Editorial

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We are pleased to present a special issue of the *International Journal of Product Lifecycle Management*, entitled 'Sustainability along the product lifecycle'. The management of sustainability issues is increasing attention over the last years. Several approaches have been studied to face with the related challenges, highlighting limitations that often occur if actions are focused on the single-company level instead of the entire process. This special issue is part of an effort to encourage the submission of works related to such topics, overcoming the single-company sustainability vision moving toward a more extended approach.

The special issue is composed of nine papers, and it is structured into two different parts. The first part deals with LCA methodologies applied on different case studies of specific industries, while the second one with the development and validation of general frameworks and decision support tools. In the special issue, an important industry addressed is the coal mining Industry, studied by three presented works. Although necessary for energy purposes, operations of the coal-mining industry are considered especially damaging to the environment. Nonetheless, and due to the pressure received from various stakeholders, the mining industry, and particularly the coal-mining industry,

has been facing stringent challenges regarding sustainability, safety, productivity and welfare of the workforce.

In the *first part* of the special issue, the first two paper deal with estimation of environmental impacts in the coal mining industry, presenting different LCA methodologies applied to two different case studies. In the first work, the research question is centred on interpreting impact analysis results with energy sources using the LCA method in coal mining. These interpretations are categorised as global warming potential, ozone depletion, human toxicity potential, freshwater eutrophication and land use. Therefore, this research aims to investigate the effects of global warming, acidification, eutrophication and eco-toxicity. It supports decision-makers, specifically in fuel, electricity, and water as energy sources, and impacts management schemes in Indonesia. It also uses biodiesel fuel, electricity and water.

The second paper discusses the usefulness of the LCA approach to CO_2 emission for integrating sustainability criteria into the decision-making process of energy supply technologies alternatives in the aluminium industry in West Kalimantan Province. The purpose of the research is to examine the environmental impact of biodiesel-powered excavation and loading equipment and vehicles operating on the haul road, as well as the energy strategy for producing marketable washed bauxite and the resulting unwanted waste. The study, which used SimaPro software to assess CO_2 emission impact directly related to the type and amount of energy consumed by the mining, showed that construction infrastructure, land clearing, and tailings storage facility maintenance all contribute to increased greenhouse emissions. The Malmquist Index study, which used Banxia software to calculate an efficiency score for energy supply technologies in bauxite mining, indicates that hydropower is the best option.

The third paper presents an application of the life cycle sustainability assessment (LCSA) as a decision tool. In the paper, an approach to integrate the performance criteria in the design process of mechatronic systems is presented. In this approach, a method for determining a global sustainability indicator aggregating the indicators of each sustainability dimension is proposed. This global indicator is the LCSA which assesses environmental, economic and social impacts. The proposed approach in this paper considers all lifecycle phases to prevent the phenomenon of impact transfer. It also uses a decision support method to assist the process of selection and calculation of different indicators for each alternative and the comparative analysis of the different investigated alternatives. The proposed approach is applied in a case study consisting in evaluating and comparing two product concepts of milk frother.

The fourth paper presents an environmental lifecycle assessment case study in the construction industry, responsible for high levels of emissions and consumption. The work proposes an environmental lifecycle assessment study, which aims to quantify the environmental impacts of a standard designed external wall and evaluate the use of recycled materials in its insulation layer. An external wall with expanded polystyrene insulation has been chosen. Six environmental impact categories have been considered: ‘acidification’, ‘eutrophication’, ‘global warming potential’, ‘abiotic depletion – elements’, ‘abiotic depletion – fossil fuels’ and ‘ozone layer depletion’. Results show that the reinforced concrete layer has the most significant contribution to all the analysed impact categories. Moreover, comparing the insulation layer with different percentages of recycled expanded polystyrene, it has been found that the impact categories majorly influenced are the ‘global warming potential’ and the ‘abiotic depletion – fossil fuel’.

In the *second part* of the special issue, coming back to the mining industry, the purpose of the fifth paper is to identify how Industry 4.0 digital technologies can help overcome sustainability challenges in the coal mining industry. The research method adopted is the case study, where two coal primary processing plants belonging to the same company in Latin America are compared, one equipped with facilities dating back to the year 1983, the other equipped with updated facilities, commissioned in 2018–2019. The comparison focuses only in current data (2020) from both units, produced under the same managerial and legal conditions. The only difference is the technology. Findings show that the implementation of Industry 4.0 digital technologies reduced variability in quality parameters, water, and energy consumption, waste generation, and harmful emissions. Nonetheless, social implications are contradictory. Digital technologies reduced risks for operators, but the number of accidents did not reduce in the same proportion. The total amount of jobs reduced significantly.

The sixth paper describes the last case study of the special issue, proposing an IoT platform-enabled decision-making for maintenance service delivery in product-service system (PSS) context. PSS offerings are identified as "tangible products and intangible services designed and combined so that they jointly are capable of fulfilling specific customer needs. Additionally, PSS tries to reach the goals of a sustainable development, which means improved economic, environmental and social aspects." Nowadays, being able to guarantee high performance of the assets sold and be responsive to a maintenance request is considered fundamental to keep lasting relationships with customers, especially in a PSS scenario, where service is an important part of the overall offering. Digitalisation offers manufacturers new possibilities for monitoring (remotely) asset behaviour and intercepting failures before they happen. Thus, more and more manufacturing companies are setting-up IoT platforms to collect data and offer services like remote monitoring and/or preventive/predictive maintenance. The paper discusses the case of an Italian manufacturing company that is using an IoT platform to improve its maintenance service offering. Moreover, implications related to the sustainability of the PSS operations and the effects that maintenance has on sustainability are investigated.

The seventh paper focuses on the role of design-for-X approaches as means to increase product sustainability, in particular in relation to the 'reduce' objective within the circular economy '4R' framework. This paper provides two contributions. First, it develops a conceptual framework encompassing 11 levers for the implementation of design-for-X approaches to achieve 'reduce' objectives related to resource efficiency and product lifespan extension. Second, it illustrates a three-step original decision method supporting managers in identifying the best-suited levers in practical cases, based on the relevance associated with different product design priorities. This method is applied to an industrial case study in the machinery sector, showing its practical usefulness.

The eighth paper explore the current scientific literature related to the open product development process in support of sustainability, with a major focus on circular economy, and propose a framework to address the main obstacle emerged from it. More than 130 research articles have been scanned, and more than 50 have been deeply analysed. One of the main gaps discovered in the studied literature is the lack of shared information about materials. For this reason, the authors propose a framework for the establishment of a digital identity of materials by means of cyber-physical systems employed along the material lifecycle. In this way, material-related information in all the lifecycle phases can be collected and stored in a material passport to increase value chain

transparency and allow resources traceability. Sharing material passports in a digital platform would form an internet of materials that would support designers and engineers in developing more sustainable products.

The last contribution of this special issue addresses functional and technical requirements in the maritime industry. The paper define a set of life cycle centred technical and functional requirements aimed to facilitate the realisation of sustainable vessel creation developed from the results of a comprehensive literature review and focus group with maritime vessel designers and engineers. It consists of a set of requirements that consider the operationalised middle of lifecycle phase of maritime vessels through a set of high-level implementation guidelines to be considered to ensure environmental regulation and compliance to the UN sustainability goals. The aim of the paper is to increase the comprehensive consideration of life cycle thinking in the maritime industry in a way that can increase and extend value to multiple stakeholders.

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