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The factors impacting the incorporation of the Sustainable Development Goals into Raw Materials Engineering Curricula

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Abstract

It is widely recognised and acknowledged that the mining industry, if properly operating and managed, has the potential to positively contribute to "The 2030 Agenda for Sustainable Development". In this direction, the Raw Materials (RM) engineering education possesses a crucial role, given the need to instil in tomorrow's mining engineers the sustainability principles. This paper explores the educational needs of the Greek RM sector and the factors constituting the RM whole value chain SDGs-education-innovation eco-system. The research follows a two-stage focus group approach. First, the perceptions, opinions and beliefs of invited stakeholders were explored in the context of semi-structured interviews. Then, the stakeholders were requested to identify the main components of the RM-SDGs-education-innovation eco-system using the Fuzzy Cognitive Maps (FCMs) method. According to the results, the incorporation of the sustainable development (SD) principles in the educational process is considered a priority. However, only a few courses provide the basics of SD principles in the Greek RM engineering curricula, so far. Further, the FCM approach offered the means to explore the factors identified by the stakeholders as pivotal in the RM-SDGs-education-innovation system and the interactions between them.

Keywords

sustainable development goals, mining and metallurgical engineering education for sustainable development, engineering curriculum, fuzzy cognitive mapping

The factors impacting the incorporation of the sustainable development goals into raw materials engineering curricula

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Abstract

It is widely recognised and acknowledged that the mining industry, if properly operating and managed, has the potential to positively contribute to “The 2030 Agenda for Sustainable Development”. In this direction, the Raw Materials (RM) engineering education possesses a crucial role, given the need to instil in tomorrow's mining engineers the sustainability principles. This paper explores the educational needs of the Greek RM sector and the factors constituting the RM whole value chain SDGs-education-innovation eco-system. The research follows a two-stage focus group approach. First, the perceptions, opinions and beliefs of invited stakeholders were explored in the context of semi-structured interviews. Then, the stakeholders were requested to identify the main components of the RM-SDGs-education-innovation eco-system using the Fuzzy Cognitive Maps (FCMs) method. According to the results, the incorporation of the sustainable development (SD) principles in the educational process is considered a priority. However, only a few courses provide the basics of SD principles in the Greek RM engineering curricula, so far. Further, the FCM approach offered the means to explore the factors identified by the stakeholders as pivotal in the RM-SDGs-education-innovation system and the interactions between them.

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1. Introduction

In September 2015, at the UN Sustainable Development Summit in New York, all United Nations Member States adopted the outcome document “The 2030 Agenda for Sustainable Development” [1]. The Agenda, building on the Millennium Development Goals (MDGs) which were launched in 2000, involves 17 Sustainable Development Goals (SDGs) and 169 targets to be fulfilled over the next fifteen years in areas of critical importance for humanity and the planet [1]. The SDGs, contrary to the MDGs, apply to all countries and address ecological sustainability challenges besides economic and social goals [2] in the sustainability three pillars, i.e. economic, social and environmental, in a balanced and integrated manner [1]. Nevertheless, the SDGs have been criticized among others for being too ambitious, relatively vague, based on weak institutional arrangements, inconsistent − particularly between the socio-economic and the environmental goals, difficult to quantify and monitor and non-binding from a legal perspective [2−7]. Besides the challenges, however, it is argued that the SDGs are universal (i.e. they do not distinguish developed and developing countries in terms of sustainability) and allow a more logical and practical integration of the three dimensions of sustainable development [8,9], and this makes the SDGs a novel type of governance and “… one of the most intriguing new global initiatives in the area of sustainable development and environmental policy …” (p. 29) [8].

The implementation of the SDGs is a challenge for all economic activities and mining is not an exception as it is directly linked to a large number − if not all − of the 17 SDGs [10,11]. On the one hand,

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mining has the potential to create employment, foster economic development in local, regional and national scale, generate state revenues through taxes and royalties, improve transport, communication and other infrastructure, offer educational opportunities, etc. However, if not conducted properly, mining can result in long-lasting irreversible environmental problems, exacerbate social and economic inequality, trigger conflicts and contribute to political corruption [11–13]. It is thus evident that the mining industry is capable of contributing both positively and negatively to the SDGs achievement [14]. In recent decades, the industry has made significant advances in improving the way it manages its potential environmental and social impacts in the context of company-community conflict minimization [13,15]. But, for the RM industry to be the cornerstone of sustainable development, the RM engineering curricula need to instil in today's students and tomorrow's professionals the sustainability principles.

Within this context, a two-year integrated Regional Innovation Scheme (RIS) project entitled "Enhancing the skills of ESEE RM students towards the achievement of SDGs – EnActSDGs" was initiated in 2020. The project is funded by the EIT (European Institute of Innovation and Technology) Raw Materials and focuses on RM students from three East and Southeast Europe (ESEE) countries, namely Greece, Poland and Slovakia. It aspires to promote, in a multidisciplinary and multicultural environment, innovation, entrepreneurship and effective performance and strengthen the skills and competencies of RM university students towards the achievement of the SDGs. More specifically, the project team includes three ESEE beneficiary universities from Poland (AGH University of Science and Technology – AGH), Greece (National Technical University of Athens – NTUA, and Slovakia (Technical University of Kosice – TUKE), three innovation providers from Austria (Montanuniversität Leoben), Germany (Technische Universität Bergakademie Freiberg), and Italy (Unitrento and Hub Innovazione Trentino) and an industrial partner from Greece (MYTILINEOS). From the beneficiary universities, the curricula of three RM engineering departments were examined and more specifically the Faculty of Mining and Geoengineering of AGH in Poland, the School of Mining and Metallurgical Engineering of NTUA in Greece and the Faculty of Mining, Ecology, Process Control and Geotechnologies of TUKE in Slovakia. The scope of EnActSDGs is to provide a pathway that will ensure the incorporation of the SDGs in the curricula of the RM engineering schools beneficiary universities and establish a sustainable network and eco-system between beneficiary and innovation provider universities, research institutes and the RM industry [16]. In this direction, the structure of the curricula of the RM schools in the three ESEE beneficiary universities is evaluated regarding the incorporation of SD principles.

Based on the research conducted within the EnAct-SDGs project, this paper focuses on the identification of the educational needs in the Greek RM engineering studies and analyses the interviews conducted with Greek stakeholders following a two-stage focus group approach. First, the stakeholders were invited to discuss the educational needs and challenges for the achievement of SDGs in the RM sector through semi-structured interviews. Then, they were requested to identify the main components of the RM whole value chain SDGs-education-innovation eco-system using a widely used method employed for studying the structure and behaviour of complex systems, namely the Fuzzy Cognitive Maps (FCMs). To the authors' best knowledge, this is the first study that uses this approach to examine the factors constituting the RM whole value chain SDGs-education-innovation eco-system and their interactions.

The rest of the paper is structured, as follows. Section 2 provides a brief literature review on the role of engineering education in sustainable development with a focus on RM curricula. Section 3 describes the methodological approach. Section 4 analyses the results of the survey. Finally, Section 5 concludes with the main findings and provides recommendations for future research.

2. Literature review

The role of education in sustainable development was initially set out in the Tbilisi Declaration at the closure of the world's first intergovernmental conference on environmental education, which was organised by UNESCO in cooperation with the U.N. Environment Programme (UNEP) [17]. The principles and the programme areas of environmental education were detailed in Chapter 36 Promoting Education, Public Awareness and Training of the Agenda 21 [18]. In 2002, the U.N. General Assembly adopted the Resolution 57/254 to designate the decade 2005–2014 as the "United Nations Decade of Education for Sustainable Development (UNDESD)" [19]. Also in 2002, the World Federation of Engineering Organisations (WFEO) noted that engineering education for sustainable development (EESD) encourages engineers to play "… an important role in planning and building projects that preserve natural resources, are cost-efficient and support human and natural environments …" (p. 4) [20]. The need to incorporate sustainability into the engineering curricula was further highlighted in UNESCO's report on Engineering Initiative [21]. However, "… a large-scale transition to producing engineering graduates with the knowledge and skills to meet the changing needs of the profession over the coming …" (p. 5) had not happened till 2010 [22]. This was, at least partially, attributed to the fact that the process for updating engineering curriculum using standard methods might take over 15–20 years, creating the so-called time lag dilemma for engineering departments [23].

Over the last ten years, things have changed. As mentioned by Kelly [24], "… sustainability is explicitly included in the WFEO Model Code of Ethics under Canon 4 protection of the natural and built environment. The WFEO Model Code of Practice for Sustainable Development and Environmental Stewardship provides a comprehensive approach to sustainability in engineering practice …" (p. 1). Further, he mentions that graduates from engineering programs accredited under the International Engineering Alliance (IEA) Washington Accord "… can be expected to have an understanding of sustainability in the context of engineering practice in their field …" (p. 2). This shift is also apparent in the recent scientific literature [25–40].

Following the same trend, many RM schools and departments worldwide have incorporated the concept of sustainable development in their curricula, in response to the requirements of accreditation of their programs and the challenges of the changing environment for the mining industry. For instance, in 2005, in the Mining School of Oviedo, Spain, a minimum compulsory formation in the subject environmental engineering and technology was adopted and obligatory taught in the third year of studies [41]. To integrate sustainable development into mining engineering, the Mining Engineering Department at the University of British Columbia, Canada, established the Sustainability Working Group (SWG), bringing together a diverse array of disciplines from academia, industry, government, NGOs and mining communities. The SWG offered two undergraduate courses (i.e. sustainability and professional engineering practice) and planned a new course on aboriginal peoples and engineering [42]. In 2007, the Robert M. Buchan Department of Mining at Queen's University, Canada, introduced, as a first step, a stand-alone course in mining and sustainability. The Department continued its efforts to integrate environmental and cultural issues into technical courses as a norm [43]. Also, MSc education programs dedicated to mineral resources and sustainability were developed, which were supported, on several occasions, by initiatives like the European Institute of Innovation and Technology (EIT) and EIT Raw Materials, e.g. OpenYourMine, geomatics for mineral resource management and entrepreneurship, innovation and technology integration in mining [44]. Nevertheless, there are challenges and barriers towards incorporating sustainability principles in RM curricula, like in other engineering disciplines. In general, some curricula offer coverage of sustainability issues in a specific, i.e. stand-alone, course, while others involve sustainability in existing courses, tailored to the nature of each course [45–47].

3. Materials and methods

The successful implementation of the SD principles requires the involvement of all stakeholders of the RM sector [48,49]. Thus, towards identifying the factors interacting in the RM whole value chain SDGs-education-innovation system, information was collected from focus group interviews following a two-stage approach, as mentioned. The focus group comprised of five stakeholder representatives from academia (students and academic staff), industry and professionals, taking into account that the guidance on group size is between a minimum of four and a maximum of twelve participants [50–52]. Students' engagement is critical for achieving sustainable changes in the curriculum of HEIs not only because students need to be aware of EESD benefits but also because the cooperation between students and academic staff in forming the curricula can enhance engagement and motivation [53] and lead to improved assessment performance [54]. The academic staff has a crucial role in the diffusion of SD principles, as the staff awareness of SD affects the pedagogical techniques used to activate and motivate the students. The engagement with the RM industry and professionals is also an essential organisational issue for universities to consider when integrating SD within engineering education [55]. The industry is the main critical stakeholder applying the SD principles, while engineering students consider the industrial experience highly valuable [56].

The perceptions, opinions and beliefs of representatives of the main stakeholders were explored in the context of online focus group discussions, due to social distancing measures adopted to control the spread of COVID-19. At the first stage, the participants expressed their opinions and beliefs regarding the educational needs and challenges for the achievement of SDGs in the RM sector through semi-structured interviews. In this context, ten specific questions were prepared (see Appendix I) considering the priority action areas established by the Global Action Programme on ESD [57]. The research questions were framed by the SD awareness, opinions and perceptions of the research target groups, the role of stakeholder partnerships, the benefits of internships and the assessment of curriculum structure and content according to the SD principles.

At the second stage, the participants were asked, using the Fuzzy Cognitive Maps (FCMs) approach, to identify the main components of the RM whole value chain SDGs-education-innovation and their interrelationships. The FCMs is a popular method used for studying the structure and behaviour of complex systems introduced by [58]. FCMs present a high ability to demonstrate complexity, are not time- and resource-intensive to develop and are considered generally easy to instruct by interviewers and understand by stakeholders [59]. FCMs have gained considerable interest in a wide range of fields, e.g. environmental management, energy planning, political and social sciences, marketing, engineering, medicine and many others [60–69]. FCMs approach has also been used in educational studies. For instance, Cole and Persichitte [70] examined the potential use of FCMs in educational organization settings as means to facilitate conceptual change for educational technologists. Laureano-Cruces et al. [71] used a FCM to represent the conduct of an expert that evaluates the results of the teaching-learning process within a reactive learning environment. Pacheco et al. [72] used FCMs for the study, plan and formative assessment of the teaching/learning environment. Tsadiras and Stamatis [73] examined the interactions and causal relations among various key networked learning factors both statically and dynamically based on the knowledge extracted by a domain expert. Yesil et al. [74] employed the FCM approach to model the control engineering educational critical success factors. Gordaliza and Flórez [75] explored the possibilities offered by FCMs in the field of science education. Dias et al. [76] examined whether the structural characteristics of an FCM can efficiently model the way learning management systems can support online learning environments at higher education institutions. Mourhir and Kissani [77] built FCMs by academic staff and students to assess whether soft skills are introduced, reinforced or emphasized in engineering curricula.

FCMs are signed fuzzy digraphs which consist of nodes C_i, $i = 1 \ldots N$, where N is the total number of nodes and connecting edges. More explicitly, the nodes represent the components (also known as concepts or factors) of the system under investigation. The connecting edges represent the causal relationships among the components. Each interconnection between two concepts C_i and C_j has a weight, a directed edge W_{ij}, which is similar to the strength of the causal links between C_i and C_j and takes values in the interval $[-1, 1]$. The direction of causality indicates whether the concept C_i causes the concept C_j or vice versa. W_{ij} can be:

- less than 0 indicating a negative effect of the one concept to the other (i.e. when the value of C_i increases, the value of C_j decreases)
- greater than 0 indicating a positive effect (i.e. when the value of C_i increases, the value of C_j increases, as well)
- equal to 0 (indicating no causal relation between the concepts)

The structural properties of FCMs can be analysed based on graph theory and networks analysis indices such as the number of concepts and connections between them, the complexity index, the indegree and outdegree values, etc. [58,68,78,79].

Besides the static analysis, FCMs can be used to model the dynamic evolution of the concepts' interplay and make inferences about causation from any given set of initial conditions that may represent a policy or program. In this sense, "what-if" scenarios can be investigated, based on the activation levels of concepts at the final state and/or changes in the activation levels throughout the simulation concerning either all concepts or a subset of concepts of interest [69,79]. The simulation aims mainly to identify the general pattern of the system's behaviour via the achieved values of the FCM's concepts and not to produce exact quantitative values [69].

The input vector is 1 by n, the FCM adjacency matrix is $n \times n$, and the output is 1 by n [69]. The value A_i of each concept C_i in a moment $t + 1$ is calculated by the product of the value A_j of the cause node C_j in precedent moment t and the value of the cause-effect link w_{ij}, as follows in a memoryless process [80,81]:

$$A_i^{(k+1)} = f\left(\sum_{\substack{j \neq i \\ j=1}}^{N} A_j^{(k)} W_{ji}\right)$$

where $A_i^{(k+1)}$ is the value of concept C_i at simulation step $k + 1$, $A_i^{(k)}$ is the value of concept C_j at step k, W_{ji} is the weight of the interconnection between concept C_j and concept C_i and f is an activation threshold function (e.g. a sigmoidal function in this case, which gives values of concepts in the range [0,1]).

The algorithmic procedure consists of five steps [69], which is repeated until the minimum error difference among the subsequent concepts reaches a predefined level.

4. Results

4.1. Semi-structured interview findings

4.1.1. Integrating sustainability thinking into the traditional engineering curriculum

All the participants agreed that it is quite important to integrate sustainability thinking into the traditional engineering curriculum. The representatives from industry and professionals highlighted that it is a prerequisite for RM engineers to be familiar with the SD principles and that this knowledge should be provided by the RM curricula. The representatives from academia recognised the need to enhance the knowledge offered by the existing curriculum with regards to sustainability [82]. So far, the emphasis of the existing curriculum is placed on technological issues (e.g. reuse and recycling of raw materials), ignoring or underestimating the role of important SDGs, such as decent work and economic growth, responsible consumption and production, reduced inequality, etc.

The focus group participants were also asked to express their views on how the SDGs could be actively incorporated and promoted through the curriculum. More explicitly, they were asked to comment whether they considered that SDGs should be taught through all (or as many as possible) the courses of the curriculum (even purely engineering ones) or as a separate course on its own. All the participants agreed that if the only modification made would be a stand-alone course this would be ineffective because SD is a multidimensional topic embracing technical, financial, social, environmental and other areas. In the participants' opinion, what is needed is a compulsory course that would provide the students with the basic knowledge about SD and a "horizontal inclusion" of the SD principles across all technical and non-technical courses. Further, practically all participants underlined the important role of faculty members and the need to be at least familiar with the principles of SD to embed them into their courses.

Finally, the participants discussed the importance of internship towards gaining a better understanding of the role of SDGs for the RM sector. All the participants stressed the role of internship not only in the career path of RM students but also – and mainly to – the implementation of SDGs by the RM sector. The students, through internships, get an idea of how the RM sector deals with the SDGs and start thinking about their role, as engineers, in improving the sustainability performance of the sector. Thus, internship serves as a bridge between the university and the industry because it provides the students with the opportunity to apply the knowledge they have gained at the university in real-life cases. However, they also mentioned that the existing duration of internships offered by the School of Mining and Metallurgical Engineering of NTUA (i.e. one month) is simply not enough. To their opinion, the internship for RM engineering studies should last at least two and optimally six months.

4.1.2. The role of RM graduates in the context of SDGs implementation

Due to the multidimensional nature of SD, a series of questions were addressed to the focus group participants towards exploring the role of RM graduates in the implementation of the SDGs in the RM sector. First, the participants were asked to comment on the importance of soft skills for RM graduates. All the participants replied that soft skills possess a major role in the implementation of the SDGs. RM engineers must have the ability not only to find the best solution from an environmental, technical and economic perspective but also to effectively communicate this solution to different stakeholder groups. As was characteristically mentioned, even the best solution is condemned to fail if it's not supported by an effective communication strategy. Moreover, it was referred that social skills are necessary because they provide RM engineers with the ability to understand and to interpret the meaning of SDGs. The participants, and especially those coming from academia, argued that the existing curriculum does not offer the students the ability to develop soft skills and that systematic efforts should be put in place to improve this drawback.

Among the soft skills, the ability to work in multidisciplinary teams received particular attention. The implementation of SDGs is a complex issue and requires the joint contribution of different disciplines and stakeholders. It is, thus, more than necessary for RM graduates to understand the different "languages" and the diverse perspectives that other scientists and professionals bring to successfully collaborate with them. Similarly, the participants also mentioned the importance of RM graduates adopting and following a standard of professional behaviour and code of ethics. Their views were primarily based on the argument that SD itself establishes an ethical system. However, it was referred that even though ethical issues related to SD can be taught, ethics is more or less up to the individual.

The role of innovation and Lifelong Learning (LLL) for the implementation of SDGs by the RM sector was also discussed. All the participants underlined the significance of innovation as a means to accelerate the implementation of SD principles. In regards to LLL, the participants underlined its necessity especially in educating the employees of the sector and exposing the wider public in the principles of SD. Many RM engineers, aged more than 35 years, do not have the knowledge and competencies required to implement the principles of SD in their workspaces. LLL could, therefore, help to remove the obstacles to SD. Participants from academia and professionals proposed that RM schools should undertake initiatives and prepare appropriate programs in this direction.

4.1.3. The role of the external environment

The focus group drew attention to the role of the external environment. Two issues were examined, namely the importance of policies and legislation and the importance of the commitment of the RM sector to the principles of SD as a means for incorporating the SDGs in the curriculum of the RM schools/departments.

Concerning legislation and SD policies, all the participants stated that they play an important role. The participants from academia, in particular, indicated that (at least) some curriculum courses are reorganised in an attempt to incorporate recent developments in environmental policies and regulations. From this viewpoint, it becomes evident that education and exposure to SD policies may act as a catalyst for promoting SD principles in RM graduates. Focusing on the commitment of the RM sector to the principles of SD, all the participants were adamant that the implementation of SD principles is a must for the RM sector. Consequently, and in order to ensure the sustainable development of the sector, RM engineers with comprehensive knowledge of sustainability principles, related soft skills, innovative thinking and strong professional behaviour play a pivotal role.

4.2. FCM analysis

At the second part of the interviews, the stakeholder representatives identified, in total, fifteen components of the RM whole value chain SDGs-education-innovation system, as follows:

- SDGs curriculum enhancement (F1)
- Courses content and teaching methods (F2)
- Increase in employment opportunities (F3)
- SDGs-related legislation and policies (F4)
- Inclusion of SDGs examples in many courses (F5)
- SDGs separate courses (F6)
- Implementation of SDGs by the RM sector (F7)
- Industry-HEIs collaboration (UBC) (F8)
- Ethics code development (F9)
- Faculty knowledge about SDGs (F10)
- Soft skills (F11)
- Internship (F12)
- Lifelong learning (LLL) (F13)
- Social pressure for SD (F14)
- Social acceptance of RM sector (F15)

The concepts cover a wide range of issues from teaching approaches and curriculum structure to social pressure for SD and social acceptance of the RM sector. After having identified the components of the systems, the participants were asked to define the causal links between the components and to assess the strength of these causal relationships, in the interval [−1, 1]. In particular, the experts were asked to assign the strength of influence of concept C_i on concept C_j using the following form "the strength of influence of concept C_i on concept C_j is T {influence}", where the variable T{influence} declares the causal inter-relationships among employing a fuzzy linguistic variable with nine linguistic levels, as follows: negatively very strong, negatively strong, negatively medium, negatively weak, zero, positively weak, positively medium, positively strong, positively very strong.

Both the causal links and the weights were defined after deliberation by consensus. The FCM as agreed by the participating Greek stakeholders is illustrated in Fig. 1, created with the Pajek software (http://mrvar.fdv.uni-lj.si/pajek/). The matrix of the

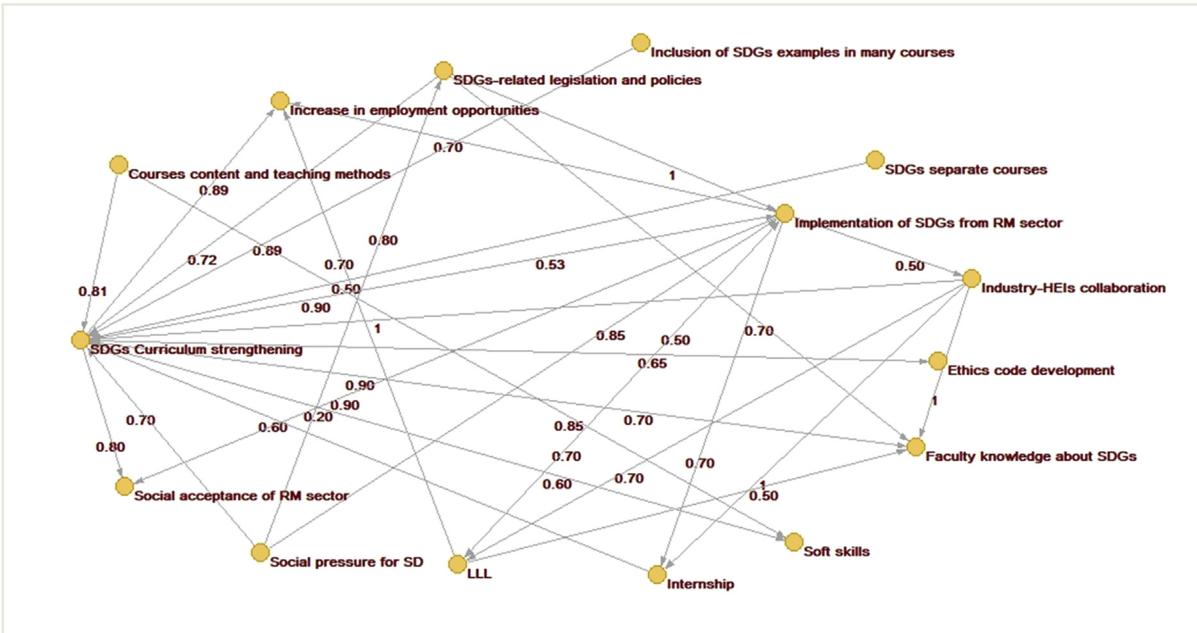

Fig. 1. The FCM of the EnAct — SDGs Greek stakeholder representatives.

weight of interconnections (i.e. adjacency matrix) is presented in Table S1 of the Supplement.

According to the participating stakeholders, the enhanced incorporation and strengthening of the SDGs in RM curricula is affected, in order of importance, by the collaboration of HEI and Industry (UBC), the implementation of the SDGs by the RM industry, the knowledge of the academic staff about the SDGs, the use of SDGs' examples in as many courses as possible, the content of the courses and the teaching methods, the existence of SDGs related policies and legislations, the social pressure for SD, the internships, the existence of a stand-alone SD course and the development of soft skills to the students. Moreover, the participants believe that the strengthening of the SDGs in RM curricula has a positive impact on the employment perspectives of RM graduates, the social acceptance of the RM sector, the knowledge of the academic staff about the SDGs, the development of ethics code and the implementation of the SDGs by the RM industry.

Selected graph theory indices obtained from the Greek stakeholders FCM developed within the EnAct Project, Greek FCM, are given in Table S2 of the Supplement, while the most central concepts are presented in Table 1.

The most central variable of the Greek FCM is as expected — the SDGs curriculum strengthening with a centrality of 11.4. The other five most central

Table 1. The most central concepts in the Greek FCM.

Concepts	Outdegree	Indegree	Centrality
SDGs curriculum strengthening	4.17	7.22	11.39
Courses content and teaching methods	1.66	0.00	1.66
Increase in employment opportunities	0.00	2.29	2.29
SDGs related legislation and policies	2.42	0.80	3.22
Inclusion of SDGs examples in many courses	0.89	0.00	0.89
SDGs separate courses	0.50	0.00	0.50
Implementation of SDGs by the RM sector	4.40	2.88	7.28
Industry-HEIs collaboration	3.70	0.50	4.20
Ethics code development	0.00	0.65	0.65
Faculty knowledge about SDGs	0.90	2.90	3.80
Soft skills	0.20	1.45	1.65
Internship	0.60	1.70	2.30
Lifelong learning (LLL)	1.70	1.40	3.10
Social pressure for SD	2.35	0.00	2.35
Social acceptance of RM sector	0.00	1.70	1.70

concepts are (in order of significance) the implementation of SDGs by RM sector, the industry-HEIs collaboration, the faculty knowledge about SDGs, the SDGs related legislation and policies and the lifelong learning (LLL). The most influencing factors, as shown by the outdegree values, are (in order of significance) the implementation of SDGs by RM sector, the SDGs curriculum strengthening and the industry-HEIs collaboration.

A number of simulations were then conducted focusing on the transient behaviour of the system during the iteration steps by means of the FCM tool, a software that works in Matlab environment [83]. In this process, known as clamping by [58], critical variables are gradually increased or decreased and the values of the final state are compared to the steady-state vector [84]. In all simulations, the initial values used for the concept under investigation were sequentially set to 0, 0.25, 0.5, 0.75 and 1, representing possible situations, i.e. from zero to the highest possible level. The simulation process took place for the most important factors and more specifically for three external (i.e. industry-HEIs collaboration, implementation of SDGs by the RM sector and SDGs related legislation and policies) and two internal university environment factors (i.e. faculty knowledge about SDGs and inclusion of SDGs examples in many courses).

The results of the simulations are presented in Figs. 2–6 and discussed hereinafter.

As illustrated in Fig. 2, clamping industry-HEIs collaboration has practically no effect on the SDGs curriculum strengthening, as well as on the rest of the parameters except for the internship, LLL and faculty knowledge about SDGs. Specifically, clamping the industry-HEIs collaboration to a low up to a medium level has a negative and significant effect (i.e. the relative change is 5% and 15%), on internship, LLL and faculty knowledge about SDGs, whereas clamping the same factor to the highest level, has a positive effect mainly on internship and LLL.

The implementation of SDGs by the RM sector factor has a more notable effect on five factors of the system, namely the internship, LLL, industry-HEIs collaboration, social acceptance of the RM sector and increase in employment opportunities, as shown in Fig. 3. In all states but the highest level, the implementation of SDGs by the RM sector has a negative influence on the above-mentioned factors. More specifically, when the implementation of SDGs by the RM sector is set to the lowest level (i.e. the RM sector does not adopt the SDGs), the final stage values are reduced by around 20% or more, compared to those recorded when the implementation of SDGs by the RM sector is set to the highest level (i.e. the RM sector fully adopts the SDGs). Hence, although the direct impact on the SDGs curriculum strengthening is relatively low, the reduction in the implementation of SDGs by the RM sector has a significant and negative effect on critical factors of the RM whole value chain SDGs-education-innovation eco-system that could jeopardise its sustainability.

As regards the SDGs related legislation and policies (Fig. 4), the relative changes are markedly higher only for the implementation of SDGs by the RM sector and the faculty knowledge about SDGs. The analysis shows that not only the interest of the RM industry but also the interest of the academic personnel are affected by the existence (and of course the implementation) of the SD legislative

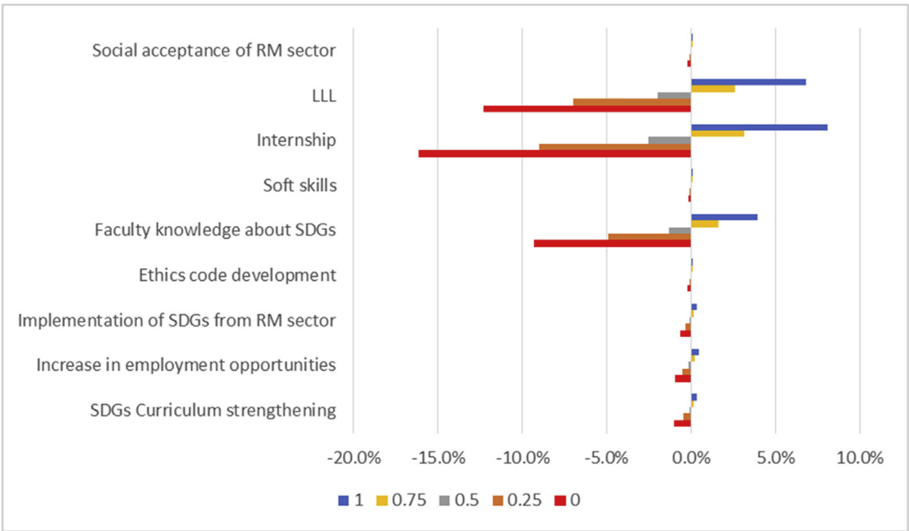

Fig. 2. The effect of industry-HEIs collaboration on the other concepts of the FCM.

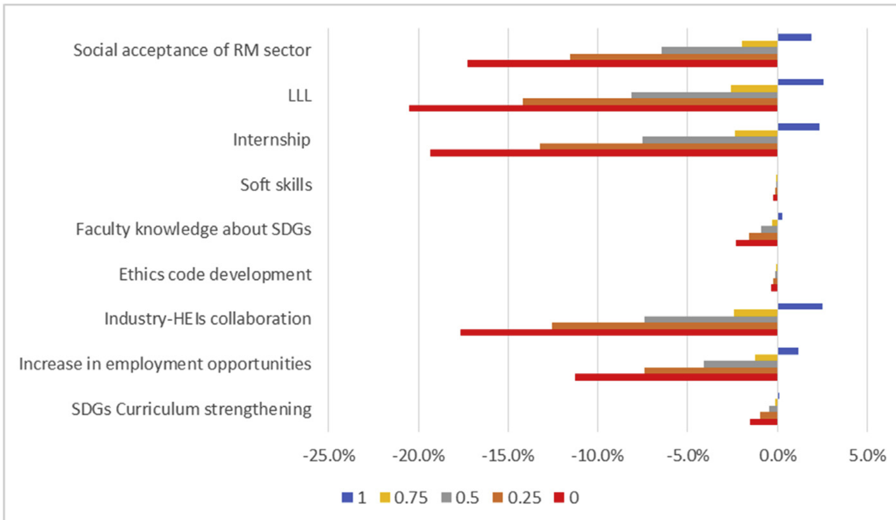

Fig. 3. The effect of Implementation of SDGs by the RM sector on the other concepts of the FCM.

framework. The impact of this parameter on the other factors, including the SDGs curriculum strengthening is negligible. Therefore, and despite the fact that the impact of this factor on the SDGs curriculum strengthening is insignificant, the application of SDGs related legislation and policies deserves certain attention because the other affected factors are of high importance.

According to Figs. 5 and 6, the effect of the internal university environment factors on the SDGs curriculum strengthening as well as on the other parameters is not significant. More specifically, in both cases, the relative change on the SDGs curriculum strengthening between the lowest and the highest clamping levels is around 1%, which is considered as the same as the impact of the other factors tested.

As a general remark, it could be argued that the impact of the factors associated with the SDGs Curriculum strengthening is not significant when considering *ceteris paribus* changes. However, the results may be remarkable when examining "worst-case" scenarios, i.e. situations where more than one critical factors are unfavourable. For instance, setting simultaneously the most important external and internal university environment factors to a low level (e.g. less than 0.25) results in relative changes of around 15% for the SDGs curriculum strengthening and up to 40% for the internship and the LLL.

5. Conclusions

The present paper aims to identify the educational needs and challenges faced by RM faculties for incorporating the SDGs into their curricula and the impact of the various external and internal factors in this procedure. The analysis is based on the opinions and beliefs of key stakeholders from the Greek academia, industry, and professionals, using information collected through semi-structured group discussions and developing the FCM of the RM whole value chain SDGs-education-innovation system within the EnAct-SDGs project.

All the stakeholders share the view that it is quite important to integrate sustainability principles into the RM engineering curricula and this should be considered a priority in the educational process. In particular, the representatives from the industry and the professionals highlighted the significance of SD principles for the RM sector and pointed out that exposure and use of the SD principles is a prerequisite for RM engineers. The analysis indicated that this has also a direct effect on students' satisfaction. However, it was argued that regarding the existing curriculum of the Greek RM Engineering School examined, School of Mining and Metallurgical Engineering, NTUA, only a few courses provide the basics of SD principles, so far. The academic participants recognised that although theoretical and technical knowledge remains an important asset for RM engineers, the need to strengthen the knowledge offered in the RM faculties with regards to sustainability and soft skills is undisputed. Therefore, the critical challenge faced nowadays by the RM Engineering departments in Eastern and Southeastern Europe, Greece included, is to ensure the right balance in their RM study programs.

Regarding the teaching approaches used to enhance RM students' skills towards the achievement of the SDGs, the stakeholders generally agree

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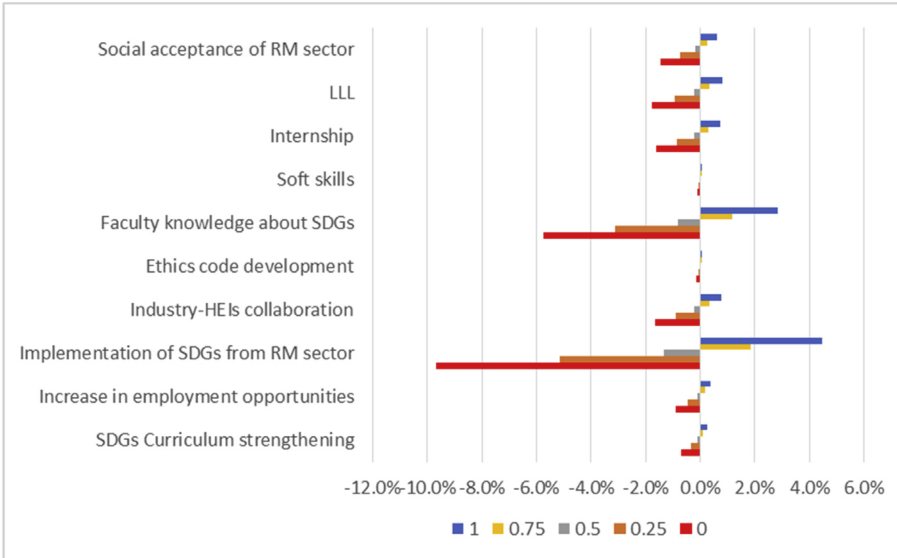

Fig. 4. The effect of SDGs-related legislation and policies on the other concepts of the FCM.

that SD principles should be actively incorporated and promoted through as many technical courses as possible. Nevertheless, it was noted that a compulsory course that would introduce the role of SD and the basics of the SDGs would also contribute towards this direction. As far as the teaching methods are concerned, the academic staff participating in the interviews and the design of the FCM suggested that the most appropriate methods for sustainability teaching are, as follows: running a student virtual mine, conducting a cost-benefit analysis, linking the applications to industrial practice and reviewing scientific articles related to SD. These teaching methods can be used to improve the knowledge and awareness of students about social, environmental, and economic sustainability through the application of sustainable engineering practices in an interdisciplinary framework. These methods could also contribute to knowledge, skills, and personal development in the areas of theoretical and technical knowledge, soft skills and decision-making techniques. In the same direction, it was mutually agreed that the internship is important not only to the career path of RM engineering students but also – and mainly to – the implementation of SDGs by the RM sector and to the enhancement of

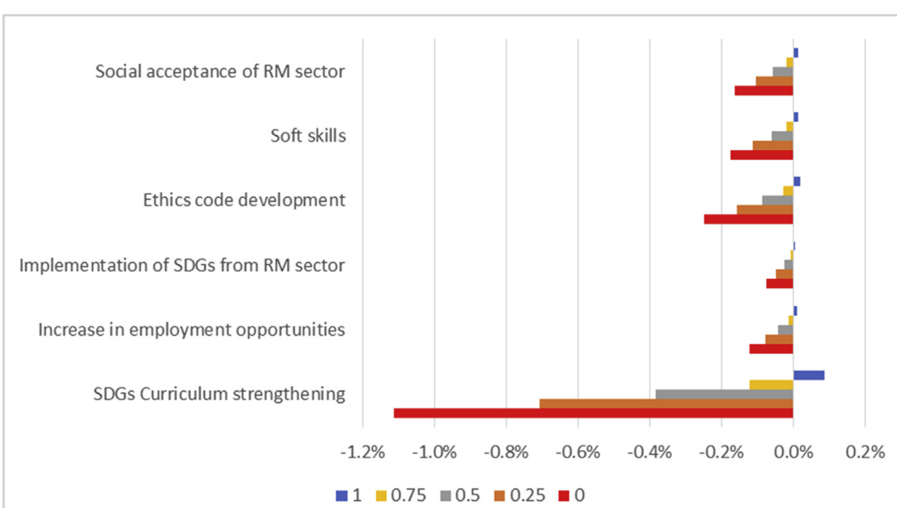

Fig. 5. The effect of faculty knowledge about SDGs on the other concepts of the FCM.

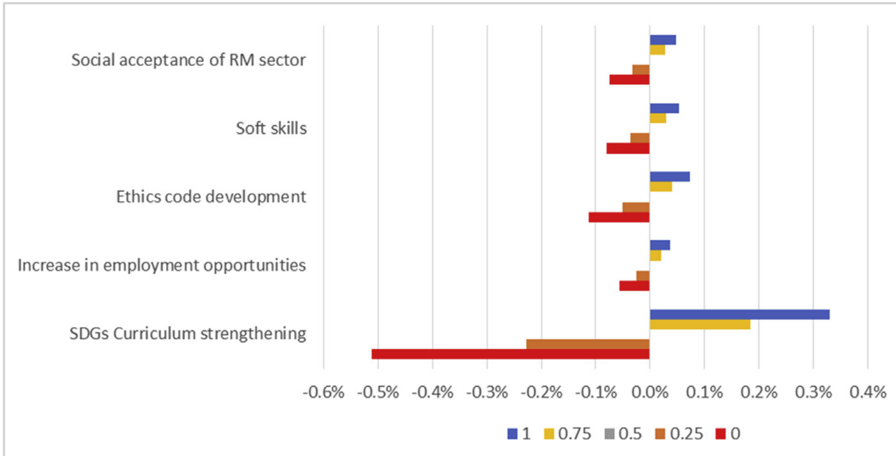

Fig. 6. The effect of inclusion of SDGs examples in many courses on the other concepts of the FCM.

cooperation between academia and industry. The students, through internships, have a first view on how the RM sector deals with the SDGs and are given the opportunity to start considering their role, as engineers, in improving the sustainability performance of the extractive industry. Further, all the stakeholders considered soft skills fundamentally important for RM engineers since they provide them with the ability to comprehend and interpret the concept of SD and, therefore, play a critical role in the SDGs implementation. Finally, all the participants stressed the importance of LLL especially when taking into account the rapid changes in technology and the future challenges to be faced by the RM sector, noting that LLL could help RM graduates to remove the obstacles towards SD.

The FCM approach offered the means to explore the fifteen factors identified by the stakeholders in the RM whole value chain SDGs-education-innovation system and the interactions between them. The FCM modelling also provided the tool to elucidate the role of the factors interacting in the above RM system. More specifically, the dynamic evolution of the system using the clamping process showed that *ceteris paribus* changes do not result in significant alterations in the SDGs curriculum strengthening. Nevertheless, if more than one critical factors are simultaneously found in unfavourable conditions then the influence on the SDGs curriculum strengthening could be important. From a policy perspective, it was concluded that external university environment factors, such as the industry-HEIs collaboration, the implementation of SDGs by the RM sector and the SDGs-related legislation and policies may significantly affect other important factors of the system like the LLL, the internship and very importantly the social acceptance of the RM sector and the increase in employment opportunities.

To the authors' best knowledge, this is the first attempt to apply the FCM method to this topic indicating the need for further research into the interacting factors impacting the RM whole value chain SDGs-education-innovation system. The model presented in this article reflects the particular characteristics and opinions of the stakeholders of the RM sector in Greece and was developed by participants from academia, students, industry and professionals. In this direction, it is suggested to expand the number of focus groups from different stakeholders, and countries and create separate FCMs per group as a means to further evaluate the factors impacting the incorporation of the Sustainable Development Goals into Raw Materials Engineering Curricula.

Conflicts of interest

None declared.

Ethical statement

Authors state that the research was conducted according to ethical standards.

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Appendix I.

Questions posed during the discussion about the educational needs, i.e. the areas that need to be enhanced in the curriculum of RM schools/departments to strengthen the skills and competencies of RM graduates and successfully achieve the implementation of SDGs by the RM sector.

Q1. How important (and why) is it to integrate sustainability thinking into the traditional engineering curriculum of the RM schools/departments?
Q2. Should SDGs be actively incorporated and promoted through all (or as many as possible) the courses of the curriculum (even purely engineering ones) or as a separate course on its own? What are the pros and cons of each approach?
Q3. How important (and why) is the commitment of the RM sector to the principles of Sustainable Development for incorporating the SDGs in the curriculum of the RM schools/departments?
Q4. How important (and why) is the role of policies and legislation for incorporating the SDGs in the curriculum of the RM schools/departments (e.g. do the RM schools consider the evolution of environmental legislation/policy when preparing/updating their curricula?)
Q5. How important (and why) is it for RM graduates to have acquired soft skills (e.g. ability to communicate with competent authorities, local communities and other stakeholders, emotional intelligence, etc.) in the context of SDGs implementation?
Q6. Is the internship important (and why) for understanding better the role of SDGs for the RM sector?
Q7. Is the role of Life Long Learning (LLL) important (and why) for the implementation of SDGs by the RM sector?
Q8. How important (and why) is it for RM graduates to have the ability to work in multidisciplinary teams in the context of SDGs implementation?
Q9. Is it important (and why) to increase the creativity and ability of RM graduates to innovate towards achieving the implementation of SDGs by the RM sector?
Q10. How important (and why) is it for RM graduates to perform under a standard of professional behaviour and code of ethics for achieving the implementation of SDGs by the RM sector?

Supplement

Table S1. The adjacency matrix of the "RM whole value chain-SDGs-education-innovation" system, as developed by the participating Greek stakeholders.

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15
F1	0.00	0.00	0.89	0.00	0.00	0.00	0.53	0.00	0.65	0.70	0.60	0.00	0.00	0.00	0.80
F2	0.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.85	0.00	0.00	0.00	0.00
F3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F4	0.72	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.70	0.00	0.00	0.00	0.00	0.00
F5	0.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F6	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F7	0.90	0.00	0.70	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.70	0.70	0.00	0.90
F8	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00	0.70	0.00	0.00
F9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F10	0.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F11	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F12	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F13	0.00	0.00	0.70	0.00	0.00	0.00	0.50	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.00
F14	0.70	0.00	0.00	0.80	0.00	0.00	0.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table S2. Graph theory indices for the Greek FCM.

Density	Complexity	Total Nr. Factors	Total Nr. Connections	Nr. Transmitter	Nr. Receiver	Nr. Ordinary
0.142	0.75	15	32	4	3	8

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