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Development of an Ontology of Sustainable Eco-Friendly Technologies and Products Based on the Inventive Principles of the TRIZ Theory (OntoSustIP) – Research Agenda

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Abstract. Rising societies' demands require more sustainable products and technologies. Although numerous methods and tools have been developed in the last decades to support environmental-friendly product and process development, an interdisciplinary knowledge base of eco-innovative examples linked to the eco-innovative problems and solution principles is lacking. The paper proposes an ontology of examples for eco-friendly products and technologies assigned to the Inventive Principles (IPs) of the TRIZ methodology in accordance with the German TRIZ Standard VDI 4521. The examples of sustainable technologies and products build a database for sharing and reusing eco-innovation knowledge. The ontology acts as a tool for systematic solving of specific environmental problems in typical life cycle phases, for different environmental impact categories and engineering domains. Finally, the paper defines a future research agenda in the field of the TRIZ-based systematic eco-innovation.

Keywords: Sustainability, Eco-Innovation, Eco-Design, Knowledge-based Innovation, Ontology, TRIZ.

1 Introduction

1.1 Sustainability in a Nutshell

It has become common knowledge that the term sustainability originates from forestry, where it was meant to describe that no more should be cut down in a forest than will grow back. In agriculture, there is a direct connection between sowing and harvesting, but in contrast to classical agriculture, this connection was particularly pronounced in

forestry: both in terms of time and space, it takes a longer time to regrow a forest than e.g. a vegetable, and moreover, regrowing a forest had to be undertaken at another place. Since forestry is no longer the main economic sector of industrial countries, this understanding of sustainability has become too narrow. Current economic and business activity is considered as affecting a variety of (not only) natural resources, be they near and/or far away. The entire tendency for long-term economic and business developments to be unsustainable is now being questioned, e.g., when short-term success is strongly rewarded, whereas e.g., landscape consumption or air pollution in a distant place is ignored.

1.2 Sustainability and Artificial Intelligence - A twofold Approach

The term of sustainability has therefore gained new attention, even the European Community has been discussing new definitions for the term, as can be seen by the “European Green Deal” and the EU Taxonomy Regulation [1]. New general approaches - be they temporally or spatially staggered - follow the direction that no negative externalities should be connected to an economic measure: Sustainability should not be a marketing buzzword, but should be about long-term oriented economic activity.

This raises the question what kinds of sustainable products, technologies, and services exist and may be conceived. The concept of sustainability alone not necessarily leads to sustainable products and technologies: There are solutions, be it products or processes, that are to be considered sustainable in the long term, but harmful and cost-intensive in the short term – and vice versa (education policy can be taken as an example for cost-intensity on the short term, but sustainable on the long term).

This pacing problem (e.g., also highlighted by Matthews, Stamford and Shapira [2]) triggers the conflict thinking approach of TRIZ, which is why we are searching for solution examples for sustainable product and technology development soon and envisage a long-term Artificial Intelligence (AI) approach later.

The automation of business processes has come a long way, because today it is possible to automate any process whose sequence is precisely defined in the form of algorithms. It is more challenging with sustainability processes that require a complex assessment, and are characterized by uncertainty, missing information, or changing evaluation criteria, for example. Such processes are rather difficult to map with conventional means, for example, using IF...THEN...ELSE applications. The upcoming challenges of sustainability are not that easy to be evaluated today and thus require unconventional approaches. For example, how can a product developer or designer assess if a technology is likely to fail on low eco-friendliness in the future? Assuming that the actual evaluation is fully sufficient to service actual evaluation criteria, it is apparent that many characteristics are ambiguous and may change over time. Under this premise, the AI-application for anticipatory sustainable product and process development can be envisaged in a meaningful way.

Our approach to cope with this pacing problem is therefore twofold. In a first step, solution examples of sustainable products and technologies shall be collected and categorized not only according to the contradictory approach regarding the various categories of natural resources they are affecting. These solutions will also be assigned to

their inherent Inventive Principle(s) of the TRIZ methodology. As a second step, this allows to define future research topics in the field of eco-friendly product and process design, paving the way for future systematic and AI-supported eco-innovation.

2 The TRIZ 40 Inventive Principles and their Relation to Sustainability

The development of technical systems can have various goals. Beside the very basic goal of simple functionality, additional development goals may be efficiency, cost, simplicity, robustness, or other attributes of machines and devices. With a growing world population, the impact of technical systems on the environment as a foundation for life becomes more and more important.

According to [3], the TRIZ concepts of Ideality, resource-oriented and compromise-free problem-solving fit in perfectly with the strategy of sustainable eco-innovation. The contradictions oriented TRIZ thinking helps to identify secondary problems in the sustainable solutions and to creatively solve such eco-contradictions in advance. TRIZ also helps to mobilize resources of the existing products and processes and to reduce the negative environmental impact of technologies without efficiency losses.

A recent systematic review by one of the co-authors identifies more than 60 papers on eco-innovation methods using TRIZ elements or tools [3]. Many of them apply the 40 Inventive Principles (IPs) as one of the most important and frequently used TRIZ components and propose tools for IPs-selection for eco-innovation based on the concept of the 39×39 contradictions matrix. As well known, the classical TRIZ 39×39 contradiction matrix recommends best fitting IPs to couples of contradicting common generalized engineering parameters, an approach that seems appropriate for sustainability goals as well. For example, Chen and Liu propose a matrix containing 39 TRIZ engineering parameters and 7 eco-efficiency elements [4]. Kobayashi supports eco-innovative product design with 39×39 TRIZ contradiction matrix and 40 inventive principles [5]. Fitzgerald et al. conceptualize a 21×6 innovation matrix with 6 eco-goals and 21 functional eco-parameters [6]. Pokhrel et al. adapt 39×39 contradiction matrix to a 14×14 matrix with 3 eco-engineering parameters and 8 solution principles [7]. Ko and Chen propose eco-contradiction matrix between customer needs and eco-efficiency elements, recommending TRIZ inventive principles [8]. To this end, environmental impacts – positive or negative – also need to be considered and analyzed in order to protect the environment and ensure sustainable life.

The authors therefore suggest developing an ontology of sustainable eco-friendly technologies and products and on this foundation to statistically find correlations of IPs and environmental parameters that are affected by inventions. For this purpose, a large number of inventions will need to be analyzed. It is planned to do this analysis in an open innovation fashion by involving the entire community of inventors and scientists interested in IPs and environment.

Ontologies are broadly used in engineering for representation and classification of knowledge and for definition of relations between categories, concepts, and other entities of a specific domain. In accordance with [9] three different types of ontologies can

be distinguished based on their levels of generality: a) generic or foundational ontologies, which capture general domain independent knowledge; b) domain ontologies, which capture the knowledge in a specific engineering domain; c) application ontologies, which capture the knowledge necessary for a specific application. One of the first attempt to conceptualize an ontology for the whole specific domain of TRIZ dates back to 2009 [10]. Another conceptual work [11] proposes an ontology as an advantageous approach to bridge the problems in engineering, formulated with the help of TRIZ in terms of contradictions, with similar trade-offs in solutions in biology. The proposed ontology concept is seen as first step towards a complete AI-based problem solving system using biomimetics. Finally, the WUMM TRIZ Ontology Project [12] cites the previous research on TRIZ ontologies and aims to present the TRIZ body of knowledge as a machine-readable Resource Description Framework for the Semantic Web.

The authors advocate a hypothesis that the application of TRIZ in the field of eco-innovation requires a hierarchical structure of general engineering and ecological parameters, which comprehensively and precisely help to define various engineering contradictions in products or technologies in all phases of their life cycle. Thus, the proposed research project will try to find out how the list of classical 39 TRIZ engineering parameters must be replaced, extended or amended in the field of eco-innovation. This leads to the question of what are the relevant environmental parameters? On the one hand, these shall cover all needs of environmental protection in order to allow for all 17 sustainable development goals (SDG17) listed by the UN [13]. On the other hand, the parameters shall be detailed enough to generate a meaningful output. The SDG17 themselves do not seem to be very suitable as categories since these goals are strongly cross linked and contain many social aspects that depend on technical aspects again.

A more comprehensive way suitable for the world of engineering seems to follow the concept of life cycle assessment, LCA, [14] that is part of the environmental management described in ISO 14001 [15]. The role of life cycle assessment in a so-called Life Cycle Sustainability Assessment is further described by Klöpffer and Grahl [16]. Summed up in a few words, this concept starts with the prerequisites of manufacturing a product, where materials, land and energy are needed. It continues with the manufacture of the product again with land use, energy use, and many more aspects of environmental impairment. The same holds during the use of the product and at the end of its life when recycling and reuse should replace the waste of the product. As a suggested state-of-the-art method in LCA [14], an extended set of environmental impact categories consists of 5 main categories and in total 22 subcategories listed in Table 1. Another list of 14 environmental impact parameters for process engineering is presented in [3]. The empirically identified relationship between the eco-parameters helps engineers to see how one improved eco-parameter can affect the other eco-parameters either positively or negatively.

Derived from existing lists of eco-parameters, a reduced set of the following 10 categories will be used for initial assessment of sustainable inventions in a first step: Material consumption, Energy consumption, Land use, Water protection, Air protection, Climate protection, Waste avoidance, Safety, Protection of animals and plants, Cost reduction of sustainable product or technology. Additional categories or sub-categories can be easily added if necessary.

Table 1. Environmental impact categories according to Klöpffer & Grahl [16].

Consumption of resources	Abiotic resources (water and others)
	Biotic resources
	Land use
Chemical Emissions	Climate change
	Stratospheric ozone depletion
	Formation of photo-oxidants
	Acidification
	Eutrophication
	Human toxicity
	Eco-toxicity
	Odour
Physical Emissions	Noise
	Radioactivity
	Waste heat
Biological Emissions	Impacts on Ecosystems
	Impacts on Humans
Further categories	Casualties
	Health at the working place
	Drainage, erosion and salting of soils
	Destruction of landscapes
	Ecological systems, biodiversity
	Solid waste

3 The OntoSustIP Project at a Glance

3.1 Objectives

The primary aim of the OntoSustIP project is to identify examples of sustainable eco-friendly technologies and products, to assign them to the underlying Inventive Principles of TRIZ (according to VDI guideline VDI 4521 [17]) and to other categories of the systematic eco-innovation, such as environmental impact, eco-engineering contradictions, engineering domains, physical or chemical operating principles, life cycle phases, and others, as illustrated in Fig. 1. The empirical analysis examples of sustainable technologies and products will help to build an application ontology for sharing and reuse of eco-innovation knowledge.

The further objective of the project is the identification of strongest TRIZ IPs and inventive sub-principles to counteract specific negative impact on environment according to pre-defined eco-parameters. Such statistically strongest IPs can be in a targeted way applied to resolve typical eco-engineering contradictions. The eco-engineering contradiction is defined here as a situation in which the improvement of one eco-parameter (e.g. reduction of energy consumption) implies a deterioration of other engineering or ecological parameters (e.g. complexity of manufacturing or amount of waste) within a system or eco-system.

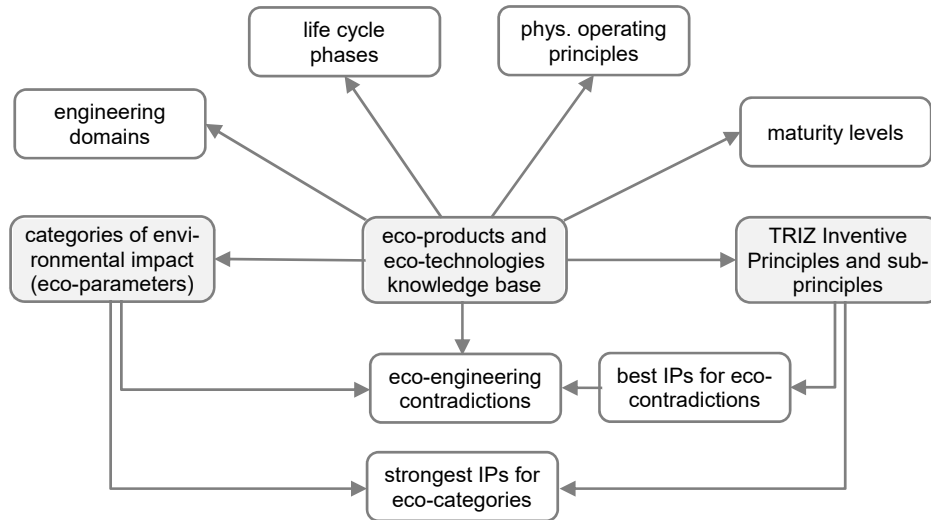


Fig. 1. Basic structure of the ontology in OntoSustIP project.

Finally, the project will create a base to define a future research agenda in the field of the TRIZ-based systematic eco-innovation. For example, it can help to evaluate the potential of TRIZ extension with the specific eco-inventive operators.

3.2 Web-Based Questionnaire for Data Collection

The first thought for creating this application ontology was related to the typical way in TRIZ of using a broad and extensive patent analysis as a starting point. Appropriate approaches have proven to be very insightful in the past (see e.g. [6, 3]). On the other hand, however, an enormous number of resources is required to perform these analyses for a large number of example solutions.

This is not only due to the process of a patent analysis per se, but also due to the peculiarity that the sought-after feature "eco-friendly" is not directly recognizable in patents. Furthermore, the basic problem is that "eco-friendly" is not an absolute characteristic of a product or technology:

- Products or technologies can be viewed from different perspectives and can therefore be assessed differently with regard to the parameter "eco-friendly". This becomes evident in the current European discussion on the assessment of the sustainability of various sources of energy. For example, there are very different opinions on the eco-friendliness of nuclear power.
- Moreover, the question of whether an innovation in a product or technology is eco-friendly can often only be answered in comparison with other solutions. These, in turn, can be relevant in different ways depending on the framework conditions and the situation – especially when comparable problem solutions influence different sustainability dimensions to different degrees.

Therefore, an open approach is used in the OntoSustIP project. A web-based questionnaire searches for examples of eco-friendly products and technologies. The assessment of eco-friendliness is deliberately left to the respondents in order to collect as much data as possible. Even though some categories and selection options prescribe the eventual structure of the results, the basic evaluation of the sustainability impact of the example is left to the participants who do the entries, as illustrated in Fig. 2. This approach leads to a higher number of expected entries, but also requires intensive post-processing of the entries by the project team.

Description (max 800 characters):
Describe your example of an innovative sustainable product or technology. What is particularly valuable about it in terms of sustainability? What is the highlight... the key point? If you want to send multiple examples, please send each one separately.

Sharkskin technology The biomimetic film is flexible, lightweight and consists of prism-shaped elevations 50 micrometres high. The elevations act like the shark's scales, reducing friction thus enabling significant fuel savings and emissions reduction. The AeroShark film has a lower manufacturing and application footprint compared to other technologies.
It is extremely resilient, withstands large temperature shifts, pressure differentials and the ultra violet radiation on high flight levels.
<https://www.lufthansa-technik.com/aeroshark>

The technology/product addresses improvement of:

Material consumption Energy consumption Land use Water protection Air protection Climate protection Waste avoidance
 Safety Protection of Animals and Plants Cost Reduction of sustainable product - technology

What environmental factors are potentially worsened by the product/technology?

Material consumption Energy consumption Land use Water protection Air protection Climate protection Waste avoidance
 Safety Protection of Animals and Plants Cost Reduction of sustainable product - technology

Inventive Principle(s) involved (max. 4) - press ctrl for multiple selection:

1 Segmentation
2 Extraction
3 Local Quality
4 Asymmetry

Separation Principle(s) involved - press ctrl for multiple selection:

Separation in space
Separation in time
Separation in relationship / conditional change
Separation in system structure

Contradiction(s) resolved (max. 200 Characters):

Reduction of energy consumption vs. higher manufacturing and application costs

Fig. 2. Web-based questionnaire (fragment with basic data of sustainable technology example).

3.3 Gathering Information for the Knowledge Base

A web-based questionnaire will be used to create the knowledge basis, on which the ontology will be developed. Since one of the goals of the OntoSustIP project is to collect a large number of examples of eco-friendly products and technologies, not only TRIZ experts but the eco-innovators and specialists are asked to contribute. The survey must also be addressed to people who have little or no knowledge of TRIZ – so there is a contradiction that the questionnaire has to fit for respondents with high TRIZ-experience and also for respondents with no TRIZ-experience. To solve this contradictory requirement, the questionnaire was segmented into a mandatory part to be completed by all respondents and another part that is open to all respondents but requires the expertise of TRIZ experts. In addition, the project team has decided to post-process all entries. This post-processing may (but does not have to) include a more detailed consultation with a respondent or other experts at a later point in time.

Descriptions of Products and Technologies. The core of the survey is the search for eco-friendly, sustainable products or technologies. As mentioned above, the assessment of whether an artifact is eco-friendly or not is left to the respondents themselves in order to receive an open and broad selection of entries. A continuous text should describe the product or technology. The knowledge and skills of the respondents will be very different – therefore, the expected entries may range from merely naming artifacts to entries that contain distinct technical information. In order to be able to include the subjective evaluation aspect, the questionnaire also asks respondents to state where they can identify particular aspects of sustainability in the respective example.

Categories: The 40 IPs and Environmental Impacts. When asked about the example, respondents are given the opportunity to tick the sustainability field in which positive effects can be achieved by the product or technology. The following 10 pre-defined eco-categories can be selected: Material consumption, Energy consumption, Land use, Water protection, Air protection, Climate protection, Waste avoidance, Safety, protection of Animals and Plants, and Cost reduction. An input field for free text permits to propose and assign additionally or alternatively any other eco-parameter or category.

The additional input options provide up to four Inventive Principles per example. Moreover, also four TRIZ separation principles can be assigned to a sustainable solution. Since an artifact can serve as an example for different principles, post-processing of the data by the project team will be necessary. Possible negative effects are asked for using the same categories. We assume that these possibilities can also be used by participants who are familiar with the corresponding sustainable products or technologies.

A free text field allows specification of contradictions which have been resolved by the product or technology. This field is also primarily directed at TRIZ experts. The formulation of the contradiction can then be checked for consistency with the innovation principles mentioned.

Action Plan and Time Frame. The project in its first phase has initially been limited to the duration of one year (01/22 to 01/23). During this time, the following activities are planned:

- until 02/22: conception of the approach and the website for the collection of contributions.
- 01/22 - 04/22: conception of the structural design of the ontology
- 02/22 – 07/22: pretests of the web-based questionnaire and first collection of contributions (example products and technologies) for the ontology
- 07/22 onwards: collection of contributions, editorial work and additions, incorporation into the structure to be developed and preparation of the regular publication
- 12/22: publication of the intermediate data
- 01/23 onwards: editing of the contributions received, insertion into the ontology and publication (every 3 months)
- 12/23: Decision or conception of continuation of the activities after the end of the first phase of project.

Support the Project with your Experience. The authors invite interested persons and organizations to bring their broad knowledge, experience with innovative sustainable products or technologies, and TRIZ skills to the OntoSustIP project. Please participate in collecting example cases and classifying or evaluating them according to given criteria on the following project website: <https://www.hs-kl.de/en/betriebswirtschaft/aktivitaeten/kompetenzzentrum-opinnometh/ontosustip-project>.

4 Future Use-Cases for Sustainable Eco-Friendly Design Based on TRIZ

4.1 Possible Outcomes of OntoSustIP

The results of this project are expected to offer a number of possible use cases. With a growing number of classified examples, several outcomes are conceivable. However, a solid and unambiguous assignment of the examples to the respective principles is crucial, highlighting the importance of the editing phase of this project. For this reason, a solid base for the description of 40 Inventive Principles with extended list of 160 operators or sub-principles presented in [3] will be used.

As depicted in the Figure 3, the database entries give examples that improve certain environmental impacts (eco-parameters) and Inventive Principles that can be identified within an example. On a most basic level, the database will provide a substantial collection of sustainability examples for the TRIZ Inventive Principles. The evaluation of probable relations between the eco-parameters and the IPs has a substantial value for further application of the ontology, such as identification of the strongest IPs for eco-categories and eco-engineering contradictions.

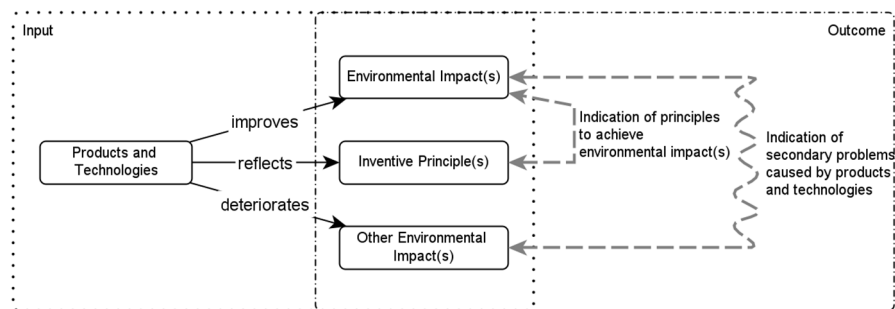


Fig. 3. Database entries given by the contributors and outcome.

For this purpose, the statistical frequency of Inventive Principles used to improve a certain sustainability factor (eco-parameter) have to be assessed. Given a sufficient number of examples are entered into the database to justify a statistical evaluation and

the principles have been assigned with high confidence, several possible outcomes are depicted in Fig. 4.

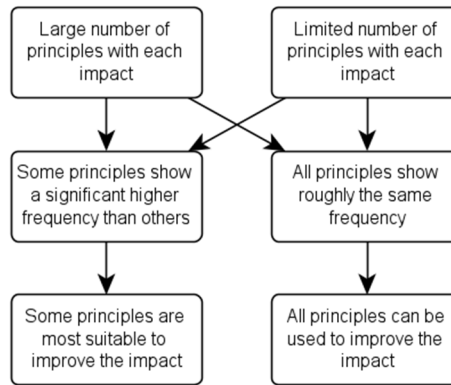


Fig. 4. Evaluation of relation of impact and inventive principles

In terms of usefulness, it will be most helpful if a distinct set of principles can be identified to address specific environmental impacts that need to be improved in new problem-solving situations. In this way the users (engineers, specialists, or ideation teams) can focus on the principles most probably able to solve their problems, enriched by examples that have been entered initially into the database. If all principles seem to be equally useful, the users will at least dispose of numerous examples to spark idea generation and support the creative process by building analogies to the examples at hand.

With the additional collection of environmental impacts that deteriorate due to the solution given by the product or technology entered, several secondary problems can be identified to be addressed in the next step. Thus, another outcome of the OntoSustIP project could be a repository of eco-engineering contradictions and challenges for further eco-innovation.

Table 2 illustrates the top 10 inventive operators (sub-principles) with corresponding parent IPs for reduction of energy consumption and losses in process engineering. The inventive operators are sorted by their occurrence frequency in the analyzed 58 thermal process engineering operations and has been derived from data presented in [3]. In general, the identification of strongest inventive operators for different environmental parameters and eco-problems specific to various engineering domains appears to be a more efficient and precise ideation technique.

The OntoSustIP project might even result in an updated contradiction matrix for eco-innovation. Contributors can enter an engineering and/or physical contradiction that is solved by the example. However, the quality and informative value of the formulated contradictions highly depend on the experience of the contributor and might be subject to a downstream editorial process.

Table 2. Top 10 inventive operators (sub-principles) for reduction of energy consumption in process engineering equipment [3].

Pos.	Inventive operator	Ranking	Parent TRIZ Inventive Principle
1	2a. Take out disturbing parts	0,053	2. Leaving out / Trimming
2	29e. Heat transfer and exchange	0,052	29. Pneumatic or hydraulic constructions
3	25b. Utilize waste resources	0,041	25. Self-service
4	2e. Extract useful element	0,036	2. Leaving out / Trimming
5	5b. Combine functions	0,034	5. Combining
6	10a. Prior useful function	0,034	10. Prior action
7	22a. Utilize harm	0,034	22. Converting harm into benefit
8	35d. Change temperature	0,034	35. Transform physical and chemical properties
9	35a. Change aggregate state	0,033	35. Transform physical and chemical properties
10	28a. Use electromagnetic fields	0,032	28. Replace mechanical working principle

4.2 First Impressions of Exemplary Data Collection and Evaluation

The following section illustrates a preliminary analysis of 50 eco-friendly products and sustainable technologies inspired by nature [18], systematically accessed from the AskNature database of the Biomimicry Institute [19] and some other sources. There is a reason to believe that the eco-friendly biomimetic technologies show a lesser secondary negative environmental impact in comparison with purely engineering inventions. The selected eco-products and technologies comprise, among others, building insulation, water filtration, underwater adhesive, air-purifying billboard, life-saving surgical superglue, self-cooling buildings, shark skin technology, biodegradable packaging. For example, the shark skin-inspired coatings and films (IP30. Flexible shells or thin films) improve aerodynamic performance and protect surfaces against biofouling thus enabling significant reduction in fuel or energy consumption and emissions [20].

The initial results of the study are briefly presented in the Table 3 and 4 in accordance with the study performed by a co-author [18]. Table 3 indicates the percentage of environmental parameters improved by a product or technology. Among 50 analyzed examples, the solutions related to climate protection (36%), energy consumption (34%), material consumption (16%), and waste avoidance (14%) constitute the majority of all eco-innovation goals, whereas 8% of eco-examples could not be assigned to any pre-defined eco-parameter. The evaluation of the eco-parameters, as defined in more detail in Table 3, allowed a multiple assignment of parameter to the eco-solutions with on average 1.6 eco-parameters improved by product or technology.

Table 3. Frequency of mentioning of environmental eco-parameters improved in 50 sustainable products or technologies, inspired by natural solutions (multiple choice).

Eco-parameter (eco-category)	Description of eco-parameter	Freq.
1. Material consumption	Raw material usage, material consumption, material losses, consumables	16%
2. Energy consumption	Amount of energy consumed, energy losses, waste energy, e.g., waste heat	34%
3. Land use	Sustainable use of land, amount of used land, land protection, drainage, erosion and salting of soils, destruction and loss of landscapes	2%
4. Water protection	Groundwater pollution chemicals, eutrophication, pollution and excessive usage of water	10%
5. Air protection	Air pollution, fly ash, dust, smog, micro- and nano particles, acidic gases emissions	4%
6. Climate protection	Global warming, greenhouse gas emissions, ozone layer depletion, deforestation	36%
7. Waste avoidance	Solid waste, packaging waste, non-recyclable waste, plastic, toxic waste	14%
8. Safety	Safety and technogenic risks, radioactivity, hazardous materials, safety in case of natural disasters	10%
9. Protection of animals and plants	Preservation and protection of animals, plants, and their habitats	8%
10. Cost reduction of sustainable product or technology	Making an existing or new sustainable products or technologies more affordable and attractive for customers, industry and society	12%

Table 4 presents the Inventive Principles most frequently “used” in 50 analysed eco-innovations. These principles show a significant higher frequency of application than others. Moreover, 20 out of 40 IPs have a frequency of mentioning between 0 and 2%. A multiple assignment of IPs to the eco-solutions results in on average 2.4 IPs per product or technology. Further analysis should identify the statistically strongest sub-principles and the relationships between the Inventive Principles and improved environmental parameters.

Table 4. Frequency of mentioning of top 10 Inventive Principles in 50 sustainable products or technologies, inspired by natural solutions (multiple choice).

Frequency	Identified IPs	Frequency	Identified IPs
28%	30. Flexible shells or thin films	18%	31. Porous materials
24%	25. Self-service / Use of resources	14%	3. Local quality
22%	40. Composite materials	14%	28. Replace mechanical working principle
22%	35. Transform physical and chemical properties	10%	15. Dynamism and adaptability
20%	17. Shift to another dimension	8%	14. Sphericity and Rotation

5 Discussion and Summary

When new technologies are used, their unintended side effects may not be recognized until they have become so widespread that they are difficult to reverse. This pacing problem that in literature is well-known by the term “the Collingridge Dilemma” [21] is also valid for sustainability and eco-friendliness: awareness awakens when negative side-effects appear to a wider public, but an evaluation only becomes accessible when a comparative value can be used. Moreover, this evaluation should be possible at the early stage of product and process development. The ontology of examples for eco-friendly products and technologies assigned to the TRIZ Inventive Principles should enhance systematic creativity and accelerate eco-innovation.

The proposed OntoSustIP project firstly tries to evaluate existing eco-solutions but is directed at facilitation of the early assessment of eco-friendly products and technologies in the near future. Nevertheless, even an evaluation will not hide the fact that every new technology has its downsides. It shall be taken into consideration that new ideas shall be given enough space to develop and improve. The OntoSustIP project provides a guideline on how TRIZ methodology can accompany here.

The initial evaluation of already collected eco-friendly products and technologies demonstrates significant time expenditures of data post-processing by the project team and requires a standardized protocol to avoid any misinterpretation of results. Therefore, we advocate the idea that the application of machine learning algorithms can considerably speed-up the evaluation procedure and to assure its high quality. A development and optimization of AI-based methods must consequently be subject of future research activities.

Future work shall also aim at developing of recommendations for systematic solving of specific environmental problems in various life cycle phases of technical systems, for different environmental impact categories and engineering domains.

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