SUSTAINABLE PRODUCTION RESEARCH: AWARENESS, MEASURES AND DEVELOPMENT

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Abstract: This paper takes its standpoint in the hypothesis that awareness of sustainability is the key to create sustainable products, and that this awareness begins already at research level. It describes the development and follow-up of a method for increasing sustainability awareness in sustainable production research. Several activities were carried out to increase the awareness. Firstly) workshops with researchers and industry on sustainability. Secondly) development of measures based on literature and interviews with researchers. Thirdly) monitoring of awareness through concept maps. Progress was evaluated by comparing the awareness of the population when the project started in 2010, and then again in 2011. The results show that the participants had shifted their view from primary emphasizing technology towards a more balanced view of sustainability where social aspects were more often taken into consideration. According to the concept maps methodology, sustainability awareness in the population increased with 25%.

***Keywords**:* Concept Map; Sustainability Awareness; Sustainability Metrics; Sustainability Research; Sustainable Production

INTRODUCTION

To promote and capture sustainability in production research

Sustainability as a vision for development in society and in companies is today emphasized within a wide area, from kindergarten to governmental boards. It is also considered that sustainability as a concept should be based on three interdependent pillars; economic perseverance, social development and environmental conservation [1]. Even if there is a common political understanding about the necessity for sustainable development, one of the questions is still how this shall be implemented in practice e.g. how the three pillars can be balanced. From a company perspective one central question is if sustainability will be profitable, “when it pays to be green” [2]. For implementation, there are today several frameworks for sustainability that can be used by organizations and companies, either for strategic guidance or as tools when developing products with improved sustainability performance e.g. the natural steps framework for sustainability, from a holistic perspective through principles for backcasting [3]. There are also plenty of resources regarding sustainability measures and indicators for evaluation of communities and companies [4-10]. The basic idea is that measuring and monitoring sustainability helps in increasing awareness and action towards sustainability.

For research activities it is not yet equally common with active use of frameworks or indicators. Nevertheless sustainability has become more and more important for universities. The current vision of Chalmers University of Technology, for example, is "Chalmers - for a sustainable future". The vision is realized through for instance The Area of Advance Production. This is a concerted action to fulfill a multidisciplinary and sustainable approach by Chalmers University of Technology and Lund University, endorsed and promoted by a large number of companies in several industrial sectors. To deliberately work with increasing sustainability in research, it was decided to find a method to measure, or estimate to what extent research will make a difference, although there are limited resources available on how to evaluate research efforts in that aspect. Finding suitable measures for such an assessment includes many challenges. The multitude of different definitions and measures available on sustainable industries or communities complicates the process of finding the appropriate measures for a specific context. Measuring a smaller set of indicators incorporates a risk for sub-optimizing as well as losing the purpose of the measured indicators. Last but not the least, measuring always brings the risk of using available data while wanting to capture more complex and immeasurable phenomena.

In the described project we have investigated the possibilities to design sustainability measures suitable for evaluating research related to product development, production systems, and manufacturing processes. The initial methodology was described and presented at the CIRP Life Cycle Engineering conference in Braunschweig 2011 [11]. The focus in this paper is on whether the measures taken into the project has increased knowledge and awareness, and in that case how.

The research questions are: (a) How has the knowledge and awareness regarding Sustainability among researchers in the Area of Advance Production changed between 2010 to 2011? (b) What differs in their awareness and knowledge? (c) What tools can be used to facilitate an increased awareness regarding sustainable production?

THE AREA OF ADVANCE PRODUCTION

The Area of Advance Production was granted financial support from autumn 2009 from the Swedish government. It incorporates over 100 researchers and spans over two universities and numerous research groups, hence also including cross-disciplinary efforts. The vision is to produce cutting edge knowledge and increase research excellence while incorporating sustainability in the core competencies in product development, production systems, and manufacturing processes. The effort will create novel manufacturing technologies and new production engineering as well as product development methods that will support economic, ecologic, and social sustainability. The overall objectives are clear; to improve excellence while simultaneously having a positive impact on at least two out of the three sustainability pillars and no negative impact on the third.

SCOPE OF THE PAPER

In this paper we aim to follow-up and describe the development of a method on monitoring sustainability awareness and promote increased awareness through workshops and sustainability metrics [11]. Throughout this paper the development and use of sustainable production metrics has been considered both a possible mean to facilitate increasing awareness as well as to show sustainability impact.

The paper is structured as follows: State of the art on sustainable production research is presented with emphasis on sustainability awareness and sustainability metrics. The recent changes of sustainability awareness in this project are then presented. This is followed by the results from multiple awareness measurements of individuals performing research on sustainable production. The paper sums up with a discussion on the findings, conclusions and future lookouts for the upcoming steps for this research effort in terms of utilizing the metrics and performing additional awareness-increasing events as well as additional measurements on the awareness level of the individuals participating.

STATE OF THE ART

Measures and indicators on sustainability

Ideally measures should be a guide to where you are, where you are heading and how far you are from the ultimate vision. For sustainability, various concepts and guidelines of what is sustainable exist, and the approaches vary from more general frameworks to more specific tools. One example is the Natural Step's four fundamental principles, upon which sustainability indicators could be built [12]: (a) Substances from the earth's crust cannot systematically increase in the biosphere. (b) Substances produced by society cannot systematically increase in the biosphere. (c) The physical basis for the productivity and diversity of nature must not be systematically deteriorated. (d) There must be fair and efficient use of resources to meet human needs.

Other approaches to measure and monitor sustainability progress includes e.g. the Global reporting Initiative (GRI) and life cycle assessment [4]-[5]. The type of indicators used in these frameworks varies from detailed measurements of e.g. energy or water use to qualitative aspects like the amount of overtime or work equity etc.

In addition to the sustainability aspects there are other important properties that indicators should fulfill. According to Sustainable Measures, six important properties of good indicators or measures are [13] given below.

Relevant

Indicator must show useful meaning on the manufacturing processes under evaluation. It must fit the purpose of measuring performance.

Measurable

Indicator must be capable of being measured quantitatively or qualitatively in multi-dimensional perspectives, e.g., economic, social, environmental, technical, etc.

Understandable

Indicator should be easy to understand by the community, especially, for non-experts.

Reliable/Usable

Information provided by indicator should be trustworthy and useful.

Data accessible

Indicator has to be based on accessible data. The information needs to be available or can be gathered when needed.

Flexible

An indicator must be compatible with open standard expressions, such as ontology base and XML documents, to support long-term archival and flexibility for future generations.

In addition, Sustainable Measures recommends that indicators of sustainability should be different from traditional indicators of economic, social, and environmental progress. Traditional indicators - such as water quality - measure change in one part of a community as if entirely independent of the other parts. Sustainable indicators – such as use and generation of toxic materials (both in production and by end user) - reflect the close connections among the three pillars of sustainability, in this case with emphasis on measuring activities causing pollution.

Social aspects are difficult to measure and use for assessment, as they could be both positive and negative and often with difficult ethical considerations. E.g. how to measure and assess the use of child labor in a companies' value chain? Or overtime in research activities? Where there today is a relative broad knowledge base for measuring ecological aspects and available LCI data e.g. through databases like ecoinvent [6], there is still lack of knowledge in how to measure and assess social aspects. Attempts to build more knowledge is e.g. the standards of social life cycle assessment (SLCA) developed by UNEP that together with existing tools for measuring environmental (LCA) and economical aspects (LCC) can be used in decision making [14]. An example is e.g. the BASF SEE Balance tool that integrates social, economic and ecological measures [15].

Monitoring sustainability awareness

In order to evaluate the awareness or knowledge among the researchers in the area of sustainable productions there are many possibilities; assignments, test, written exams, oral exams, interviews, questionnaires, conceptual maps, etc. there are pros and cons connected with the different evaluation methods. The monitoring of busy and eager researchers requires a monitoring setup that is fast and not seen as an exam. The Concept maps were considered a feasible solution for monitoring awareness as well as a well-established tool in the academic area. Monitoring sustainability awareness was for example used on research regarding engineering education for a sustainable future [16], using the Conceptual map technique. The technique was developed by Joseph Novak and his research team at Cornell University during the 1970th as a mean to represent the increased knowledge among students [17]. The use of Conceptual maps for knowledge assessment has been used widely (During conceptual mapping the concepts are being represented by squares or circles and are connected to each other by relation lines. Along the relation lines phrases are used to describe the relation. The relations can be described by phrases such as "is solved by", "is realized by" etc. The final visualization of concepts and the relations among the different concepts is called a concept map.

The technique has been used at five European technological universities, where nearly 500 students participated. It was concluded in that case that concept mapping showed to be an appropriate assessment tool to evaluate cognitive knowledge or awareness [16]. A comparative study was made at Chalmers on evaluation of increased awareness on sustainability for PhD-students after participating in a course on sustainability [17]. A strong correlation was found between a high index of the concept map and a clear view on sustainability by performing Concept maps before and after the course and comparing them to evaluations of their individual final essays on how their research related to sustainability in the essay. Based upon the suitability of the technique and the previous well verified results this seems to be an appropriate tool to measure increased knowledge and awareness in the field of sustainable production.

SUSTAINABILITY AWARENESS DEVELOPMENT METRICS

This paper takes its standpoint in the hypothesis that awareness of sustainability is the key to create sustainable products, and that this awareness begins already at research level. In order to increase awareness in the research projects of the Area of Advance Production, a procedure was developed based on interviews, workshops, and conceptual maps. The goals with the interviews and workshops were to identify and develop a set of metrics suitable for measuring progress in sustainability among the participants. Conceptual maps were used to measure and follow up the awareness.

Based upon the nature of the Area of Advance Production the procedure for finding the proper sustainable measures is quite complex. During the early phase of procedure development it was clearly stated that the individual researchers as well as the industrial participants should be incorporated in the work of defining the measures for sustainability. Based upon this reasoning a procedure was proposed consisting of the following three methods and tools; Interviews, Workshops and Concept mapping which are presented and described in more detail in Knutson Wedel et al. in 2011 [11].

Increasing Awareness

In order to increase sustainability awareness amongst the researchers in the sustainability production initiative, seminars workshops and discussions were arranged early in various ways with the aim to identify proper metric together. Some arrangements were hands on workshops where the researchers had to search for knowledge. Others were more informative lecture-like sessions with information from major sources on sustainable production related topics. Another type of session was an informal dialogue where the researchers described their own area of research and how that relates to the three pillars of sustainability, social, economic and ecological. By repeated dialogues the researchers had the possibilities to test various measures and discuss the applicability. This was all a part of an effort to increase the knowledge regarding what sustainability measures the researchers could use in the ongoing research projects today as well as in the near future, which also aimed at increased awareness on sustainable production. These measures could both be quantitative and qualitative.

Conceptual maps

As described above, the changes in awareness of sustainability among both academic and industry participants were decided to be monitored by conceptual maps (Cmap). The maps are made continuously including before and after conduction of the research projects. It has shown good result on the issue in previous research and especially regarding sustainability [18], [19]. In this paper we are especially interested in the knowledge and the awareness of sustainable production. The population chosen consists of researchers within the area of production, including people from industry and academia closely related to the research area. The Cmaps are made anonymously and it is therefore not possible to control who the sample consist of. The samples where from the same population though. The participants were given a short introduction on the Cmap process and its essentials, thereafter given an A3 paper each with the words "Sustainable production" printed in the middle. They were then, during 15 minutes, writing down all the concepts they thought was correlated to sustainable production and made the relations among these concepts. The sample for 2010 consisted of 39 participants and the corresponding sample for 2011 was 48.The analysis of the Cmaps can be either qualitative or, as in our case; quantitative. The quantitative analysis aimed at finding out the category relevance index, complexity index as well as the Relative measure of connections among different categories. The category relevance index provides information about what categories the participants think sustainable production is most related to. The complexity index, evaluates how rich and connected the participants see the concepts they relate to sustainability. The categories used in this research were developed by Segalàs [18] and are categorized in ten categories that are divided into four main areas:

Environment

C1. Environment

All types of pollution and degradation of the environment, but also the conservation of the biodiversity. Notations such as ecological footprints have been put into this category.

C2. Resources scarcity

The main concepts for this category are un-renewable resources and the endless material resources. Adding to this is also concepts about recycling, re-usage of material and goods and maintenance to prolong the lifetime of for example machines.

Social aspects

C3. Social impact

This category mainly consists of the well-being of individuals, their health and quality of life, but also concepts connected to risk management. The ability to work and be healthy, for example.

C4. Values

This is related to ethics, respect for traditions and different cultures and the preservation of these. The category also includes awareness, to have knowledge about sustainability and hence be able to make changes.

C5. Future (temporal)

This category is about the time aspects, future generation and different scenario analysis to predict what is going to happen in the future and hence what actions is needed today. As for example forecasting, backcasting and LCA (life cycle analysis).

C6. Unbalances (spatial)

The distribution and uses of goods and resources is included in this category, it is about fair distribution of resources but also a fair use of them. Globalization and cooperation between different regions are included here, especially I- and U-countries.

Economy

C7. Technology

This category is about different technologies available, but also the usage of them and how efficient resources are used (especially energy consumption, but also flexibility and quality). The impact of technologies is also included, transportation and logistics solution for example, but also buildings, products and services.

C8. Economy

Concepts connected to costs, economical resources, the role of economy and fair trade. Included are also competition and market strategy and behavior.

Institutional

C9. Education

The spreading of knowledge by different education institutions, researches and the knowledge spread by media, both true and untrue information. Competence and the rise of awareness and knowledge are also included in this category as well as communication since it is a part in spreading awareness and knowledge.

C10. Actors and stakeholders

Different rules and laws, both national and international, stated by governments and non-government-organizations. Individuals and different groups of people (for example customers) and what demands they place on companies as well as regions.

The category relevance index value (CRi) is calculated using equation 1

$$CR_i = \frac{CD_i \times SC_i}{\sum_{i=1}^{i=NCa}(CD_i \times SC_i)} \qquad \textbf{(1)}$$

Where CDi (Concepts' distribution among categories) is calculated using equation 2 and SCi (Percentage of participants that write concepts assigned to a certain category) is calculated using equation 3.

$$CD_i = \frac{NC_i}{\sum_{i=1}^{i=NCa} NC_i} \qquad \textbf{(2)}$$

$$SC_i = \frac{NS_i}{NS} \qquad \textbf{(3)}$$

Where NCa is the number of categories, 10 in this case, NCi is the number of concepts per category. NSi is the number of participants referring to a specific category i and NS is the sample number of participants that participated in the observation.

The complexity index is a relative value which means that the index should be compared with another index that has the same prerequisites. The complexity index (CO) is calculated using equation 4:

$$CO = \overline{NC} \times L_{Ca} \qquad \textbf{(4)}$$

Where $\overline{NC}$ (average concept per participant) is calculated using equation 5 and L_{Ca} (Relative measure of connections among different categories) is calculated using equation 6:

$$\overline{NC} = \frac{\sum_{j=1}^{j=NS} NC_j}{NS} \qquad \textbf{(5)}$$

$$L_{Ca} = \frac{\sum_{j=1}^{j=NS} NL_j}{N_{Ca} \times NS} \qquad \textbf{(6)}$$

Where NS is the number of participants in the sample and NL is the number of links inter-category among concepts. In the sustainable production project the complexity index will be measured several times with different groups. Since the samples are from the same population the evolving awareness within the population can be visualized with the results from the Cmaps.

RESULTS

Development of measures to increase awareness

The process of developing measures for sustainability is assumed to contribute to an increased awareness of sustainability in the population. The measures were developed by interviews and the procedure, described in Knutson Wedel et al. [11], were continuously refined through discussions with the researchers. This continuous dialogue seemed to be a successful method to find measures that the incoherent group of production research projects could apply. It also contributed to the measures as such being further developed. Some of the old measures were removed, found too difficult to use, while others were refined and key metrics added. One example of how a metric was developed is measure no 1: “Business”. The former Description was Number of new or reformed services, products and technologies leading to decoupling, and the metrics value was “Number of”. See Knutson Wedel et al. [11] for more details on the initial set of metrics. The new description is “Number and type of new or reformed services, products, resources and technologies leading to decoupling”. And the new Metrics is now measured as: (a) description of each of the reformed services, products, resources and technologies developed (b) Graded on a maturity level according to: 1.Research planned, 2.Theory developed, 3.Theory applied, demonstrator up and running, 4.Implemented in real case, verified results.

A condensed set of 11 measures were by this method identified, many of them “sustainable” in the sense that they are addressing several of the three aspects of sustainability simultaneously.

Changes in sustainability awareness

To follow up the effects in awareness from the activities made, conceptual maps were used. The first round of conceptual maps was performed 2010 in the beginning of the activities in the Area of Advance Production. In this paper these results are compared to the results of a second round, one year later, on the participants. In the first round there were 39 participants and in the second there were 48 participants. The participants were a *sample* from the Area of advance production *population*. Figure 1 shows the average numbers of concepts, words, per category for both the first year and the second year. It is interesting to see that the first round had slightly more concepts than the second round.

The average number of concepts per category does not show the distribution among different categories and as can be seen in figure 2 the difference among different categories is quite substantial. Figure 2 shows the percentage distribution of concepts among the ten different categories. It can be seen that during 2010 *C7, Technology*, have more than one third of all concepts in it but *C6, Unbalances*, barely has any concepts. Since both the first and the second year are shown in figure 2 it can be seen that the distribution among the categories has evolved some. The awareness is now more balanced between the categories. All categories, except within the *Social aspects area,* have decreased some. Since it was the *Social aspects area* that held the least concepts in the first year it is a positive change that can be seen in the second year when they all increased (C3-C6).

It is not only the number of concepts that are of interest, the distribution of the participants mentioning different categories is also interesting. Figure 3 shows the fraction of participants providing notions in each category. It can be seen that in both the first and the second round most of the categories were mentioned by more than half of the participants. It is only Values, Future and Unbalances that falls below the 50%-mark in both rounds. Category C9, Education, increases in the second round and passes the 50%-mark. However, there are two categories (C2 Resources and C10 Stakeholders) that decreases in the second round indicated that these categories are not mentioned by as many participants in the second round as in the first round. All other categories increases, or have the same percentage of participants.

By combining the distribution of concepts and participants among the different categories figure 4 can be presented. This gives a measurement of the category relevance and it can more clearly be seen which categories are placed into focus by the participants and which categories they are less aware of.

In addition to the distribution among the different categories, also how many connections that can be found between them are of equal interest since this indicates awareness of interdependency; that a single category does not give sustainability but they are all connected to each other in one way or another. To measure this, connections between different categories were counted and divided by the number of participants times the number of categories. This gives a relative measurement of the awareness of the connections between the different categories, i.e. sustainability in a sense.

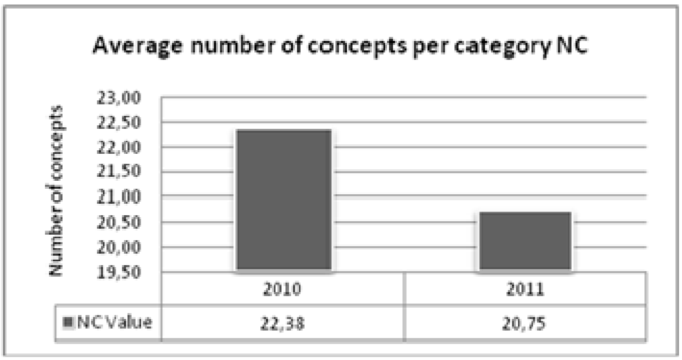

Figure 1: Average number of concepts per category

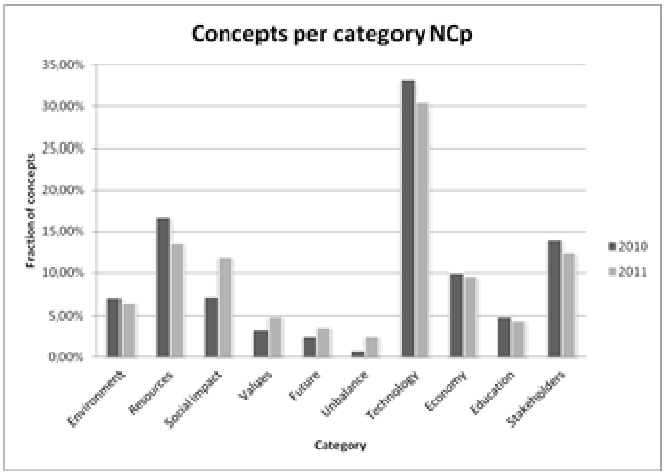

Figure 2: Percent distribution of concept per category

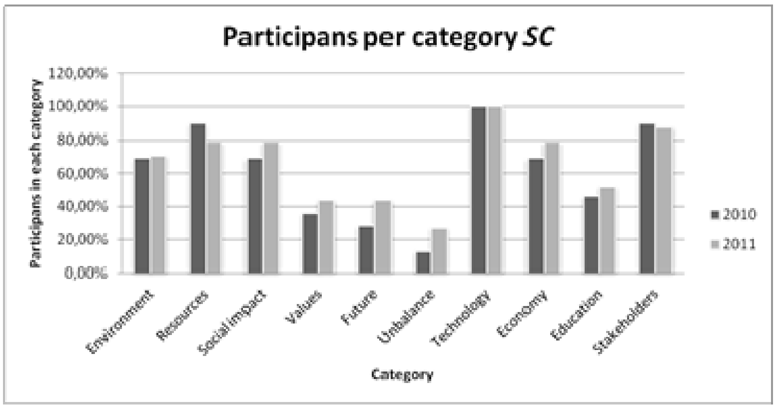

Figure 3: Percentage of participants per category

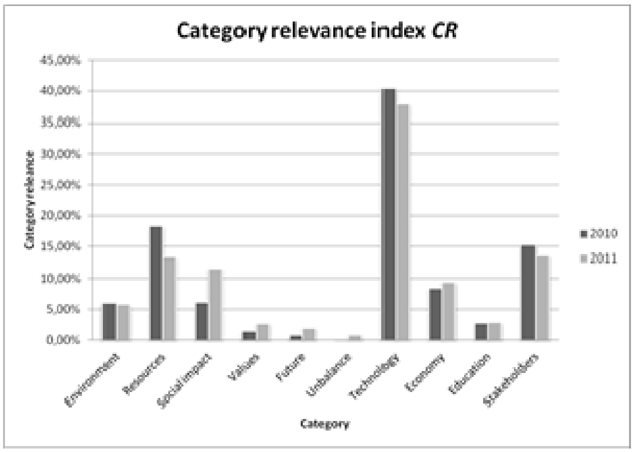

Figure 4: Category relevance index

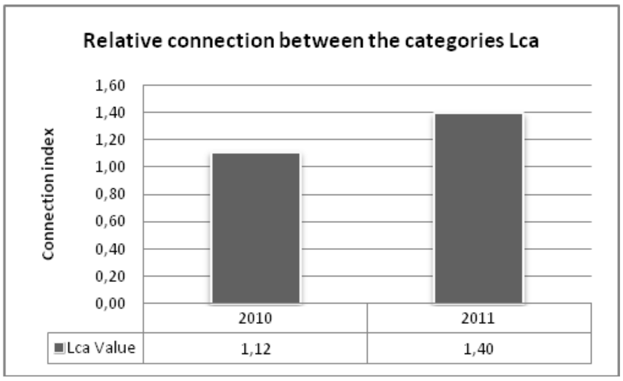

Figure 5: Relative connection between categories

The result is shown in figure 5. It can be seen that the Relative connection between categories has increased in the second round and this indicates that more connections between categories could be found in the second round of Cmaps, resulting in a 25% increase; from 1.12 to 1.40. The complexity measure has changed from 24.97 to 29.01 which is a 16% increase and means that the number of relations in-between categories of dissimilar type has increased.

DISCUSSION

The results generally indicate an increase in sustainability awareness between 2010 and 2011. One exception may be that the total number of concepts decreases in the second round of Cmaps. In most cases an increase should be expected since knowledge is supposed to have increased, so should also the amount of concepts. Why it is the other way around in this case can be because it is easier to quickly write down several concepts within the same category, but it takes more time and effort to include concepts in several categories and link them together. Since the distribution between the categories is more even, both in number of participants and concepts, in the second round this may very well be the reason for why the average number of concepts per category has decreased.

What could be of concern though is that two categories have fewer participants using them in the second round than in the first. This could be that new knowledge that was fresh in the memory was noted on the Cmaps first, but it could also be that these two categories (*C2 and C10 or Resources and Stakeholders*) have been less emphasized upon during the year in-between the tests since these two were natural part of the researchers everyday work before the area of advance on sustainable production started.

Several Cmaps have only a few concepts, that are very broad in their meaning and consists mainly of words such as; environment, sustainable society, sustainable economy and technology. The amount of lines between the words are however large, which could indicate knowledge on that they influence each other, but not understanding of how they are connected in more detail.

The category relevance index shows no significant differences between the two rounds, main emphasis is still in *C7 (Technology)*. However worthwhile to notice is that all minority categories increase, and all major categories decreased. The category index for *C3 (Social impact)* has increased most even though the participants were engineers with a focus on technology. It might possibly be interpreted as a change in focus of the participants, widening the technology focus towards social aspects. In order to be sustainable a more balanced concept map is to prefer, which is also the case in the second year in relation to first.

The relative connection between the categories has increased and this indicates an increased awareness about sustainability and the need to view all categories together and not only focus on one or two areas. It is interpreted as a 25% increase in awareness and according to the method it should be right. If this is an increase in knowledge that there are connections between the categories or if it is in true an awareness of these connections and what they are, can however be discussed.

It needs to be noted that the population consist of just over 200 researchers and the sample is rather low. However, future Cmaps will be evaluated and added to the dataset in order to increase the validity.

CONCLUSIONS

In this paper, we have described the follow-up and development of a method on monitoring sustainability awareness and promote increased awareness through workshops and sustainability metrics.

The results are the following: (a) A continuous dialogue and cooperation with researchers was a successful method to design a set of measures suitable for an incoherent group of production research projects in order to increase awareness on sustainable production. (b) Concept mapping was found to be a method, which did fill its purpose for the area of advance on sustainable production at Chalmers, to monitor sustainability awareness of the participants. The resultant measurement showed that the participants had a highly uneven view on sustainability where technology related issues were addressed foremost. The social issues, like values and equity, were not considered in the beginning of the area of advances' activities. However, the awareness has now increased on the before less frequent categories in favor of other categories, indicating a more developed understanding of sustainability (c) The awareness on sustainable production has increased with 25% as monitored by the Relative measure of connections among different categories, see formula 6 and figure 5. (d) It needs to be noted that the population consisted of just over 200 researchers and the sample is rather low. Future Cmaps will be evaluated and added to the dataset in order to increase the validity.

FUTURE WORK

The next step, of utilizing sustainability measures for sustainable production research, is to continue with refinement of measures relevant and feasible for the research topics. Participating researchers will also be coached in using the measures and the methodology, through additional workshops and discussions. Further evaluations of the result in sustainability awareness will be made by utilizing the awareness measurements in conceptual maps with samples from the same population.

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