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# Supporting sustainable innovation through TRIZ system thinking

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## Abstract

Reaching a sustainable approach in industrial development is a complex challenge that involves several knowledge spheres. The lack of a common vision about sustainability complicates this research issue. The paper proposes a tool that faces with this obstacle during the first phases of design by means of a new instrument: the SUSTAINability map. It is based on two key items of TRIZ: the existence of Laws describing the Evolution of Engineering Systems and the System Operator. In order to clarify the logic of the proposed approach, that has been structured such that no TRIZ background is needed, the paper includes the presentation of a case study, in the field of clothes cleaning.

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*Keywords:* Sustainable innovation; Product service system; System thinking; System operator; Laws of evolution;

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## 1. The Sustainable Development

The perception of the sustainability dilemma is expanding in the world, even if this term is today often abused or improperly used [1]. Sustainability is more and more a “cool” keyword for marketing, where “to be green” demonstrated a strong capacity of attracting money also without real benefits [2], but also in the research field the word is overused.

All over the literature appears the definition of the Sustainable Development from the Report of the Brundtland Commission [3] as development that “meets the needs of the present without compromising the ability of future generations to meet their own needs”. This simple statement immediately asks for multi-dimensional directions of development: technical, economical, social, political, etc.. However the Brundtland definition does not provide a concrete and precise action plan [1]. Table 1, extracted from Rees [4], provides a minimal set of “necessary conditions for sustainability that stress the need to reconcile the ecological, cultural and economic dimensions of human well-being”.

It is interesting to notice how these conditions, read from an ecological and geopolitical point of view, do not widely differ from the past conditions of human development. In other words, looking at the first condition, the man from the prehistory has fought for having products and service in relation with the rate of nature production by means of technical evolution. So the Sustainable Development is not a new issue, but it uses a different approach due to the present conditions. The human consciousness of its potential impacts increased because the balance of the

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power of the relation between Humankind and Nature had been changing [5]. For example, this change clearly appeared after the demonstration of the destructive force of the atomic bombs [6].

Furthermore, the negative consequences of the introduction of a variety of substances and processes modified the human perception of nature, leading to the comprehension that Nature would not stand our modern development any longer. A new age has started, the age of sustainability.

Several approaches aim at achieving this objective by following different directions. Besides, a common strategy does not exist, but there is a general consensus on the urgency of changes [7].

**Ecological stability requires that:**

consumption by the economy of the products and services of nature be compatible with rates of production by the ecosphere;

the production of wastes by the economy remains within the assimilative capacity of the ecosphere;

economic activity protects the essential life-support functions of the ecosphere and preserves the biodiversity and resilience of Earth's ecological systems.

**Geopolitical security requires that:**

society satisfies basic standards of material equity and social justice;

governance mechanism be in place to enable an informed citizenry to have an effective participatory role in decision-making;

people share a positive sense of community cohesion (local and global) and a sense of collective responsibility for the future.

Table 1: Necessary Conditions for Global Sustainability extracted from Rees [4].

## 2. Sustainability in Product Design

During the conceptual design phase, the designer makes choices which are heavily related to sustainability. The multi-disciplinary aspects of sustainability are a challenge for Product Design due to the typical lacks of environmental and social competences in traditional engineering curricula.

From a practical point of view, the issue requires new abilities, thus also a new education approach. From a research point of view two ways are possible:

- methods developed within a certain discipline, integrating elements from other domains (aiming at a really multi-disciplinary approach);
- Mono-disciplinary methods characterized by enhanced usability from specialists from other domains (aiming at a multi-disciplinary discussion by exploiting individuals' competences).

Nowadays, the first option is the most common in literature and then, a social expert rarely plays a relevant role in the application of a design tool. As far as experts from any specific field cannot entirely understand specialistic instruments of different domains, a valuable objective is to arrange means to provide a comprehensive summary with contents from different disciplines, easy to read even without specific field expertise. This paper pursues this objective through the introduction of an original instrument, hereafter called SUSTAINability map.

In the Product Design sphere a large variety of methods related to assessment, improvement, management and communication is available: Design for X [8,9], EcoDesign [10,11] and the ISO 14000 family of standards, that comprises LCA [13]. They are in a mature phase and they could be used successfully in companies also if some themes of research are still open.

For example, the integration of EcoDesign methods in companies is often difficult because they remain tools for experts [10] and they have a great impact on design resources, firstly on time [11]. That said, EcoDesign is used since 90s [13]. These tools are generally focused on environmental preservation although economic criteria are sometimes considered.

According to Russo and Regazzoni [14], the main benefit of TRIZ in EcoDesign consists in providing guidelines that have a general value and provide detailed prescriptions to increase product sustainability. In the TRIZ literature, the majority of papers in this area presents comparisons between EcoDesign and TRIZ key concepts, while a smaller number of scholars proposes an integration of design tools. In both case, sustainability is not investigated in its various aspects, also when authors, as Ikoenko [15] and Jones and Harrison [16], refer

directly to it: the TRIZ literature mainly regards the reduction of resources used by the Technical System (TS). They take into consideration the TS Life Cycle, and the related processes, but they don't focus the attention on the environment (e.g. the Product Service System, PSS) where the TS satisfies a human desire. Then, they don't advise on advantages due to a different organization of elements (e.g. services, "players") involved in the environment. Consequently, the TRIZ community has not investigated sustainability with a systemic vision as proposed, for example, by PSS methodologies. In fact, TRIZ scholars typically analyze the environmental footprint of a TS, in terms of resources consumption and harms to the environment, without taking into account that sustainability should link the usage of resources to the satisfaction of human needs.

Goedkoop [17] defines PSS as a system of products, services, networks of "players" and supporting infrastructure that continuously strives to be competitive, satisfy customer needs and have a lower environmental impact than traditional business models. According to Vezzoli [18], the innovation beyond the product to the "satisfaction" of a given demand for well-being could promote radical changes for sustainable consumption. From a TRIZ perspective, the introduction of services is a transition to super-system and somehow it is an approach aiming at the function delivery without the existence of the TS. However, Baines et al. summarized that PSS methodologies often link to sustainability, but only Manzini, Vezzoli and Clark see it as the ultimate goal [19]. Moreover, UNEP [20] states that PSSs do not necessarily lead to sustainable solutions and sometimes they could generate unwanted side effects.

Recent research in the field of Design for Sustainability has proposed maps for modelling the relationship between processes and customer in order to show the overall organization and customer needs. These models are usually simple, so a large number of people with different background understand them (see, for example, Bistagnino [21]). These maps, as well as the System Operator, move from a single element upward the super-system, assisting the complex systems comprehension.

The Design for Sustainability usually introduces changes in all spheres of its analysis; from a technical point of view, it dictates new requirements or significant changes in their expected value (e.g. the transition from a product to a service usually needs a new or modified TS).

The resolution of emerging contradictions, coming from the changes, and the introduction of a more appropriate technology for delivering the function, could avoid undesired side effects in the transition toward sustainability. The authors believe that classical TRIZ could facilitate this task. In fact, it is commonly used for increasing the efficiency of the process for solving contradictions and for technology transfer.

A classical PSS example illustrates the abovementioned use of classical TRIZ: the pay-per-use case study of washing machine. The customer does not own the washing machine, but he only pays for the number of washes. After a first experimental period, companies decided to stop the project. Actually, the new interaction with the customer would have required a new design of the washing machine for achieving higher level of efficiency and life capability. The new scenario modified the value of some parameters producing new contradictions or changing their relative weight. For example, the installation and the maintenance time became more important because of the labour costs.

Despite classical TRIZ could effectively solve emerging contradictions, on the other hand, an even basic TRIZ knowledge is unusual for a designer. Then, this paper uses a more general description of the TSs evolution, based on the existence of Objective Laws of Systems Evolution, in order to provide a tool that, without a TRIZ background, identifies evolutionary directions that a TS can undertake.

### **3. Scenario investigation through a SUSTAINability map**

The proposed tool wants to support the systematic identification of innovation opportunities for achieving the satisfaction of a certain need, in a sustainable background. This work desires to offer a simple but systematic instrument that directs the evolution of a given TS. The embodiment design of the identified directions of evolution is out of the aims of this work.

The use of a more abstract level of analysis, as well as a human centered instrument, allows the rapid identification of priorities, because of the absence of technical details.

Some aspects of the theoretical dissertation underlying this work are presented hereafter. The quest starts from the parallelism with the Florenskij's vision of culture: "science and technique could be interpreted as the activity of space organization. The intermediate space of science and technique combines the real and the abstract vision" [22].

Several problems can be easily solved by working at more abstract level. The intermediate space or, for the scopes of this paper, the borders of TSs, could be used as a key to the reading. Indeed, if someone is asked to think of a system he would probably imagine a real thing; on the contrary, he will focus the concept at a more abstract level if he is asked to figure out the TS border. Besides, the contour of a TS is not capable to track the TS evolution except for some aspects, as the size. However TSs “communicate” to each other by interactions that actually belong to the boundary space. If TSs evolve, it is supposed that interactions trace their evolution. So this work proposes the use of the space of interactions for describing the evolutionary process.

### 3.1. Reference Models

The main reference models adopted for the construction of the proposed tool are the Maslow’s Hierarchy of needs [23], the Altshuller’s Laws of Engineering System Evolution (LESE) [24, 25] and the System Operator [24]. Other TRIZ models don’t explicitly appear, but they were considered during the tool building.

Because of the lack of a common definition of needs in literature [26], this paper proposes some reference denominations for a clearer description of the following concepts. The benefit expected by an individual in a given context, i.e. in a given range of space and time, is defined “partial need”. The ultimate need is the most important need belonging to the basic expectation of human. The definition of their structure and the importance assigned to ultimate needs, at collective level, are related to social sustainability.

It is out of the aims of this paper to investigate the development of needs. Consequently, the work only creates the necessary conditions for introducing the needs into the discussion. In order to show how the tool works it is proposed the adoption of the Maslow’s Hierarchy of needs [23], due to its simplicity: ultimate needs are grouped into different classes from the survival requirements, to the self-actualization, the fulfillment of human potentiality. The Hierarchy is usually portrayed in the shape of a pyramid.

A detailed description of the LESE and of the System Operator is omitted here, because they are well-known by the TRIZ community. However their main aspects related to this work are discussed.

The LESE summarize the path of system evolution at abstract level but they provide more detailed directions at a physical level when they are specified into trends or patterns, as the System of Inventive Standards in Classical TRIZ. It is a hypothesis of this work that this process could follow the opposite direction, transforming the variety in a common aspect subjected to laws of evolution.

The System Operator is a model describing the system thinking approach of talented and creative problem solvers, but from a practical point of view, it is also a powerful and easy-to-use instrument for modeling complex situations. One of the meanings of the horizontal axis is the temporal sequence. The tool analyses only the present column of the process due to usability reasons. When the solver moves toward super-system, the elements of upper screens, in the same column, are analyzed at the same moment. However their life span is generally longer than the subsystem elements, if the last ones are a part of them. From this consideration, the structure of the tool induces the designer in expanding the time boundaries of his analysis; thus the tool can consider aspects that are out the operative time of the TS in the initial screen.

Having introduced the reference models of the SUSTAINability map, it is possible to underline the two main foundations that characterize its structure:

- the relation Humankind-Nature, that is the most important change in the industrial society inherent sustainability, is composed by a series of interactions that involves TSs. These interactions should provide information about sustainability. Each TS has its Mode of Deployment (MoD). Chandrasekaran [27] defines the MoD as the description of a TS’s connections (structural relations and actions) with its environment;
- the TS, at an abstract level, connects needs and resources. As above proposed, partial needs are closely related together, while the hierarchy of ultimate needs is described by the “Maslow’s pyramid”.

Figure 1 provides a graphical summary of the previous concepts.

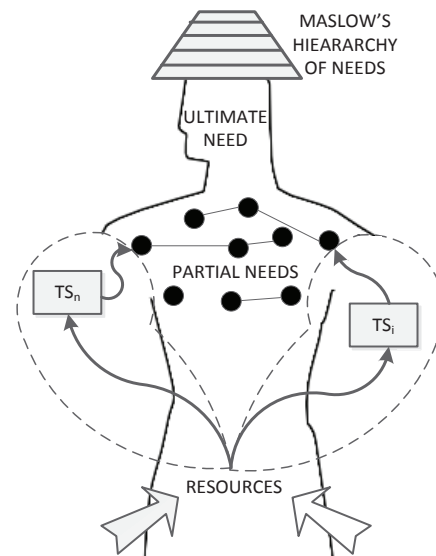


Figure 1: The graphical description of the main foundations of the SUSTAINability map. The dashed line represents the MoD.

### 3.2. Description of the tool

This chapter describes the structure of the tool and the way to apply it: the first requires to make some references to the relevant TRIZ models and key concepts; besides, as already stated above, the application of the tool can be performed also by users with no TRIZ background. Hereafter, the designer is intended as the user of the proposed tool.

The tool starts from the identification of the MoD, which today satisfies, even partially, a specific partial need. After that, the designer moves in the super-system screens of System Operator, to investigate the TSs that are related to the satisfaction of the partial need, up to embrace an ultimate need. The designer is asked to analyze these MoDs, by using a subjective model. Moreover, this model must consider the material and energy flows.

The SUSTAINability map is built from this information, then the definition of a set of scenarios starts. During the following steps the designer should make notes of new directions of investigation. The identified scenarios could sometimes be merged, so a new “macro scenario” appears. Scenarios are identified by using a sequence similar to the LESE. Since there are substantial similarities between LESE and Law of development of needs proposed by Petrov [28], the following steps are similar to those to be applied in the identification of evolutionary scenarios through the LESE: the last three steps are related to the Static, Kinematic and Dynamic Laws respectively. It is worth to highlight that, in this study, the focus of the analysis is constituted by the interactions between elements, rather than the elements themselves.

In the fifth step, the tool rapidly detects directions of improvement in the present MoD. They could be considered possible directions for Eco-efficiency. Then, the sixth step suggests future scenarios that have higher potentiality to change the current relationship between resources consumption and needs. Finally, the transition from the present MoDs to new ones is helped by the introduction of new technologies, as it is outlined by the seventh step. The overall flow of the proposed tool is depicted in Figure 2.

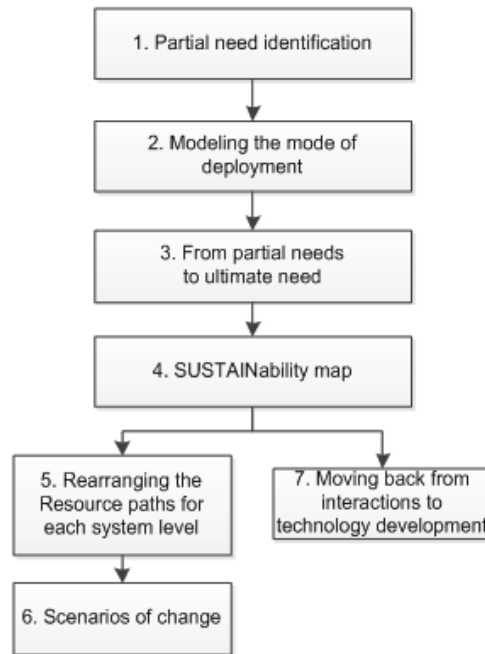


Figure 2: The diagram flow of the proposed tool.

### 1. Partial need identification

Starting from the current context of a given TS, the designer identifies its motivation as a partial need and the main elements related to its delivery. The classical TRIZ concept of Useful Function (UF) here assumes the meaning of “an action able to contribute to the satisfaction of a partial need”.

The final description of the present context must contain:

- a complete model of the UF, i.e. the TS, the Object (Individual, Collectivity, etc.) and the parameter of the Object affected by the above defined UF (Functional Parameter);
- the partial need.

Their sequence of identification cannot be defined a priori, because it depends on different factors: the problem type, the partial need, the personal attitude of the designer, etc. The UF is usually the first element identified by the designer, then the TS, the Object and the Functional Parameter.

### 2. Modeling the mode of deployment

Model the current MoD that involves the Object of the UF, underlying its energy and material flows. The designer can choose the modeling method by exploiting his background and experience; e.g.: by sketches, process maps.

### 3. From partial needs to ultimate need

- a. If the identified partial need is not an ultimate need, the super-system MoD is analyzed, as just made in the first step. This MoD exploits the last Functional Parameter identified within this analysis.
- b. The designer repeats steps 1 and 2 with the newly MoD identified in step 3.a.
- c. Repeat the step 3.a until an ultimate need is reached.

### 4. SUSTAINability map

The SUSTAINability map expresses the current knowledge of the designer and it does not need the integration of external information through a retrieval phase. The models of the MoDs occupy the different levels of the SUSTAINability map, starting from the bottom following the order of the previous steps. They are broken down in a manner similar to the model of minimal TS capable of delivering a function according to the TRIZ 1<sup>st</sup> Law of Evolution.

- a. For each level the designer identifies Tool, Object, Enablers, Supplies and Resources; in details:
  - The Tool is the TS which performs the UF, identified in the step 1.
  - The Object is the one defined at the step 1.
  - Enablers are all the TSs that act complementarily to the Tool in order to make it work correctly (e.g. the fuel pump of a car).
  - Supplies are all the services or infrastructures which enable the resources to be useful for the Tool or for the Enablers (e.g. the petrol station for a car).
  - Resources are identified by energy and material flows.

If an element is in two or more different boxes of the map, the designer could consider them as a unique element or he could separate it in its parts for a more detailed analysis. Figure 3 shows the resulting structure of the SUSTAINability map.

This map enables the introduction of interactions that flow from resources to needs satisfaction. For each level the designer identifies the interactions between elements. Then, the Resource paths are identified. A Resource path goes from the right to the left side of the SUSTAINability map and it collects the interactions that move from a Resource towards a need. It could be divided in different branches. For example, if a Resource is used by two elements, both the branches of interactions belong to the Resource path, as it appears also in the example in Figure 5.

5. Rearranging the Resource paths for each system level
  - a. Checking for a lack of interaction between elements, and between elements and Resources. The lacks are potential directions of improvement of the current MoD. A possible interpretation of the 1st LESE allows to claim that during the evolution process the level of flexibility for each Resource path increases from one interaction to many interactions, from one to more branches in order to improve the controllability of the MoD.
  - b. Looking for path jumps in the chain Supply-Enabler-Tool-Object of the existing element. A jump identifies a new direction of investigation in order to improve the overall efficiency of the MoDs.
  - c. Each Resource path has its operative time. Their superposition indicates new directions of improvement of the satisfaction level.

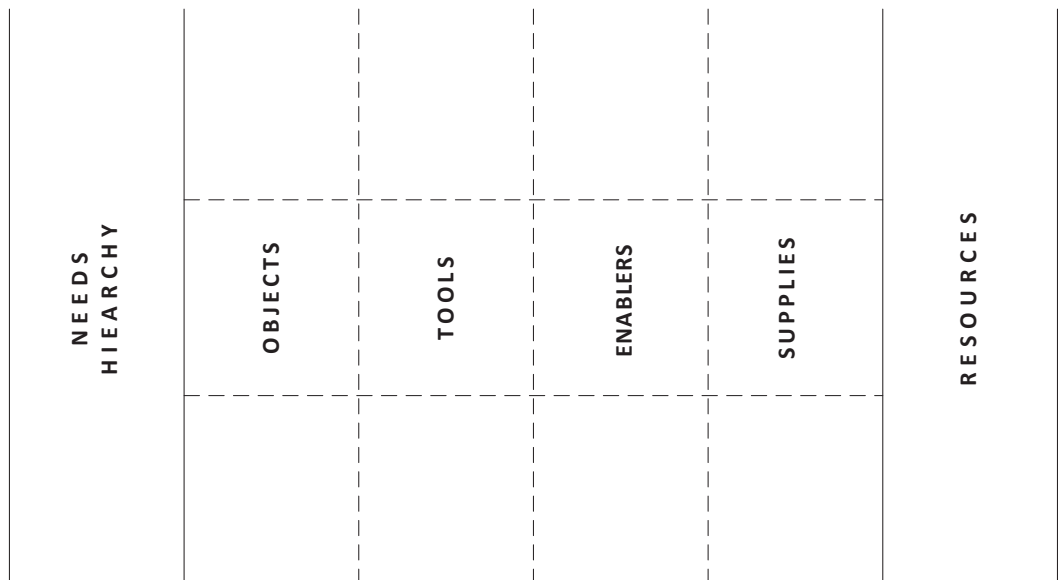


Figure 3: The structure of the SUSTAINability map. Interactions will ideally connect Resources and Needs through the elements.

#### 6. Scenarios of change

This step identifies interactions that produce important changes in the MoDs. Depending on the current level of evolution that the SUSTAINability map describes, two directions are possible: the tool firstly proposes scenarios that increase the interactions between levels; finally, it suggests the “de-materialization” of the interactions of the map according to the convolution trend depicted by the LESE.

- a. Similar types of elements (e.g. Tools) stay on the same column of the SUSTAINability map. Interactions occupy the space between columns (e.g. the space between Enablers and Tools). If there are several interactions between two columns, these interactions tend to integrate their physical effects (e.g. steam instead of water and thermal energy). In the case that an element is in two boxes, both its interactions on the left and on the right of the element tend to integrate.
- b. When the SUSTAINability map has just covered the evolution paths described in the previous steps (e.g. only one level is occupied for the satisfaction of an ultimate need), solely the interaction between the Tool and the Object is kept in order to favor the transition to super-system delivery of need. The Resource paths disappear not for their absence, but because they involve the super-system, out of the modeling phase of the first steps.

The last direction is easier to understand through the example proposed later within the study case. However it is evident that the transition to super-system can produce the introduction of a service. It is important to underline that the transition is possibly guided by the relations between ultimate needs.

#### 7. Moving back from interactions to technology development

The new directions of improvement should be integrated by building the new SUSTAINability map. After that, the necessity to design one or more TSs usually arises. This phase proceeds with the use of standard techniques of Product Development.

### 4. Case study: Cleaning clothes

In order to better clarify the proposed tool a case study is here reported, in the field of clothes cleaning. The household appliances leader companies compete with each other for firstly achieving radical change in resources consumption. It is an interesting case because the large diffusion of washing machines causes a big amount of resources consumption at regional accounting. In addition the TS is greatly related to the satisfaction of important human needs. The case study was conducted as an auxiliary activity within a larger national project in the field of energy and water savings, coordinated by the Italian headquarters of an international corporate. The description underlines both main and more critical stages.

#### 1. Partial need identification

A common Italian home was the reference context, where clothes are usually cleaned by a washing machine. The cleaning process remove stains, odors and pathogens. A general Functional Parameter “cleanliness of clothes” could comprise all these concepts. Then, the partial need is the availability of cleaned clothes; the clothes are the Object and the UF is “to clean”.

#### 2. Modeling the mode of deployment

The clothes cleaning MoD is composed by several phases: collecting, sorting, cleaning, drying and ironing. The analysis of TSs involved in the case study was performed using the model proposed by Cascini et al. [29]. This model for function-behavior analysis integrates, among other reference models, the Energy, Material and Signals model [30]. Figure 4 depicts the functional model of a general TS that cleans clothes.

#### 3. From partial needs to ultimate need

In the current context, men dress cleaned clothes (partial need) taking them from the wardrobe. From a functional point of view, the human being, i.e. the Object, is dressed (Functional Parameter) with cleaned clothes. The Maslow's Hierarchy was used to identify the ultimate need: “clothing”.

#### 4. SUSTAINability map

The map itself, reported in Figure 5, summarizes the process of identification of elements and interactions from the models of step 2. These models were mainly based on general information about household appliances.



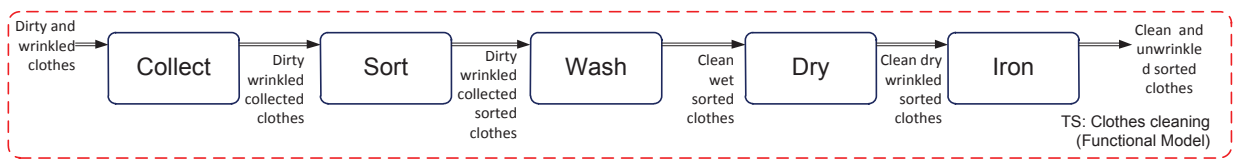


Figure 4: The functional model of a general TS that cleans clothes modeled according to the integrated model for function-behavior analysis [29].

In order not to weigh down the current discussion, some elements, e.g. clothes basket, are removed if they don't add new clarification on the use of the tool.

#### 5. Rearranging the Resource paths for each system level

- a. Looking at Figure 4, the Energy path is composed just by two interactions but there is no interaction with the clothes horse. A new direction of improvement is the introduction of the energy in this element. But it is easy to understand that this direction is not new because the use of dryers is already typical in certain contexts. It is an interesting example: it demonstrates that proposed scenarios do not necessary save resources and it also shows the ability of the tool for suggesting relevant information searches. Indeed, in this case the existence of a dryer is obvious, but it is not a general feature. The Air path indicates some more recent directions of research that today need future development: the use of air in the iron and in the washing machine.
- b. All Resources are directly transmitted to the Tool, without any Supplies. A new element that increases the effectiveness of the water in the washing machine could be introduced (e.g. a water softener). The new TS should improve a particular field by means of water properties, and it does not correspond to the introduction of a new substance.
- c. The case study demonstrated that during this sub-step the designer is asked for more attention than in the other sub-steps because the map does not indicate the temporal sequence. The interactions that compose different Resource path are examined by a neighbor criterion based on the SUSTAINability map. The energy and water interactions toward the iron have the same operative time. It is interesting to notice how different would be this assessment in the TRIZ traditional solution process. A contradiction about the water reservoir would probably emerge: when water is filled and when water is used. On the contrary the air interaction to clothes horse happens in a different moment. If these interactions will take place at the same moment, the iron works on the clothes horse while the air is drying clothes or vice versa.

#### 6. Scenarios of change

- a. Continuing the focus on Resources-Enablers space, the Energy and Water branches toward the iron should be integrated. However it does not mean an introduction of an external steam generator that is part of the iron. The previous steps have indicated the absence of Supplies. A Supply could be able to integrate these two Resources. Such supply could be a boiler or, using different means not involved in the description of the map, the national electric system and the waterworks, a heat solar system or a heating distribution system. Other examples are offered by the integration of interactions that come from wardrobe, with interactions from iron and clothes horse.

The scenarios proposed by the last sub step of step 6 usually occur after the directions of previous steps have been already followed. In the previous steps, clothes horse and iron strive for integration using water, energy and air or a mix of them. At the same time new interactions between Resources and wardrobe could be created. Furthermore, an integration of the interaction between clothes and iron or clothes horse and clothes and wardrobe is supposed. At this point, the wardrobe could become a TS which changes a wet and creased cloth in a ready to use one, by the exploitation of steam and air. If, only for explanation of this sub step, this moment of evolution is supposed to be reached:

- b. the wardrobe could substitute the washing machine itself also by means of new technology development. Finally, the SUSTAINability map presents only the Tool-Object interaction and air, “steam” and cleaning mixture paths. These last interactions will disappear if the super-system (e.g. a service) looks after the cleaning of clothes, causing the repetition of the tool application due to new context.

7. Moving back from interactions to technology development

- a. The case study used a function oriented approach for searching new technologies. However, the results are out of the aims of this paper.

The application of the tool provided several scenarios for the case study. Table 2 presents their classification according to information that comes from the main project activities:

- “Scenarios” are the directions identified by the tool use;
- Some scenarios are quite similar and they are summarized by a “Macro scenario”;
- Some scenarios are today “incomprehensible” by a technical point of view; in other terms in order to assign them an interpretation some external knowledge should be acquired;
- “Old scenarios” are just used in other context or for special applications;
- “Under development scenarios” show their first application in the market or there are ongoing researches;
- “Feasible scenarios” are new scenarios for the industries.

While under development scenarios have been advantageously used for understanding the present directions of research, feasible scenarios provided by the step 5 demonstrated remarkable chances of introduction. On the contrary, the opportunities, offered by feasible scenarios from the step 6, were not considered interesting by the experts of the field of clothes cleaning. Their judgment mainly regarded the problems related to the introduction of a completely new interaction between the user and the TS. However, the risk of the introduction of too innovative interactions for the customers is common to EcoDesign [11] and PSS methodologies [19]. At the same time, the experts agreed that these feasible scenarios would surely increase men satisfaction and it could be able of saving resources.

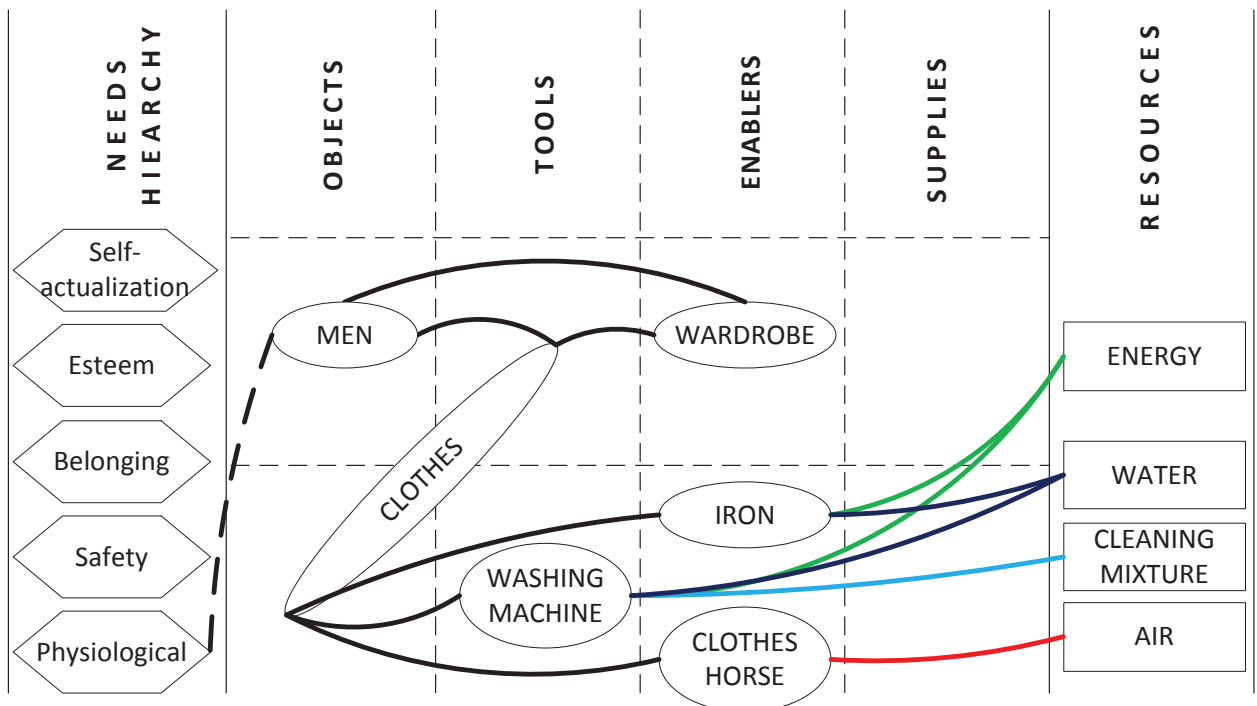


Figure 5: The SUSTAINability map of the case study. Interactions that run from the same Resource have the same color in order to identify the branches of the Resource path. However, all interactions are considered in a similar way.

## 5. Conclusions and future developments

A new approach toward the preliminary analysis of sustainability problems is proposed. Due to its level of abstraction the tool can be applied in different fields. The case study has highlighted some desired aspects of the tool: its use, after a first approach, is simple and rapid and it systematically moves the designer in different directions. The present directions of the research activity in the field of clothes cleaning were identified by the scenarios. It is interesting to notice that these directions of improvement were effectively used in the information retrieval activity of the main project. The description of evolution of interactions seems to be a valid approach. The results encouraged an extensive validation also if they underlined how difficult the transition to feasible scenarios is perceived by the experts of the field, both for technical and business reasons. Then, the integration of the tool with established business methodologies is recommended.

At the moment, the tool does not compare the identified scenarios in terms of their ability to achieve sustainability. However, it provides evolutionary scenarios of TSs into a model which emphasizes the relation between resources and needs, orienting the designer towards sustainability. The sustainability assessment of these scenarios is a further direction of research, but the model seems to be able to integrate this aspect, providing a summary of specialistic information.

The discussion on the structure of needs is out of the aim of this paper, but it represents an important further direction of improvement.

### List of acronyms

LESE: Laws of Engineering System Evolution

MoD: Mode of Deployment

PSS: Product Service System

TS: Technical System

UF: Useful Function

Scenarios	Incomprehensible scenarios	Macro scenarios	Old scenarios	Under development scenarios	Feasible scenarios
18	6	4	3	3	6

Table 2: Summary of scenarios proposed by the tool for the case study

### References

- [1] Vezzoli C.A., Manzini E., 2008, "Design for Environmental Sustainability", Springer London, ISBN 978-1-84800-163-3, pp. 3-13.
- [2] Esty D.C., Winston A.S., 2006, "Green to Gold. How Smart Companies Use Environmental Strategy to Innovate, Create Value, and Build Competitive Advantage", Yale University Press, ISBN 977-0-300-11997-8, pp. 7-64.
- [3] World Commission on Environment and Development, 1987, "Our Common Future", Oxford University Press, ISBN 978-0-19-282080-8, pp. 1-66.
- [4] Rees W.E., 1995, "Achieving sustainability: Reform or Transformation?", *Journal of Planning Literature*, Vol. 9, No. 4, May 1995 pp. 343-361.
- [5] Banathy B. H., 1998, "Evolution guided by design: a systems perspective", *Systems Research and Behavioral Science*, Vol. 15(3), pp. 161–172.
- [6] Thomas E.D., 1945, "Atomic bombs in international society", *The American Journal of International Law*, Vol. 39, No. 4, Oct 1945, pp. 736-744.

- [7] Meadows D., Randers J., Meadows D., 2004, "The limits to growth. The 30-Year Update", Chelsea Green Publishing Company, ISBN 978-1-931498-58-6, pp. 235-263.
- [8] Edited by Huang G.Q., 1996, "Design for X. Concurrent engineering imperatives", Chapman & Hall, ISBN 0-412-78750-4.
- [9] Kuo T., Huang S.H., Zhang H., 2001 "Design for manufacture and design for 'X': Concepts, applications, and perspectives" *Comput Ind Eng* 2001 12; 41(3), pp. 241-260.
- [10] Le Pochat S., Bertoluci G., Froelich D., 2007, "Integrating Ecodesign by Conducting Changes in SMEs.", *J. Clean. Prod.*, 15(7), pp. 671-680.
- [11] Knight P., Jenkins J.O., 2009, "Adopting and Applying Eco-Design Techniques: A Practitioners Perspective", *Journal of Cleaner Production*, 17(5), pp. 549-558.
- [12] ISO Central Secretariat, 2009, "The ISO Survey of certifications 2008", ISO, ISBN 978-92-67-10509-3, pp. 29-39.
- [13] EPA, 1995, "Life Cycle Design Framework and Demonstration Projects", EPA/600/R-95/107.
- [14] Russo D., Regazzoni D., 2008, "TRIZ Laws of evolution as eco-innovation method", *Proceedings of IDMME - Virtual Concept*, 8-10 Oct. 2008
- [15] Ikovenko S., 2007, "Problem Identification Approaches in Sustainable Design", *TRIZ Developers Summit 2007*, <http://www.triz-summit.ru/en/section.php?docId=3738> (accessed June, 15 2010).
- [16] Jones E., Harrison D., 2000, "Investigating the use of TRIZ in Eco-innovation", *TRIZ Journal*, September 2000.
- [17] Goedkoop M.J., van Halen C.J.G., te Riele H.R.M., Rommens P.J.M., 1999, "Product Service systems, Ecological and Economic Basics", [http://www.pre.nl/pss/download\\_PSSreport.htm](http://www.pre.nl/pss/download_PSSreport.htm) (accessed June, 15 2010), pp. 17-26.
- [18] Vezzoli C.A., 2010, "System Design for Sustainability. Theory, methods and tools for a sustainable "satisfaction-system" design", Maggioli Editore, ISBN 978-88387-4440-8, pp. 1-88.
- [19] Baines T., et al., 2007, "State-of-the-Art in Product-Service Systems", *Proc. Inst. Mech. Eng. Pt. B: J. Eng. Manuf.*, 221(10), pp. 1543-1552.
- [20] UNEP Sustainable Consumption & Production Branch, 2002, "Product Service Systems and Sustainability: Opportunities for Sustainable Solutions", La Fenice Grafica, ISBN 92-807-2206-9.
- [21] Bistagnino L., 2009, "Design sistemico. Progettare la sostenibilità produttiva e ambientale", Slow Food Editore, ISBN 978-88849-9189-8.
- [22] Tagliagambe S., 2006, "Come leggere Florenskij", Bompiani, ISBN 978-88452-5752-0.
- [23] Maslow A.H., 1943, "A Theory of Human Motivation", originally published in *Psychological Review*, 50(4), pp. 370-396.
- [24] Altshuller G.S., 1984, "Creativity as an Exact Science: The Theory of the Solution of Inventive Problems", Gordon and Breach Science Publishers, ISBN 0-677-21230-5, pp. 223-231.
- [25] Salamatov Y.P., 1991, "System of The Laws of Technical Systems Evolution" in *Chance to Adventure* (in Russian), Karelia Publishing House, ISBN 5-7545-0337-7, pp. 7-174.
- [26] Ericson A., Müller P., Larsson T., 2009, "Product-Service Systems—From Customer Needs to Requirements in Early Development Phases", *Proceedings of the 1st CIRP Industrial Product-Service Systems (IPS2) Conference*, pp. 62-69.
- [27] Chandrasekaran B., Josephson J.R., 2000, "Function in Device Representation", *Engineering with Computers* 16(3), pp. 162-177.
- [28] Petrov V., 2005, "Laws of development of needs", *Proceedings of the 5<sup>th</sup> ETRIA TRIZ Future Conference*, ISBN 3-7011-0057-8, pp. 151-164.
- [29] Cascini G., Rotini F., Russo D., 2008, "Networks of trends: systematic development of system evolution scenarios", *Proceedings of the 8<sup>th</sup> ETRIA TRIZ Future Conference*, ISBN 978-90-365-2749-1, pp. 31-40.
- [30] Pahl G., Beitz W., Feldhusen J., Grote K.H., 2007, "Engineering Design. A Systematic Approach", 3<sup>rd</sup> edition, Springer, ISBN 978-1-84628-318-5, pp. 26-33.