide different measures of innovation, such as: the steps of the innovation cycle starting from the early patents [27], the effectiveness of patents as an incentive for innovation [28], the value of patent citations as a measure of knowledge flows [29], the measures of patents significance to evaluate the size distribution of innovation [30], the technological pervasiveness and variety of innovators [31] and the cumulative innovation and the market value [32]. Moreover, in the field of technological innovation, the tool of content analysis was used to identify patents deemed sustainable [33].

The work is structured as follows: in the first part, a theoretical background is shown on (1) the relationship between SGDs and innovation in the industrial sector and (2) the use of patents for the analysis of sustainability-oriented innovation. In Section 3, materials and methods are presented. Thereafter, the results obtained are presented and discussed and, finally, limits and future research opportunities are briefly highlighted.

2. Theoretical Background

2.1. Relationship between SDGs and Innovation in Companies

Over the last few years, the attention paid by the scientific community to the areas of innovation and sustainability has always remained very high. Despite contributions to the issue, the precise definition of these concepts and the ways to pursue them is still subject of scientific debate. However, what seems to be confirmed by several parties is the existence of a link between innovation and sustainability. Nidimolu et al. explain that sustainability is able to indirectly reduce costs by avoiding waste in the use of raw materials and induces companies to look for better products or to create new ones [2]. In the context of Industry 4.0, some authors identify innovation as a useful tool for increasing the sustainability of processes in manufacturing companies [5]; others consider open innovation as the right way to sustainability in the context of newly born companies [3]. Even in the context of non-manufacturing companies the link between innovation and a sustainable orientation exists [7]; through the use of case studies it has been shown that the driving force of sustainability is open innovation and that both contribute to the co-creation of value [34] and that better market performance is also achieved. Van Tulder considers open/inclusive innovation the type of innovation most consistent with sustainable development [26], since cooperation saves intellectual and time resources, avoiding waste and unnecessary duplication in the processes that lead to the development of a new product designed to achieve the same functions [35,36]. "Open innovation", is defined as the result produced by a collaboration between several subjects in the field of research and development through a cooperative rather than a competitive approach [37,38]; the most tangible result of this phase are patents [3].

Different parameters and concepts can be used to describe global efforts to pursue sustainability, e.g., the Global Report Initiative (GRI) [39], the Environmental Sustainability Index (ESI) [40] and the Environmental Performance Index (EPI) [41]. Among them, SDGs are widely used in literature [42–53] and can provide a detailed description of the generic concept of "sustainability" through the use of the 169 specific targets. The link between innovation and sustainability can be expressed through the links between innovation and each of the 17 goals. For example, regarding the problem of poverty described in SDG 1, an innovation in management didactics and training was suggested to improve the understanding of such a complex problem by the managers of tomorrow [54]. Other authors suggest the need for innovation in learning programs of economic schools, as to introduce theories concentrating efforts in the reduction of poverty [55]. Indeed, the innovation of students' curricula up to high school is considered as a *conditio sine qua non*, not only for reducing poverty, but also to promote equality, as suggested by SDGs 5 and 10 [56].

Access to sustainable energy, as required by SDG 7, is an essential prerequisite for achieving many goals that extend far beyond the energy sector, such as eradicating poverty (SDG 1), increasing food production (SDG 2), providing clean water (SDG 6), improving public health and education (SDG 4), creating economic opportunities (SDG 8) and empowering women (SDG 5). As a matter of fact, as highlighted by some authors, SDG 7 seems to be a real booster for others and should be supported by the Climate Innovation Centers of the World Bank [57] through the creation of a network of "energy access innovation centers". Furthermore, in richer countries, SDG 7 is integrated through some innovative elements of Industry 4.0, such as real-time monitoring, digitization or control via big data [57], despite the perplexities of some authors [58] on real sustainability linked to process optimization. Indeed, most of the technologies born with the promise of producing the same things in less time and/or with fewer resources did not help with increasing free time or consuming less, but rather to overproduce through planned obsolescence, which makes so-called ecological modernization unsustainable [23,59]. Some authors [60] also expressed critical opinions as to the use of blockchain for supply chain management, but others [61] showed that this technology can help pursue some SDGs, for example, through the use of RFID in those contexts where traceability is important for health.

As for the poorer and more rural areas, some contributions suggest that it is possible to pursue quality education (SDG 4) through technological innovations [21] by bringing electricity to underdeveloped areas through models of innovative business [62]. In order to do so, a truly innovative, long-term approach is required for the design of innovative energy services [63].

Moreover, with regard to SDG 11, innovation is considered fundamental for aiming at urban and societal resilience through sustainable energy planning [64]. An example proposed in the context of poor countries is the construction of igloo-shaped houses [65], prefabricated or printed using large 3D printing systems. The exploitation of innovative mechanisms based on natural organisms, for example for cooling or the absorption of pollutants [66,67], can also be considered as an innovative option to pursue SDG 11 [68].

Innovative management of raw materials contributes to the pursuit of circular economy (SDG 12). The adoption of innovative cleaner production methods favors not only SDG 12, but also the protection of terrestrial ecosystems (SDG 15) [11]. Furthermore, in a long-term scenario, circularity and climate action (SDG 13) are more easily reachable if the development of innovations is also used in the field of maintenance, making it more sustainable [69,70].

Finally, SDG9 is per se strictly connected to innovation, representing a prerequisite for most of the other goals.

In Table 1 several contributions highlighted in literature are classified according to the relationship between SDGs and innovation, distinguishing whether the orientation towards SDGs enhances the pursue of innovation, the achievement of innovation enhances an SDG orientation, or a mutual enhancement between them is possible.

Table 1. Summary of contributions delineating a positive link between innovation and SDGs at the firm level.

SDG	SDG Enhancing Innovation	Innovation Enhancing SDG	Mutual Enhancement
1—No poverty		[54,55,71]	
2—Zero hunger			
3—Good health		[72]	
4—Quality education	[56]		
5—Gender equality			
6—Clean water			
7—Affordable energy			
8—Decent work			
9—Industry and innovation	[11]		[17,21]
10—Reduce inequalities			
11—Sustainable cities		[64,65,67]	
12—Responsible consumption	[11,21,56]		[11,21,56]
13—Climate action		[21]	
14—Life below water			
15—Life on land	[11]		
16—Peace and justice	[3]		
17—Partnership for goals	[56]	[72]	

Even if different studies suggest specific links between innovation and SDGs, there is a lack of measurement systems to verify the actual existence of them: the authors face arguments and formulate hypotheses that corroborate through contingent case studies. In order to fill such a gap, in this work patents are used as the basis of a quantitative indicator system for defining relationships between SDGs and innovation and for measuring the quality of sustainability-oriented innovations.

2.2. Use of Patent Data for Sustainability Analysis and SDGs

If the link between SDGs and innovation is to be investigated in a quantitative way, the analysis of the patent features that contribute to sustainability-oriented innovation becomes of interest to this work. Yet, before doing so, the issue of how to classify a patent as sustainability-oriented or not arises.

Some authors clarified that selecting keywords is an effective method for automating the search for textual content within patent abstracts, provided that some precautions are introduced [73]. Other contributions attempted to link patents to SDGs through textual analysis of their abstracts showing that 12.2% of all multinational patent applications are related to sustainable development [74]. Other results based on patent data show that innovation efforts of polluting firms is significantly biased towards environmental innovations and that "environmental innovations" tend to crowd out other more profitable, at least in the short run, innovations [75]. Using data from granted EPO patents, the characteristics of innovative activity in the domains of green ICT were also examined in the literature [31], highlighting high growth, high levels of technological pervasiveness, a notable entry of new innovators and a variety of actors, mainly large companies and universities. Other authors, by choosing appropriate keywords for patents classification, suggested that technological capabilities and environmental regulation stimulate innovative activity in the biofuel sector [76]. A study based on patent data from China demonstrated that rising levels of carbon emissions accelerate the need for eco-innovation, create opportunities for innovators and increase the thrust of environmental regulation [40]. By proposing original textual identification to identify green patents, other authors showed that green design increases the environmental inventions of leading R&D investors more than non-environmental ones [77]. Other contributions propose a systematic patent analysis method to identify the problems to be solved for the planning and development of sustainable technologies through the use of keywords, grammar-based text extraction and shared word analysis techniques [78].

From the review of the previous works, it can be concluded that quantitative patent analysis using textual analysis is an effective method for identifying sustainable technologies [33].

3. Materials and Methods

3.1. Patent Selection Criteria

The patents selected for the study are all the priority documents filed from 2015 to 2017 and thereafter granted by the European Patent Office (EPO), the United States Patent and Trademark Office (USPTO) and the World Intellectual Property Organization (WIPO) with an abstract written in English. The selection of the time range, from 2015 to 2017, had two motivations: first, the SDGs were born in 2015 and therefore the authors decided to start the analysis from that point. Second, the patents were extracted from PATSTAT database and the latest version available for authors was October 2018, which reports granted documents filed no later than 2017.

A total number of 227,029 patent filings was analyzed.

3.2. Labels Associated with Each SDG

For the purpose of this study, a three-step methodology was performed. During the first phase, the authors selected a first set of (single or multiple) keywords through a textual analysis of each of the 169 targets of the SDGs and the corresponding synonyms capable of providing the same meaning. Thereafter, an Excel-based tool was developed capable of automatically labelling patent abstracts. Potentially, 17 possible labels can be associated to each patent abstract, corresponding to the SGDs, but normally it was found that only a maximum of three SDGs are met at the same time. Once the automatic labelling was obtained, a sample of patent abstracts was manually analyzed for robustness check, identifying those capable of contributing to the pursuit of SDGs. In this way, the number of false positives (type I errors) and false negatives (type II errors) was iteratively optimized until a reasonable compromise was reached between the errors. In doing so, priority was given to the reduction of false positives, because it is preferable to have greater certainty that the abstracts on which the analyses are made actually concern sustainable technologies, rather than including a larger but less reliable group of data. The process is schematized in Figure 1.

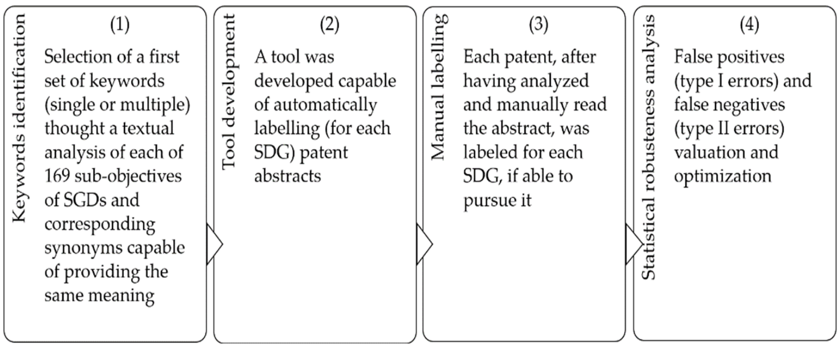

Figure 1. Diagram of the procedure followed.

3.2.1. Keywords Identification

The keywords providing labeling criteria were defined by the authors through the methodology of brainstorming. This was the most critical part of the research, being considerably subjective. Indeed, by examining literature contributions, the keyword selection process can be categorized into three types: extracting them from an existing digital dictionary [73], taking them from an abstract database of selected sample patents [79] or through a brainstorming process [80]. Since this work is the first to use textual analysis to evaluate sustainability-oriented innovation starting from SDGs, it was impossible to refer to existing dictionaries. For this reason, the third method was chosen, consistently with [76]. Even if aware of the limitations of this method, the high level of detail of the 169 targets allows to limit the subjectivity in the definition of keywords. As an example, in Table 2 all the keywords related to SDG 6 "Ensure availability and sustainable management of water and sanitation for all" are reported.

Table 2. List of keywords for the SDG 6.

safe drinking water	purified water	sanitation	water quality
hazardous chemical	hazardous material/s	untreated wastewater	safe reuse
water use efficiency	water pollution/s	sustainable withdrawal	freshwater
water scarcity	water ecosystem/s	water harvesting	desalination
water efficiency	wastewater treatment/s	recycling technology/ies	reuse technology/ies
sanitation management	water management		

3.2.2. Automatic Tool Development

MS Excel was used to develop the automatic labeling tool. The percentage of patents considered sustainable for at least one of the SDGs was around 1.2%.

3.2.3. Manual Labeling

Once the form with the values of the automatic compilation was obtained, a manual labeling process was performed for comparing the results. A sample of 2000 patents on 227,029 was manually analyzed and tagged as being related or not to one or more SDGs. The value 2000 is precautionary with respect to those identified by literature as minimum to guarantee the representativeness of the chosen sample (99% confidence level, 2.87% margin of error). Moreover, the classic precautions were taken regarding the heterogeneity of the sample examined, for example by choosing the patents to equally cover the various patent offices.

Disambiguation issues arose as to some SDGs. For example, with regard to SDG 7, some patents concerned instruments that used devices capable of transforming wind or solar energy into electricity: such patents were labeled as meeting SDG 7 since indirectly favor the use of renewable energy. Vice versa, in other cases, technologies such as solar panels or wind turbines were only the field of application of management and control tools and were declared to improve their performance in a generic way, or to increase the power supplied in cases of necessity, but without any reference to efficiency (as specifically indicated in target 7.3). For this reason, such patents were excluded. As to SDG 4, some patents concerned technologies for the production of tools for distance learning or the replacement of analogue devices with digital ones. Yet, unless rare cases where a real pursuit of the target was highlighted, such patents were not labeled as meeting Goal 4, since the question is linked to political will rather than a technological choice. The same reasoning was made for other SDGs such as the 17th, linked to the need for partnership of the actors involved, or the 5th regarding the implementation of the propaganda of gender ideology.

The ratio of patents meeting at least one SDG from the manual labeling process was around 9%. Comparing our results with other authors [74], similar results were obtained in terms of percentages of labels assigned to SDGs, leading to think that similar criteria were used. In fact, most of the labels pertain to SGDs in which technological choices are preponderant over political ones.

3.2.4. Statistical Robustness Analysis

The results obtained from the manual procedure were compared with those obtained automatically through the keyword-based methodology to estimate the ratios of false positives and false negatives. An Excel procedure was implemented: labels obtained from the two procedures (for each SDG, 1 if inherent, 0 otherwise) have been overlaid through the function *IF* (*AND* (*'Automatic compilation'! Cell x = 1; 'Manual compilation'! cell x <> 1); 1; " "*) to identify false positives and the function *IF* (*AND* (*'Automatic compilation'! cell x <> 1; 'Manual compilation'! cell x = 1); 1; " "*) to detect false negatives. Ratios of 14.5% of false positives (type I) and 40.5% of false negatives (type II) were found. These shares were compared to the ratios deemed as acceptable in literature: in the field of patent abstracts, the ratio of false positives varies from 4.92% to 22% [81], while the ratio of false negatives ranges from 16% [81] to 52% [82] or, in some cases [83], they are not even counted. For this reason, according to the objectives of our work, the values found were considered as acceptable.

3.3. Variables Used in the Analysis

Even if the described methodology allows to define 17 different dummy variables indicating the focus of the patent on each SDG, since some of them were very seldom present in patent abstracts, for the purpose of this work it was decided to present the results classifying them in 4Ps (people, planet, prosperity, partnership and peace) adapting the classification from a previous taxonomy [84] (Figure 2). Therefore, four **dummy variables** were defined assuming value 1, if at least one keyword was found within the patent abstract, belonging to one of the SDGs of a cluster, value 0 otherwise. A Further dummy—SDGs—is defined when the patent abstract reports at least one keyword related to any of the 17 Goals, representing the maximum level of aggregation.

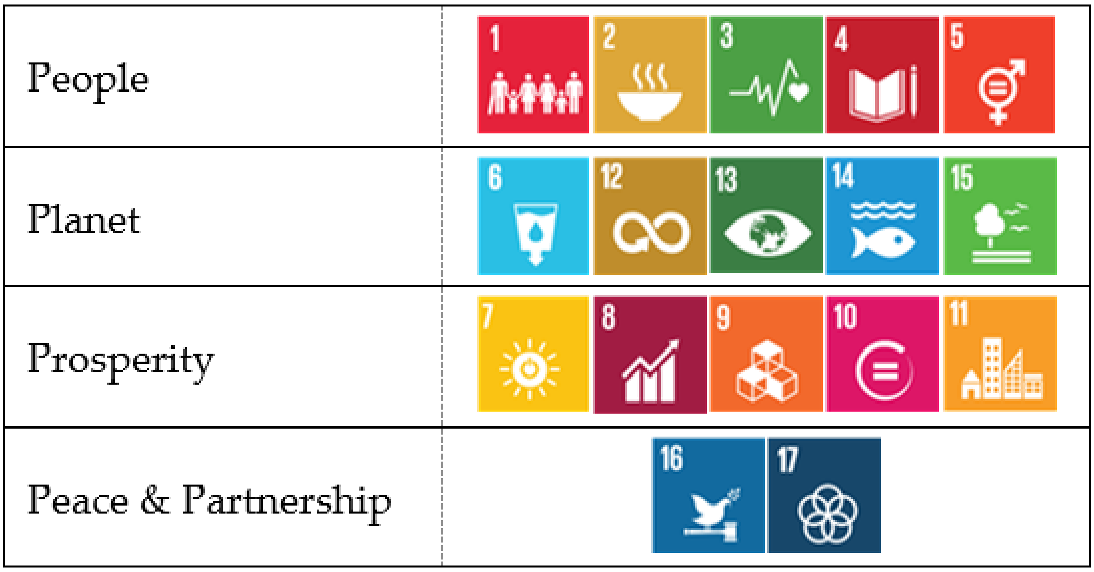

Figure 2. SDGs clustering on the base of the pillars of sustainable development.

In order to understand whether and to what extent sustainability-oriented innovations differ from non-sustainability-oriented ones in terms of patent quality, such dummies were correlated to some features of patents. Indeed, in literature patents have been treated as the most important output indicators of innovative activities and patent data have become the focus of many techniques and tools for assessing innovation. Among the information available in such documents, international patent classification (IPC) codes define the knowledge base on which the patent is build [85]. Other information can be extracted from the assignee field, which can be used to evaluate joint innovation projects [86], or from patent families and citations, which are employed to define the market success and the technological acknowledgment of the patented technology [87,88]. Furthermore, the analysis of data on backward citations provides important information on the extent of reliance on previous technology [89] defining the incremental nature of innovation [90] and identifying the patent as basic or trivial [91]. This can also define the value [92], technological importance [93], originality [28] or quality of the patent, when linked to other data [94]. Scope and clarity of patent claims have been interpreted in the academic world as indicators for the quality of patents [95–97], impacting on innovation in some business sectors [97,98].

In this paper, a number of indicators was selected, also according to literature [99]. All the variables considered in the work are *ex ante* measures of patent quality, i.e., variables available at the date of patent publication. In particular, the number of different IPC codes reported in the patent application are considered as a proxy of the **breadth of knowledge** included in the patented technology. Two different hierarchical levels are considered: IPC code at the 4th level (i.e., before the slash), and IPC code at the 5th level (i.e., entire code). The breadth of knowledge measured with the 4th level indicates a more general technological area in which the patent provides innovation, whereas the breath at the 5th level indicates more in detail the specific technology/product/application [85]. For instance, the 4th level code G02B1 indicates "Optical elements characterized by the material of which they are made; Optical coatings for optical elements", whereas the more detailed 5th level G02B1/08 adds the further information "made of polarizing materials" in contrast with G02B1/06, "made of fluids in transparent cells" or G02B1/04, "made of organic materials, e.g., plastics".

As regards the measure of **openness**, the number of different applicants who contributed to the development of the patent was assessed. Indeed, if the patent has two or more applicants, it is likely to assume shared R&D efforts, risks and costs, which lead to the sharing of patent results [35,36].

The amount of backward citations was considered indicative of the reference to the previous state of the art [92]. Indeed, the obligation for the patent applicant to cite all the existing patent literature is present and, even if any important reference is left out, the patent examiner reports the lack and reference is forced. Therefore, this variable provides a third party verified measure for the previous knowledge on which the patent is built.

The presence of a new combination of IPC codes (at the 5th level) within a patent, when compared to the combinations of IPC codes of all patents in the world until that moment, is considered as an **architectural novelty.** Indeed, a new combination of IPC codes means that those technologies have never been used all together, so that several modules are combined in a new architecture [85].

The technological extent of the protection provided by the patent, i.e., its **scope**, is quantified by the number of claims [95–97], defining the subject matters, the methods and/or the applications where the use of the technology can be considered as exclusive. In particular, all independent claims must have a new and inventive common feature, otherwise an objection may be incurred for lack of unity of invention.

Given that patent documents can cite as previous art not only patent literature, but also non-patent—such as scientific papers in peer reviewed journals—a **scientific base** of the patent can be defined, when citations are made to non-patent documents [100].

Finally, the geographical **acknowledgment** of the protection is measured with the number of patent offices that granted the patent. Indeed, the greater the number of offices in which the patent is granted, the greater the commercial protection [101]. In Table 3 a synthesis of the variables is provided.

Table 3. Synthesis of variable description.

Variable	Operationalization
People	Dummy variable assuming value 1 when the patent abstract contains at least one keyword referring to SDGs 1, 2, 3, 4 or 5, 0 otherwise.
Planet	Dummy variable assuming value 1 when the patent abstract contains at least one keyword referring to SDGs 6, 12, 13, 14 or 15, 0 otherwise.
Prosperity	Dummy variable assuming value 1 when the patent abstract contains at least one keyword referring to SDGs 7, 8, 9, 10 or 11, 0 otherwise.
Peace & Partnership	Dummy variable assuming value 1 when the patent abstract contains at least one keyword referring to SDGs 16 or 17, 0 otherwise.
SDGs	Dummy variable assuming value 1 when the patent abstract contains at least one keyword referring to any SDG, 0 otherwise.
4th level breadth	N° of distinct IPC codes at 4th level included in the patent.
5th level breadth	N° distinct IPC codes at 5th level included in the patent.
Openness	N° of patent applicants.
Prior art base	N° of backward citations.
Architectural novelty	The presence of a new combination of IPC codes (5th level) within a patent, compared to the combinations of IPC codes of all patents in the world until that moment (dummy).
Scope	N° of claims of the patent.
Scientific base	N° of backward non-patent literature citations in the patent family.
Acknowledgment	N° of patent office that granted the patent.

4. Results

The patents found to be sustainable according to the automatic Excel procedure are classified after the 4Ps in Table 4, also indicating the different patent offices of application, as reported in PATSTAT.

Table 4. Sample description.

Topic	Patent Office			
	EPO	USPTO	WIPO	Total Sample
People	6	47	42	95
Planet	114	736	694	1544
Prosperity	96	723	409	1228
Peace & Partnership	0	6	5	11
Total SDGs-related	209	1464	1094	2767
Not SDGs-related	17,534	149,658	57,070	224,262
Total sample	17,743	151,122	58,164	227,029

Overall, the patents considered useful for contributing to the pursuit of SDGs correspond to approximately 1.2% of the total sample. Slight differences are found among the three patent offices, with WIPO reporting the highest rate of sustainability-oriented patents (1.8%) and USPTO the lowest one (1.0%). Yet, such differences are not statistically significant.

As with regard to the cluster of Peace & Partnership, we found a very limited number of matches, 11, which can be considered negligible considering the sample of 227,029 patents. Presumably, this is due to the social and political nature of this area, as well as to the interdisciplinary and complex issues faced in it. For the same reasons, the People cluster also has a limited number of matches, whereas Planet and Prosperity are far more represented, respectively covering 56% and 44% of sustainability-oriented patents.

Therefore, from a preliminary analysis, it turns out that Prosperity and Planet are the areas to which most of the patents are dedicated. Indeed, by focusing on the specific SDGs, we realize that the first five all belong to Prosperity (SDGs 7, 8 and 11) and Planet (SDGs 6 and 12), with the most present one being SDG 12 "Ensure sustainable consumption and production patterns" (Figure 3).

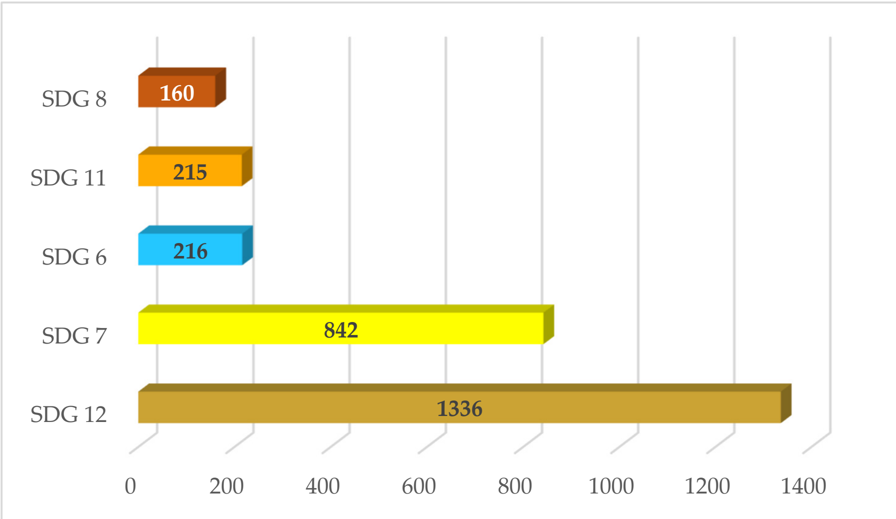

Figure 3. Top five SDGs with keywords found in patent abstracts.

In order to discriminate SDG-related and non-SDG-related patents in terms of quality features, ANOVA analysis was performed using the dummy SDGs as the discriminating variable (Table 5). All patent quality variables but three (namely, 4th- and 5th-level breadth and scientific base) show significant differences as to SDG- and non-SDG-related patents, suggesting that orientation towards sustainability actually has an effect on the nature and quality of the new technologies developed by companies. For a deeper analysis, the relationships between patent quality indicators and orientation towards sustainability was also investigated through correlation analysis: in Table 6 statistically significant correlations are highlighted in bold. In what follows, ANOVA and correlation results are discussed.

Table 5. ANOVA results for patent quality indicators using the presence of an SDG-related keyword in patent abstract as a discriminating factor.

Variable	SDGs-Related Patents	Not SDGs-Related Patents	F	Sig.
4th-level breadth	2.193	2.235	2.537	0.111
5th-level breadth	3.053	3.092	3.045	3.062
Openness	1.206	1.248	8.842	0.003
Prior art base	5.467	4.477	4.164	0.041
Architectural novelty	0.290	0.335	27.785	0.000
Scope	6.717	4.550	151.717	0.000
Scientific base	0.665	0.545	1.099	0.294
Acknowledgment	0.381	0.280	70.909	0.000

Table 6. Pearson's correlation coefficients between patent quality indicators and presence of SDGs-related keywords in patent abstracts (* correlation is significant at the 0.05 level; ** correlation is significant at the 0.01 level).

Variable	People	Planet	Prosperity	Partnership and Peace	SDGs
4th-level breadth	**0.006** **	**0.005** *	0.001	**−0.005** *	0.003
5th-level breadth	0.003	−0.003	**0.007** **	−0.003	0.002
Openness	0.001	0.003	**0.006** **	0.002	**0.006** **
Prior art base	−0.001	**−0.005** *	−0.001	−0.001	**−0.004** *
Architectural novelty	0.004	**0.007** **	**0.011** **	−0.003	**0.011** **
Scope	**−0.009** **	**−0.023** **	**−0.013** **	−0.003	**−0.026** **
Scientific base	0.002	−0.004	0.000	0.000	−0.002
Acknowledgment	**−0.007** **	**−0.016** **	**−0.008** **	−0.001	**−0.018** **

5. Discussion

The variations of the variables that the ANOVA test showed to be less significant are related to the number of backward non-patent literature citations in the patent family, but above all the number of distinct IPC codes included in the patent. The number of different 5th-level IPC codes of a sustainable patent would not appear to be correlated to the Prosperity cluster, indicating that the breadth of areas is only necessary to obtain patents linked to the sociopolitical and environmental aspects of sustainability and not cheap ones. The exact opposite is true in the case of the number of different 4th-level IPC codes; in this case, the breadth of areas is related to Prosperity and therefore to the economic side of sustainability. Other authors have found a connection between breadth and economic importance [102]. Even a greater number of applicants is related to Prosperity, but also to sustainability in general.

A strategy for the development of the innovations of an open-type enterprise seems to contribute to the development of patents that help in the pursuit of the SDGs related to economic growth, the use of clean energy and the development of innovative infrastructures. This result fits with the knowledge already found in literature; for example, an open strategy is considered a systemic managerial approach of an individual and intercompany type that is already satisfactory compared to previous approaches (closed innovation or frugal innovation limited to reducing complexity and costs) [26].

A patent containing many backward citations is less likely to be able to help in the pursuit of SDGs that belong to the cluster of the environment and the planet. They are also inversely related to the SDGs in general. Presumably, to try to solve the problems linked to the planet, it is not necessary to rely on already known technologies, but it is necessary to focus on the originality of the solution. To confirm the hypothesis, there is even the dummy variable "architectural novelty"; if equal to 1, it indicates a patent that will probably contribute to pursuing the SDGs of the Planet's cluster, but also that of Prosperity and all SDGs in general. In fact, architectural innovations have an impact on the value chain [103]. In the case of Prosperity, unrelated to backward citations, it is possible to interpret this result considering that to develop innovative technologies in the field of renewable energy or in the development of resilient cities and sustainable infrastructures, it is not so important to be original by citing little past patent literature, but it is important to exploit already existing technological modules in a new architectural structure.

In the case of the number of claims, they are inversely correlated with the probability of pursuing the SDGs. The greater the aspects upon which a patent claims to intervene, the lower its possibility of contributing to sustainability. This could be due to the existence of so-called "blocking patents", whose claims serve only to exclude as much as possible the publication of others [104], without sustainable goals. References to non-patent scientific literature do not seem to affect the development of sustainable patents.

Finally, as with regard to the number of patent offices in which a patent has been granted, it is negatively correlated with the probability of contributing to the pursuit of SDGs. This could indicate that excessive attention to the commercial and economic performance aspects of a patent is indicative of a poor attitude towards the pursuit of SGDs.

Previous literature on the implications of innovation on SDGs and vice versa, mainly deriving from qualitative analysis, lead to various hypotheses and considerations. With this work, proposing a quantitative methodology, some of them are confirmed by our results, while other aspects emerged as new and can be analyzed in the future. For these reasons, the potential of the tool is demonstrated as significant.

On the basis of correlation analysis, it is possible to suggest some best practices for patent developers that aim at obtaining sustainably oriented innovation. In particular, when developing a patent, they should refer to the targets of SDGs, which are more precise, specific and quantifiable measures if compared to the general concept of sustainability. Another strategy suggested is to exploit the opportunities of open innovation and to avoid the development of "blocking patents", which, having a large number of claims, hinder the publication from competitors. Rather, companies' research and development resources should be focused on seeking truly innovative solutions, from an architectural point of view.

6. Conclusions

The study has some limitations. First, as highlighted in the previous paragraphs, the brainstorming and labeling phase of patent abstracts cannot be replicated exactly, due to the differences between the backgrounds, know-how and skills of the experts who will approach the activity in future work. However, this does not preclude the quality of the work, considering that other authors have adopted the same methodology and considering comparable results achieved. The choice of keywords could also be the subject of conflicting opinions from other authors, but the procedures used have already been used in the literature. Further developments may concern the possibility of refining keywords by analyzing a new sample of patent abstracts, perhaps more recent (considering that the formulation of the 169 targets of the SDGs is only 7 years old). A further possibility is to involve a panel of experts in the process of validating the keyword set.

Second, the patent quality measures used in this study are all *ex-ante* indicators, available at the date of publication of the patent document. This implies that most of them define more a potential quality rather than an actual one, which can be determined only by the use of *ex-post* indicators such as forward citations received several years after the publication. For this reason, a further development could be the enrichment of the analysis by using additional patent data and indicators.

Third, at the moment the work does not include any insight on the sectors in which sustainability-oriented innovation is more widespread. The detection of the sector in which a patent is developed is not trivial. From one side, the use of IPC codes does not always provide a clear definition of the industry, since different technologies can be used in more sectors for different applications. From the other, the analysis of the applicant field is also problematic: once again a company can operate in more market segments and industrial sectors. The solution could be provided by the triangulation of data with the combined analysis of applicants and IPC codes.

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