Life cycle assessment (LCA) as a sustainability and research tool in energy degree programmes

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1 INTRODUCTION

Energy plays a critical role in global sustainable development processes according to the United Nations (UN) report “The Future We Want” [1]. The UN 2030 agenda introduced 17 sustainable development goals and 169 targets to be met by 2030 including a goal for energy to be affordable, reliable, sustainable and modern energy for all [2,3]. In Europe, the use of energy from renewable sources is promoted by European Union (EU) energy policies [4].The UNECE strategy (2005) [5] highlighted the use of formal, non-formal and informal learning and the training of educators with

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the SD abilities in order to promote education for sustainable development (ESD). The UN Decade 2005 – 2014 for ESD (UN DESD) encouraged governments and organisations to integrate the principles, values and practices of sustainability into all aspects of education and learning [6]. However, sustainability still remained a challenge in education after the UN DESD. Therefore, a new action plan was launched to follow and ensure the implementation of ESD in all teaching and research [2]. Kandpal and Broman (2014) [7] reviewed a global status of renewable energy education and identified a variety of challenges in energy education including unavailability of well-structured curricula, lack of motivated and competent teachers, unavailability of adequate funds and uncertainty on the employment prospects of the student. They found out that renewable energy courses are missing links to environmental interactions and sustainable development. This paper introduced a teaching concept (Fig 1) to train and motivate teachers to integrate ESD into the energy degree programmes.

Life cycle assessment (LCA) is one of the techniques developed to increase the awareness of environmental protection, and the possible impacts associated with the product systems [8]. LCA is a systemic tool for comparing and identifying the best sustainable solutions to the product systems. Sustainable and secure energy solutions are needed to overcome environmental problems, mitigate the impacts of global warming and increase welfare of people locally and globally. The overall concept of sustainability is understood as sustainable development (SD) with the environmental, economic and social dimensions [9]. Sustainable energy and sustainability dimensions in teaching pose the challenges to energy education at universities in order to produce experts for the needs of the sustainable society. Education has seen as an incentive for people to use their individual potential and contribute to social transformation [2].

Teaching and research can be combined by employing the concepts of learning and teaching using research-based assignments and projects inside and outside the classroom [10,11]. The research-teaching nexus was further developed by Healey (2005) [12]. He presented a model of four research categories integrating research and teaching by using research-led, research-oriented, research-tutored and research-based categories. The research categories represented either content-driven research or focused on conducting research and its problems. In addition, these research categories included teacher-focused teaching and student-focused learning. All the research categories influenced the students' learning process. They enabled students to learn research skills and techniques, become familiar with current research, learn to be engaged in research discussions, learn to carry out research and act as a researcher. This model by Healey is used in this paper (Fig. 4) to explore how LCA-based research appears in the energy degree programmes.

A teaching concept (Fig. 1) helps teachers to combine LCA, sustainability and education by using teaching and learning methods connected with research and sustainability applications in energy education. Sustainability applications train students to understand, discuss and interpret the findings of the used studies. Students learn to identify the most significant sustainability aspects and environmental impacts of the case studies. They learn to identify the best life cycle phases of the systems for the optimisation of improvements. The use of LCA-based research helps students to recognise e.g. planetary boundaries, limits to growth, local conditions and the cost effectiveness of their solutions. First and foremost, students learn to know LCA and enhance their interpretation skills of LCA and sustainability and thus avoid misleading conclusions. In energy education, this concept enables critical debates about the current topics of the energy technologies and their local and global sustainable solutions.

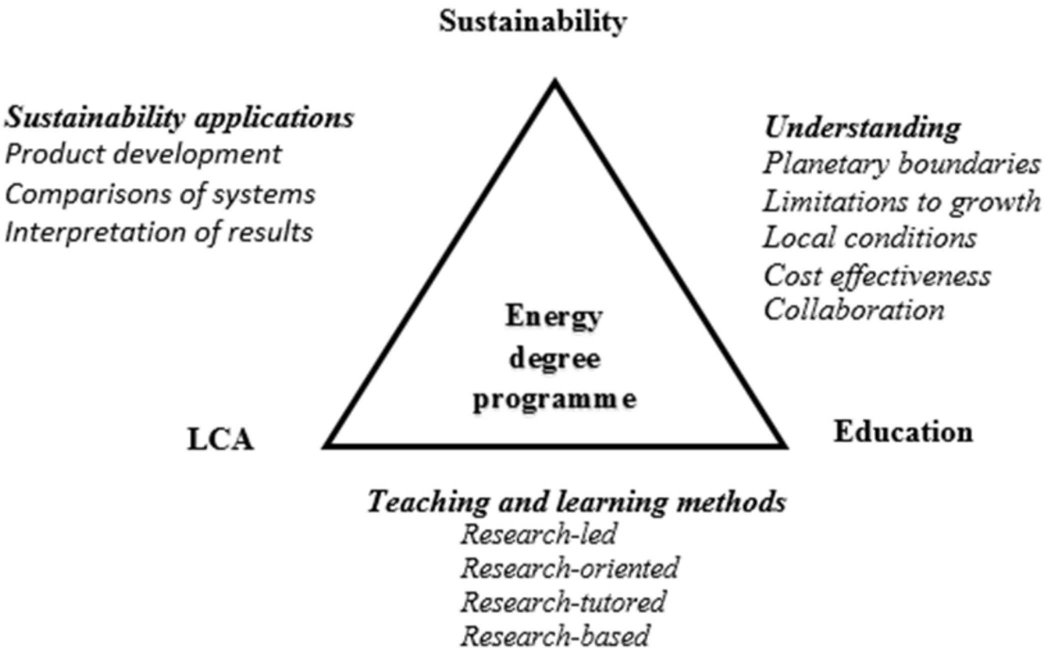

Fig. 1. A concept connecting sustainability, education and LCA in energy education.

In spite of the various uses of LCA in research and business, the role of LCA seems to be unexplored in energy education. Teachers lack information on how LCA is taught and how LCA is connected to SD in the energy degree programmes. Therefore, this study explored the use of LCA and LCA-based research in the energy degree programmes at Baltic, Nordic and Finnish technical universities. A survey was sent to the responsible teachers and professors focusing on the use, importance, incentives and teaching and learning methods of LCA. The results of the LCA teaching and learning methods of the survey were placed in a research-teaching nexus model applying the Healey model [12] in order to identify how LCA-based research manifests itself in energy education. The findings of this paper are presented and discussed for enhancing the use of LCA and LCA-based research in sustainability assessment in the energy degree programmes at technical universities to educate future LCA experts in sustainable energy for future needs of sustainable societies.

2 LIFE CYCLE ASSESSMENT (LCA) AS A SUSTAINABILITY TOOL

Life cycle assessment (LCA) has a following description in the ISO 14040 standard [1] "*LCA addresses the environmental aspects and potential environmental impacts (e.g. use of resources and the environmental consequences of releases) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave)*." The framework of LCA consists of four phases, namely Goal and scope definition, Inventory analysis, Impact assessment and Interpretation. The inventory phase produces data to be used in impact assessment and in the interpretation of the overall results.

During the past few decades, LCA methodology, databases and software have been developed as well as LCA standards [1,13] and LCA guidebooks [e.g.14-16] in order to improve the scientific use of LCA. The development of the LCA has been supported by the UNEP/SETAC Life Cycle Initiative to enhance decision-making towards more sustainable product systems and processes [17,18]. For example, LCA-based indicators, eco-labels and carbon footprints support corporate strategic planning, product development and marketing in industrial, governmental and non-governmental sectors [19]. However, all the uses of LCA do not aim to improve sustainability, e.g. the carbon footprints help to improve marketing and business but they do not provide information on how to tackle climate change. At the moment, the most typical sustainability applications of LCA addressed the product development and comparisons of systems.

Due to the growing information needs of decision-makers in different sectors of society, there was also an urgent need to extend the use of LCA to harness the economic and social dimensions of sustainability [20,21]. Ness et al (2007) [22] highlighted that the environmental-focused realm of LCA has to be expanded to a wider interpretation of sustainability. A life cycle sustainability assessment (LCSA) combines environmental life cycle assessment (LCA), life cycle costing (LCC) and social life cycle assessment (SLCA) [23,24]. The combination of LCA and LCC provides information to choose the most cost-effective solutions. The combination of LCA and SLCA provides information to identify the aspects threatening the social sustainability of the solutions.

Ever since the early years of LCA, LCA has been used to calculate the emissions and environmental impacts of the energy systems in order to make improvements in energy technologies and systems. In connection with LCA, the energy systems typically consist of the fuel chain and the production phase of energy generation in the power plant (i.e. cradle-to-gate) excluding infrastructures, buildings and machines. Recently, Asdrubali et al. 2015 [25] reviewed 100 LCA renewable energy case studies for comparing energy systems, Turconi et al. (2013) [26] reviewed 167 LCA energy case studies for comparing sustainability indicators, and Evans et al. (2009) [27] reviewed about 50 LCA energy case studies of greenhouse gas emissions. They all reported that there were weaknesses and gaps in the results of the reviewed LCA energy case studies addressing the used knowledge, data, assumptions and considerations of the energy systems. In order to ensure better data, transparent and precise information to assess and interpret LCA-based sustainability results, the training of students on LCA skills and energy knowledge is crucial.

3 RESEARCH METHODS AND MATERIALS

This study explored the use of LCA and LCA-based research in the energy degree programmes by using a survey and Healey´s model [12]. The survey was sent to the selected teaching staff at Baltic, Nordic and Finnish technical universities in the autumn of 2012. In total, the respondents consisted of 16 teachers and professors at ten universities. The number of the respondents varied in each issue and it was limited because the respondents were chosen with care highlighting the fact that they are aware of the actual situation of energy education at their universities. Therefore, the target group consisted of teachers and professors who were responsible actors in the energy degree programmes and courses therein. They were also supposed to know how energy is being taught. The chosen energy target group may have set limitations to the generalisation of the results and applying them in other disciplines.

The survey questions concerned the use, importance, incentives and teaching and learning methods of the energy courses in the energy degree programmes (Table 1). The survey included 16 incentives and 26 teaching and learning methods. The use of LCA in research was analysed by applying the Healey model that combines research and teaching that is described in the introduction section. The teaching and learning methods of LCA were analysed using the experience of the authors and the descriptions of the teaching methods [28] and thereafter they were placed in four research categories (Fig. 4) for further interpretation.

Table 1. LCA questions and answer options of the survey.

Questions	**Options**
Is LCA used in the bachelor and/or master energy degree programmes (majors/ minors/ elective studies/ no studies)?	*Yes/No*
What is the importance of LCA in the energy degree programmes and what are the future prospects for LCA and energy?	*Very high/ High/ Medium/ Low/ Not important/ I cannot say*
What are the main incentives to incorporate LCA into the energy degree programmes?	*Global challenges, Environmental problems, Public pressure, Demand from employers, Demand from students, University strategy, Learning outcomes, Engineering competences, Interdisciplinary education, Integration of research and teaching, Sustainable development, Economic awareness, Social awareness, Environmental awareness, Environmental politics and laws, Other incentives*
What are the main teaching and learning methods for LCA?	*Assignments, Debate, Drama pedagogy, E-learning, Exams, Exercises, Field trips, Group work, Independent studying, Learning by doing, Learning café, Learning diary, Lectures, Mind map, Panel discussion, Peer teaching, Preliminary test, Personal guidance, Presentations, Problem-based learning (PBL), Project work, Reading circle, Seminar, Supplementary reading, Workplace practice, Others*

4 RESEARCH RESULTS

Findings of the survey showed that the use of LCA varied in the energy degree programmes at the Baltic, Nordic and Finnish technical universities. According to the open ended comments, LCA was also used by doctoral students at universities. LCA was better used in the master than bachelor level energy studies (Fig. 2). Minor studies of the bachelor and master degree programmes dominated the use of LCA. LCA was less used in the major studies of the degree programmes. Additionally, LCA was used in elective studies and as a separate course in the master degree programmes. Findings also indicated that LCA was not used in all the bachelor and master energy degree programmes.

Respondents indicated that LCA was more important for the master than bachelor level studies. The importance of LCA varied from a high level to a not important level. Additionally, many respondents could not give any answer to the importance of LCA (Fig. 3). The future prospects indicated that LCA will have a high importance and energy a very high importance in the energy degree programmes in the future.

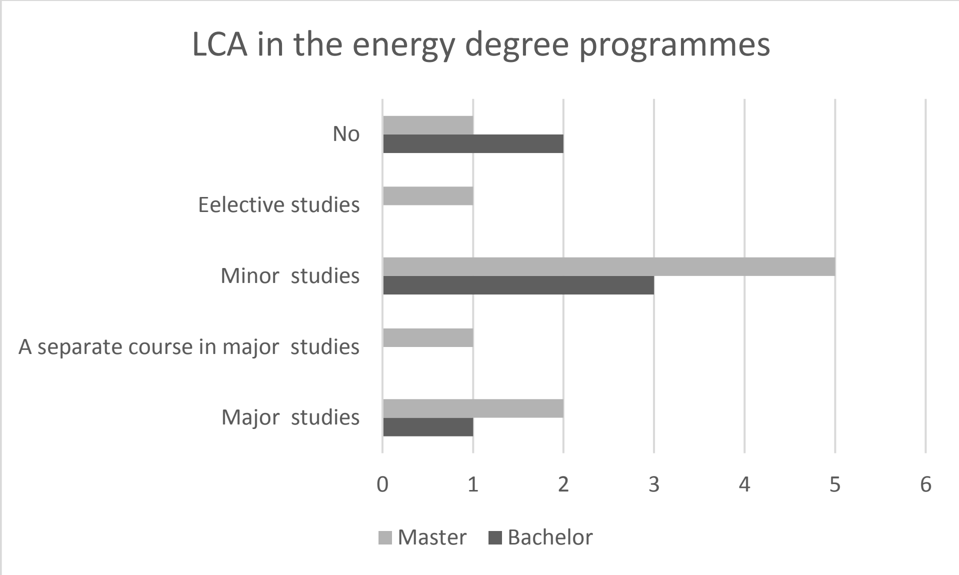

Fig. 2. The use of LCA in major, minor and elective studies and as a separate course in the energy degree programmes. N = 10.

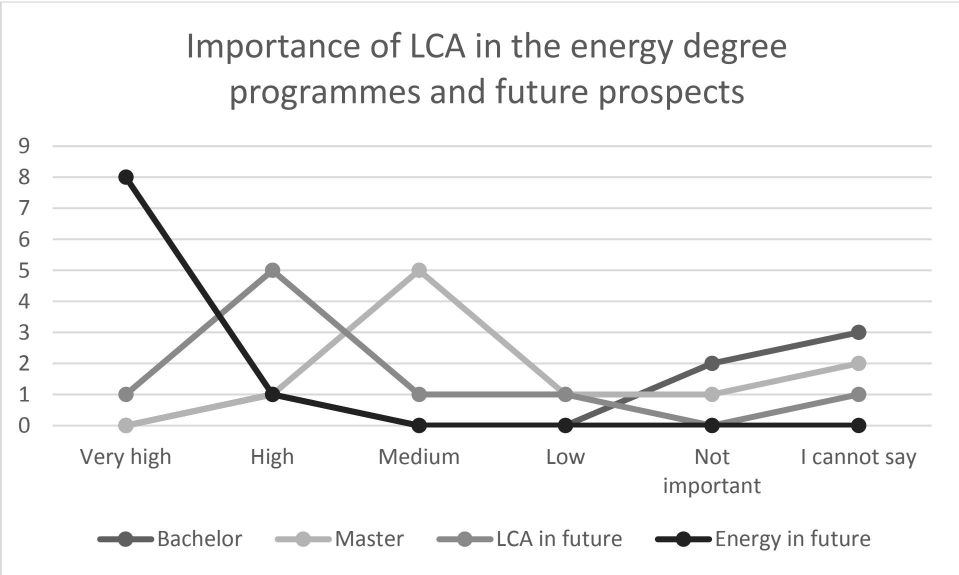

Fig. 3. The importance of LCA in the major subject studies of the energy degree programmes and future prospects for LCA and energy. N = 10.

Findings showed that sustainable development was the main incentive for the use of LCA in the degree programmes followed by environmental awareness, environmental problems, demand from employers and global challenges. Integration of research and teaching, engineering abilities, and environmental politics and laws were identified as moderately important incentives by the respondents. Only a minority of respondents recognised that interdisciplinary education and demands of students were incentives for the use of LCA. Findings revealed that social and economic awareness as well as public pressure, university strategy and learning outcomes were identified as the weakest incentives among all the presented incentives for the use of LCA. Results of the incentives in the use of LCA are presented in Fig. 4.

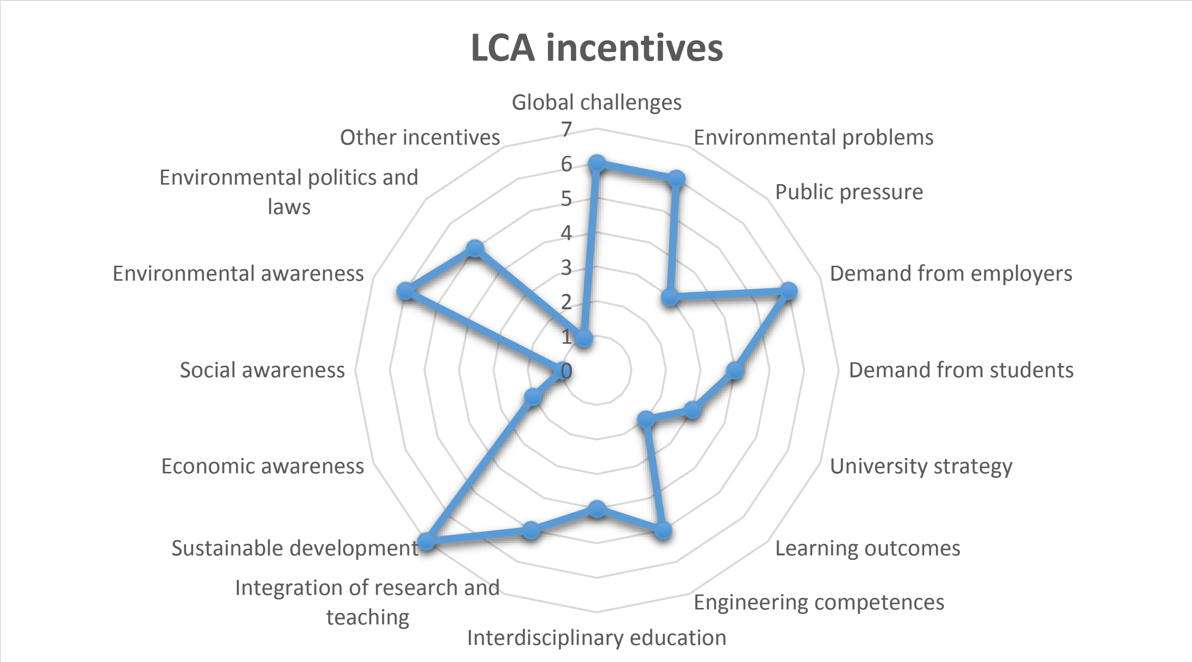

Fig. 4. The incentives for LCA in the degree programmes. N = 14, the respondents were allowed to give one answer per each issue.

26 teaching and learning methods included 93 responses. Results showed that LCA was taught with a large variety of teaching and learning methods (Fig. 5. Respondents identified that the most used methods were lectures, assignments and exercises in the use of LCA in teaching. The use of LCA was moderately recognised in debates, E-learning, exams, field-trips, group works, mind maps, panel discussions, peer teaching, problem-based learning, seminars and supplementary reading by the respondents. The least used methods included drama pedagogy, learning café, learning diary, reading cycle and workplace practice. The results of the responses are further analysed through the Healey model (Fig. 6).

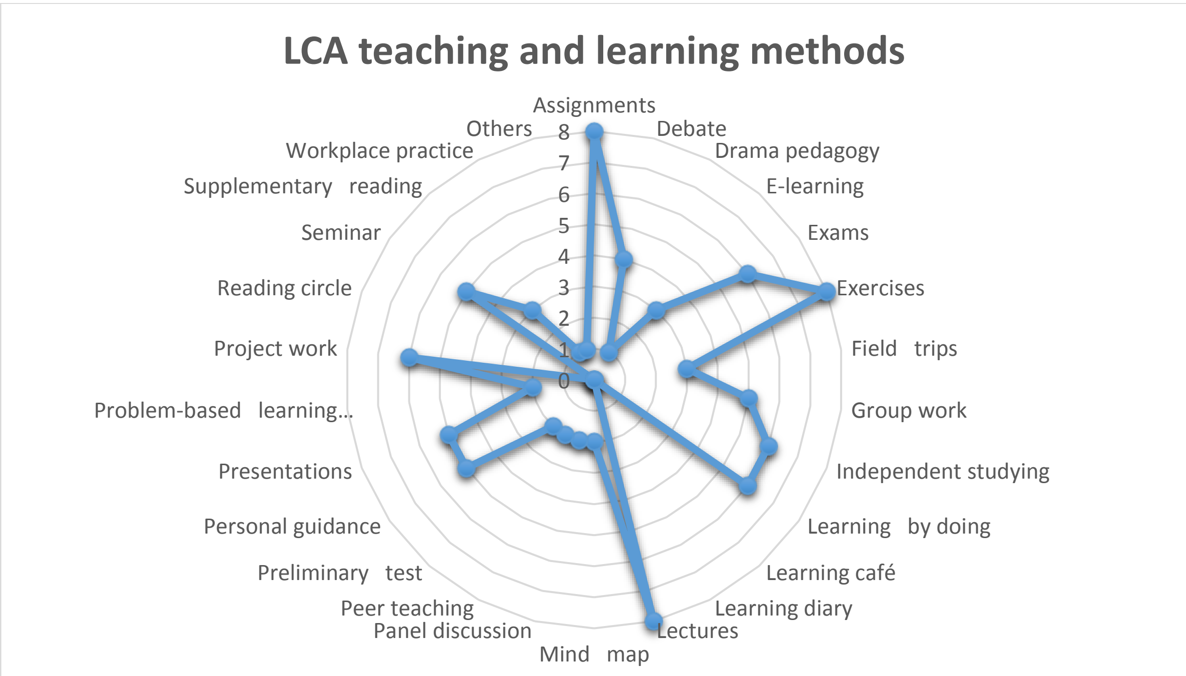

Fig. 5. The main teaching and learning methods used in the degree programmes. N = 14, the respondents were allowed to give one answer per each issue.

93 responses to the teaching and learning methods were placed in four research categories using the Healey model in Fig. 6. The results showed that the LCA teaching and learning methods were quite counterbalanced between the student-focused (46 responses) and teacher-focused categories (47 responses). Research content received 50 responses divided into research-tutored (18/93) and research-led (32/93) categories. Research processes and problems received 43 responses divided into research-based (28/93) and research-oriented (15/93) categories. The teaching and learning methods of LCA enabled the use of all the research categories in teaching in the energy degree programmes.

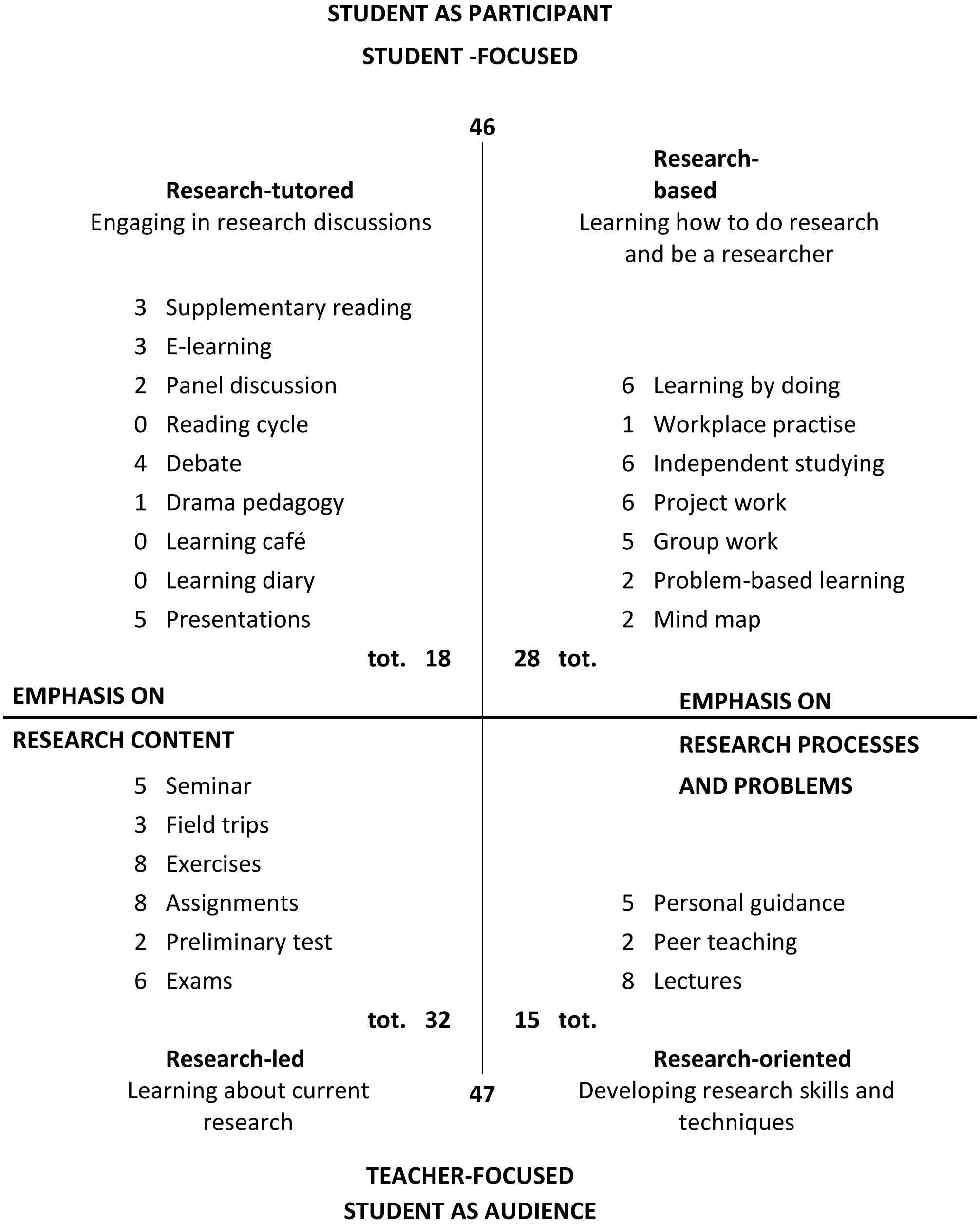

Fig 6. The LCA teaching and learning methods of the survey in the four research categories of the Healey model [12].

As an example, the most common teacher-focused and student-focused methods were as follows:

- Teacher-focused methods: lectures, assignments, exercises and exams

    - Lectures have put an emphasis on research processes and problems.
    - Assignments, exercises and exams have an emphasis on research content.
- Student-focused methods: presentations, debates, independent studying, project work and learning by doing
    - Presentations and debates highlight research content.
    - Independent studying, project work and learning by doing emphasise on research processes and problems.

5 DISCUSSION AND CONCLUSIONS

Sustainable development is a challenge for teachers at universities. Teachers need training on SD skills and tools in the integration of all the dimensions of SD into energy education. However, the findings did not support the practice of using LCA as a broader framework for sustainability assessment (LCSA) in energy education. LCA has been typically used in assessing environmental issues such as the carbon dioxide emissions of the energy systems. Therefore, more attention needs to be paid to the enhancement of the social and economic incentives when using LCA and sustainability in energy education. The economic and social dimensions of SD are normally studied by using separate tools such as multiple forms of LCC and SLCA. Due to the complexity of sustainability assessment, it is important to train teachers and students in the use of LCA and related SD tools. Incompetent and inexperienced researchers might fail to interpret the study results and thus they might draw misleading conclusions. This is also identified by the reviews of the LCA energy studies highlighting the importance of the proper energy data for transparent and adequate information on the energy systems for decision-making purposes in politics and business.

This paper presented a LCA-based teaching concept (Fig. 1) for combining LCA, sustainability and education and placed the LCA teaching and learning methods of the survey on a research-teaching nexus model by Healey (Fig. 6) for exploring the use of LCA in the energy degree programmes. The findings of the survey showed that LCA was more common in the master than bachelor energy degree programmes. However, LCA was not used in all energy degree programmes at Baltic, Nordic and Finnish technical universities. Especially the bachelor energy students would benefit from LCA during their bachelor studies in order to become familiar with LCA before their master studies. In spite of the varying importance levels of LCA, the respondents indicated that the importance of LCA and energy will significantly increase in the energy degree programmes in the future. It might mean that the number of LCA and energy experts would also increase in the future to prepare sustainable solutions to decision-making purposes in society. Moreover, all over the world the SD and energy experts are needed to implement the global action plan to avoid climate change by limiting global warming and to implement the SD energy goal of the UN agenda 2030 for affordable, reliable, sustainable and modern energy for all.

The traditional teaching and learning methods such as lectures, assignments, project work and exams were used in LCA. In spite of the useful contributions to solving the problems, problem-based learning was less used in LCA in the energy degree programmes by the respondents. Therefore, the use of problem-based learning as a student-focused method should be enhanced as part of sustainable energy education in the future. Teachers are key actors in choosing the best appropriate teacher-focused and student-focused teaching and learning methods for the integration of ESD into their energy courses. The teaching and learning methods of LCA in the Healey model revealed that LCA was perceived in all research categories and enabled students with diverse skills and learning.

The research-teaching nexus model (Fig. 6) by Healey helps teachers to use LCA-based research in teaching. The teaching concept (Fig. 1) guides teachers to combine LCA, education and sustainability in energy education. Sustainability applications help students to learn to do LCA and recognise the most significant sustainability aspects and impacts of their applications. Students learn to discuss and interpret the complexity of findings for improving the sustainability of the energy systems. In tackling the future challenges for SD and sustainable energy, universities have a vital role in educating future LCA and energy experts to be able to use LCA and LCA-based research in the sustainability assessment of the energy systems and services. Summing up, more research is needed to motivate teachers and increase the use of LCA as a sustainability and research tool in the energy degree programmes at technical universities to educate future LCA experts in sustainable energy for the needs of sustainable society.

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