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Making real progress toward more sustainable societies using decision support models and tools: Introduction to the special volume

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Abstract

Academics, politicians, professionals and the general public are aware that without stewarding our planet's natural resources, man is on the pathway towards a global collapse. Over the next three decades mankind is expected to consume an estimated 140 billion tons of minerals, ores, fossil fuels and biomass per year – three times current consumption. Social welfare and human wellbeing are threatened with the scarcity of natural resources; consequently, nations and their societies are also at risk of collapse. The readers of this special volume will find a compilation of scholarly research papers with real-life applications that take the challenge of proposing decision-making models and tools to address sustainability challenges in integrative ways. The main focus of this special volume is integration of sustainability dimensions (economic, social, environmental, ethical and time) into decision-support models and to identify pathways to achieve more sustainable societies. The majority of the research in this special volume, 74 percent, focuses on environmental and economic dimensions. Only 26 percent integrated social dimensions with them. Methodologically, a range of mathematical models and tools are presented to support prescriptive decision-making, with some descriptive models integrated, to support decision-makers in solving practical problems across a variety of industries and scenarios. The breadth and complexity of issues facing organizations and society requires innovative applications of these methodologies. The concerns cover a spectrum ranging from energy to solid waste management. A multitude of levels from broad-based policy concerns to strategic inter-organizational sustainable supply chain management and significantly, shop floor operational issues are also covered. The variety of problems and solutions exemplifies the potential for modelling and operations research for addressing some of our world's most pressing concerns.

Keywords: sustainability, decision support systems, modelling, formal modelling, quantitative methods, society, operations research, environment

1. Introduction

Sustainability has been a concern of various actors for decades, with its most visible and early incarnation from the Brundtland Report (United Nations, 1987). Since then interest in the topic has seen exponential growth in scholarly research and publications (e.g. Wilkinson *et al.*, 2001; Brandenburg *et al.*, 2014; Carter and Rogers, 2008). The advent of utilizing decision-support and analytical tools has recently seen this growth, as evidenced papers published in the *Journal of Cleaner Production* during its 23-year publishing history.

Sustainability is not only good for the environment and society, but also for organizational economic health. Sustainable corporate practices can help organizations reduce risks, avoid or reduce waste generation, increase material and energy efficiency, and innovate by creating new and environmentally friendly products and services (Gunasekaran and Spalanzani, 2012). Sustainability has been defined in the triple-bottom-line context where organizations should integrate economic, social and environmental objectives into their business strategies and seek to optimize the balance amongst these three dimensions (Székely and Knirsch (2005)). Various actors, academics, politicians, professionals and the general public, have arrived at the realization that managing natural resources such as biodiversity, air, water, energy and other natural resources risk of social, economic, and human health collapse is inevitable.

By 2050 it is expected that mankind will probably consume three times its current annual consumption, or an estimated 140 billion tons of minerals, ores, fossil fuels and biomass per year (UNEP-IRP Report (2011)). To responsibly address this unsustainable consumption issue the economic growth rate needs decoupling from the rate of natural resource consumption. Not only are environmental concerns an issue, but social welfare and human wellbeing are also threatened from scarcity of natural resources. Nations and their societies are at risk of collapse due to these scarcities and inequities of access.

Given these realities, this special volume (SV) presents a compilation of high quality scholarly research papers. These papers and their research targeted practical applications using sustainable decision-making models and tools to aid in green growth, decoupling of economic growth and from environmental burdens, and other sustainability challenges. The main focus of this SV was to encourage researchers and practitioners integrate all sustainability dimensions (economic, social, environmental, ethical and temporal) into decision-support systems to identify, propose and test pathways for achieving more sustainable societal patterns.

2. Reasons for this Special Volume

Given the complex, social, political and economic interactions with natural systems, the need for tools to aid managers and decision-makers is urgent. Practical mathematical models coupled with technological and analytical solutions can be important tools for these real-world decision-makers. It is increasingly evident for many that it is essential to have the right models, tools and methodologies to support decision-making. Going beyond conceptual mathematics and analyses is needed to identify improvement in approaches for implementing real-world solutions.

In this broader social and academic context, the operations research/management science (OR/MS) research community is ready to lead in developing models to deal with various tangible and intangible measures, such as the ‘‘people’’ performance measure. This context increases the OR/MS research opportunity to make important and timely contributions to help organizations and managers achieve holistic, triple bottom line objectives (Tang and Zhou, 2012). In this SV OR/MS is viewed as a scientific approach to support decision-making in complex systems (Altay and Green, 2006).

Assessing and evaluating progress towards more sustainable, green growth societies, can be greatly supported through the proper environmental-economic-social monitoring and analytical support tools. These tools are necessary to guide key decision-makers to make the right actions and improvements towards sustainable societal lifestyles (Klemeš et al., 2012). In this context, mathematical models and solution methods were reviewed and used to provide quantifiable information for the decision-makers to provide them structured opportunities to evaluate, propose, test and implement actions that balance the complex economic-environmental-social interactions with a variety of man-made and natural systems.

Triple bottom line (TBL) impacts of managerial and policy decisions and practices can be effectively analysed and managed through appropriate use and development of quantitative formal modelling assessment methodologies to support decision-making. The need for suitable analytical, formal, and simulation models of sustainable business development decisions and making optimal decisions based upon full quantification of the short and long-term various costs and benefits of their actions has become increasingly evident. The relative scarcity of sustainable business development in this arena has been recognized (Gunasekaran and Spalanzani, 2012) and this SV helps to fill this gap in this research area.

To effectively envision, propose and implement solutions for making progress on forming more sustainable societies requires the capacity of increasingly complex mathematical models and decision-support systems. This theme is consistent with requirements identified by various researchers' articles in this SV. It is expected that increasingly complex mathematical tools need to be utilized to 'solve' sustainability challenges. Yet, the complexity should not undermine their usefulness and practical feasibility. From a practical viewpoint, the transition to using these concepts and tools by businesses, institutions and governments will be based on how user-friendly and effective decision-support models and tools can be integrated into their practice.

Another, implicit, reason for this SV was that much of this work establishes the foundation for future research. The complexity of the problems documented by the researchers in this SV requires that they address all sustainable issues in a comprehensive way. Yet, clearly there are limitations to all models that pursue such an ambitious goal. Each model has its limitations and these limitations identify further gaps in the research that need to be bridged. In addition, these works set the foundation for additional future research. This SV is a modest contribution to construct a fruitful bridge for knowledge exchanges between operations researchers, operations managers, decision analysts, and decision-makers. Alas, as a research community, we need to be able to stand on each other's shoulders to help us achieve the goal of a sustainable world. In terms of historical timelines, we are still very early in this process, especially when it comes to sustainable societal transformations.

3. Overview of the Papers in this Special Volume

The 38 papers for this SV are summarized and evaluated using two major thematic areas: (1) sustainability approaches and (2) methods and tools for decision-support. The first categorization focuses on an overview of the articles and how they address sustainability dimensions. The second summation category focuses how the papers utilize analytical models and their contributions. Most of the papers have contributed to multiple aspects, as shown in Table 1. Each paper shown in Table 1 is also classified based on the general analytical approach used. The remainder of this section highlights how each article of the SV contributed to sustainability (in section 3.1) and to new tools and methodologies (in section 3.2).

Table 1 - Papers in this Special Volume classified by Methods and Tools for supporting decision- making

Author	Title	*Optimization Models*	*Simulation and heuristics*	*Multi-criteria Decision Analytical Approaches: ANP,*	*Individual LCA-based*	*Integrated LCA-based*	*Soft O.R.-based techniques*
Abdulrahman, Subramanian, Liu and Chiu	Viability of remanufacturing practice: a strategic decision making framework for Chinese auto-parts companies			X			
Arafat, Jijakli and Ahsan	Environmental Performance and Energy Recovery Potential of Five Processes for Municipal Solid Waste Treatment				X		
Aras, Korugan, Büyüközkan, Şerifoğlu, Erol and Velioğlu	Locating recycling facilities for IT-based electronic waste in Turkey	X					
Camacho-Vallejo, González-Rodríguez, Almaguer and González-Ramírez	A Bi-level Optimization Model for Aid Distribution after the Occurrence of a Disaster.	X					
Chandran, Hoppe, De Vries and Gorgiadou	Conflicting Policy Beliefs and Informational Complexities in Designing a Transboundary Enforcement Monitoring System						X
Fikar and Hirsch	A metaheuristic for routing real-world home service transport systems facilitating walking		X				
Golinska, Kosacka, Mierzwiak and Werner-Lewandowska	Grey Decision Making as a tool for the classification of the sustainability level of remanufacturing companies			X			
Guerrero-Baena, Gómez-Limón and Fruet	A multicriteria method for environmental management system selection: an intellectual capital approach			X			
Janeiro and Patel	Choosing sustainable technologies. Implications of the underlying sustainability paradigm in the decision-making process						X
Jawad, Jaber and Bonney	The Economic Order Quantity Model Revisited: An Extended Exergy Accounting Approach	X					
Kundu, SenGupta, Hashim and Redzwan	Taguchi optimization approach for production of activated carbon from phosphoric acid impregnated palm kernel shell by microwave heating		X				
Lam and Lai	Developing Environmental Sustainability by ANP-QFD Approach: the Case of Shipping Operations			X			
Lambrecht and Thißen	Enhancing sustainable production by the combined use of material flow analysis and mathematical programming	X					
Liu, Dang, Li, Lian, Evans and Yin	Production Planning of Multi-stage Multi-option Seru Production Systems with Sustainable Measures	X					
Liu, Xie and Liu	A method for predicting the energy consumption of the main driving system of a machine tool in a machining process	X					
Luo, Huang and Zhang	Energy Cost Optimal Operation of Belt Conveyors using Model Predictive Control Methodology	X					

Madan, Mani, Lee and Lyons	Energy Performance Evaluation and Improvement of Unit-Manufacturing Processes: Injection Moulding Case Study						X
Martin	Incorporating Values into Sustainability Decision-Making						X
Moreira, Santa-Eulalia, Aït-Kadi and Wang	A conceptual framework to develop green textiles in the aeronautic completion industry: a case study in a large manufacturing company						X
Mota, Gomes, Carvalho and Barbosa-Povoa	Towards supply chain sustainability: economic, environmental and social design and planning	X					
Munisamy and Arabi	Eco-efficiency Change in Power Plants: Using A Slack-Based Measure for the Meta-Frontier Malmquist Luenberger Productivity Index			X			
Neshat and Amin-Naseri	Cleaner Power Generation through Market-Driven Generation Expansion Planning: An Agent-Based Hybrid Framework of Game Theory and Particle Swarm Optimization	X					
O'Driscoll, Kelly and O'Donnell	Intelligent energy based status identification as a platform for improvement of machine tool efficiency and effectiveness		X				
Paraskevas, Kellens, Dewulf and Duflou	Environmental Modelling of Aluminium Recycling: A Life Cycle Assessment Tool for Sustainable Metal Management	X					
Poplawska, Labib, Reed and Ishizaka	A dynamic framework for stakeholder identification and salience measurement using fuzzy logic methodology applied to a corporate social responsibility case study		X				
Qiang	The Closed-loop Supply Chain Network with Competition and Design for Remanufacturability	X					
Rahman, Hagare and Maheshwari	Framework to assess sources controlling soil salinity resulting from irrigation using recycled water: An application of Bayesian Belief Network.		X				
Rashidi, Shabani and Farzipoor Saen	Using Data Envelopment Analysis for Estimating Energy Saving and Undesirable Output Abatement: A Case Study in the OECD Countries			X			
Rosa and Beloborodko	A decision support method for development of industrial synergies: case studies of Latvian brewery and wood-processing industries						X
Seddighi and Ahmadi-Javid	A sustainable risk-averse approach to power generation planning with disruption risk and social responsibility considerations	X					
Sevigné, Gasol, Rieradevall and Gabarrell	Methodology of supporting decision-making of waste management with MFA and CLCA: case study of paper and board recycling					X	
Souza, Salhofer, Rosenhead, Valle and Estellita Lins	Definition of Sustainability Impact Categories Based on Stakeholder Perspectives					X	
Sproedt, Plehn, Schönsleben and Herrmann	A Simulation-based Decision Support for Eco-efficiency Improvements in Production Systems		X				
Tajbakhsh and Hassini	A Data Envelopment Analysis Approach to Evaluate Sustainability in Supply Chain Networks			X			
Wei, Zhao and Li	Price and warranty period decisions for complementary products with horizontal firms' cooperation/non-cooperation strategies	X					

Yilmaz, Anctil and Karanfil	LCA as a Decision Support Tool for Evaluation of Best Available Techniques (BATs) for Cleaner Production of Iron Casting			X
Zhang and Haapala	Integrating Sustainable Manufacturing Assessment into Decision Making for a Production Work Cell		X	
Zhu, Lujia, Mayyas, Omar, Al-Hammadi and Al Saleh	Production Energy Optimization Using Low Dynamic Programming, a decision support tool for sustainable manufacturing	X		

3.1. Sustainability approach – dimensions

In this section papers that used sustainability perspectives were divided into two sub-categories: (1) those, which focused on all three dimensions of sustainability; and (2) those, which addressed various organizational, environmental dimensions including, energy, greenhouse gas emissions, solid waste management, and miscellaneous environmental topics.

As can be seen from the categorizations, social dimensions, as a general category, were the least explored and were also the least integrated into the impact analyses of firm's planning and performance. Recently, authors have argued for the importance embracing social issues has for firms' image and productivity (e.g. Ansett (2007)). The lack of research in the social dimensions continues to be a major gap amongst the formal modelling and analytical research community.

3.1.1. Comprehensive Sustainability – papers addressing all three sustainability dimensions

Only 26% of the SV papers addressed all three sustainability dimensions, the remaining papers focussed on the balance of environmental and economic dimensions. This breakdown shows the challenge and presents the opportunity to make progress in addressing all three dimensions simultaneously, in all decision-making contexts.

There is a three-fold challenge associated with integrating social dimensions into sustainability: first how to measure and second how to model their impacts and third how to solve the problems in an integrated manner. Addressing this concern, Mota *et al.* (in this volume) proposed a social indicator, the 'Social Benefit' indicator, which is suitable for assessing strategic decisions in the design of supply chains. This social indicator considers the impact of social and political concerns on corporate performance. Application of this holistic approach within a case study of a Portuguese battery producer and distributor was presented. The proposed approach can direct improvements in all three dimensions of sustainability and offers important managerial insights. The authors found that with a small compromise in economic performance, an improvement in social contributions can be achieved. In their evaluation, they found that reduction in environmental impacts can be obtained by reducing the number of warehouses and by increasing transportation.

Golinska *et al.* (in this volume) proposed a set of indicators to classify environmental sustainability status and challenges facing small and medium industries engaged in remanufacturing of parts. These indicators played a valuable role in identifying and prioritizing operations for improvement initiatives. A field study from automotive parts remanufacturing companies was used. The authors found that the criteria with highest priority for corrective actions included: overall equipment effectiveness, adequacy of remanufacturing process planning, availability of materials for the economic performance dimension, and innovation level and average work comfort level for the social performance dimension. Relatedly, Souza *et al.* (in this volume) developed a methodology for the selection of social and economic impact categories based on consultation of real stakeholders, and elicitation and structuring of their perspectives. They applied their methodology in the case of Brazilian waste electric and electronic equipment (WEEE) reverse logistics. Interestingly, their proposed method was sufficient for manager's decision-making without having to use quantitative scores. This approach was especially useful for managers who are not comfortable or are distrustful of strict reliance on quantitative data for decision-making.

Zhang and Haapala (in this volume) developed a systemic approach to assess broader sustainability impacts that integrates economic, environmental, and social impact assessment at the operational work-cell level. A case study from a stainless steel industry organization was used to test the system. Cutting tool cost was found to be the largest contributor to production costs for the investigated work cell. In addition, the level of environmental and social impact varied according to cycle time. The systemic nature of these dimensions further supported and exemplified the tradeoffs and synergies that managerial decision-makers may encounter at the operational level of analysis.

Application and integration of classical environmental and operational tools using the broader sustainability dimensions is a goal of Jawad *et al.* (in this volume). In this study classical exergy analysis, sustainability dimensions of labour, capital and environment were integrated with an extension to the classic economic order quantity (EOQ) model. Product level inventory policies for firms located in the USA, Germany and China were then evaluated. The application focused on what locations would be most advantageous from the broader sustainability dimensions. When exergy was considered, a counter-intuitive result was found. Interestingly, it was documented that it was cheaper and less environmentally damaging to produce in the US or Germany than in China. A more complete organizational accounting with additional sustainability dimensions and a variation in perspective was found in many other studies as well. The intuition associated with just economic concerns may be misguided and is an important managerial consideration associated with any sustainability integrated decision-making contexts.

Higher, inter-organizational supply chain level, analyses was the focus of the paper by Tajbakhsh and Hassini (in this volume). Their methodology evaluated operation of a chain of business partners focussed upon maximizing economic returns, minimizing environmental impacts, and also meeting social expectations. By using two case studies, one in the manufacturing sector and the other in the service, banking, sector, they gained a number of insights for improving their supply chain design. For example, they obtained a result for supply chains in the beverage sector, which stipulated that to improve its overall sustainability performance, emphasis should be placed upon the retailer echelon. Their methodology provided insight to where sustainability design emphasis should be placed within their particular supply chain.

Wei *et al*. (in this volume) investigated the relationships between price and warranty for complementary products in a competitive environment. Because warranties have become a popular measure for increasing market demand by reducing risks for consumers, it has become a relevant aspect of corporate and business sustainability (Ahi and Searcy, 2013; Marrewijk, 2003). The game theoretic analysis showed that retailers have the higher profit advantage when they are leaders. All channel members as well as consumers benefit from lower retail prices, longer warranty periods and larger profits when the two manufacturers' adopt cooperative action approaches. The integration of warranties and sustainability is the unique contribution of this work, setting a foundation for building on the roles of warranties from the multiple sustainability dimensions.

Assessing stakeholders' importance in a corporate social responsibility context was the goal of Poplawska *et al.* (in this volume). A framework was developed and applied to construct and to visualise the profile of key stakeholders and to measure their salience. The implementation of the proposed framework can be of great value to large international and geographically dispersed organisations. It is not always clear to organizations on which stakeholders they should engage, especially in global markets and supply chains. The guidance provided with their approach is important to help organizations balance sustainability among stakeholders.

In a power generation planning domain, Seddighi and Ahmadi-Javid (in this volume) proposed a sustainable risk-averse approach that considers several socio-environmental factors for planning the expansion of the South-western Iranian power generation system. Greenhouse gas emissions, air and noise pollution, hazardous wastes, life-threatening issues and social expectations were some of the factors considered by the researchers. They demonstrated the importance of incorporating disruption risks and sustainability issues in the expansion planning of power systems. Additionally, the results can be extended to other countries operating under a regulated market environment such as Canada, Ireland, Malaysia and South Africa.

Social aspects can also be addressed by solving a humanitarian logistics problem. Camacho-Vallejo *et al.* (in this volume) developed and tested a mathematical model to optimize the distribution of international aid to people affected by catastrophic disasters, such as Earthquakes, Tsunamis and Storms. They found that it was necessary to have a centralised agent to coordinate the supply and demand efforts, they also recommended the use of a bi-level model for future research.

Martin (in this volume) explored methods to incorporate values in sustainability decision-making. He discussed empirical, normative and other decision-making methods based upon a conceptual architecture borrowed from the Aristotelian ideas of Episteme, Techne and Phronesis. Stakeholder and organizational values played an important role in this philosophical and values-oriented study. It was concluded that decision-making methods that provide a transparent means to value outcomes and to integrate disparate information and perceptions (and values) are the most useful in heterogeneous stakeholder settings. The values play a central role in qualitatively assessing the tradeoffs associated with the various dimensions of sustainability, which was a major thread throughout most of the papers in this SV.

3.1.2. Sustainability – The environmental and economic linkage

Of the 38 papers in this SV, 28 addressed environmental and economic dimensions. Among them, *energy aspects* were addressed in eight papers, greenhouse gas emissions were addressed in five, remanufacturing, waste reduction and eco-efficiency were addressed in eight and the remaining seven addressed miscellaneous topics. The remaining subsections provide an overview of the contributions of each of these papers.

Energy aspects

Beginning at the operational organizational level, four papers focused on the relationships between manufacturing equipment and energy usage and efficiency concerns. Madan *et al.* (in this volume) proposed a systematic approach to help researchers make energy consumption comparisons for different manufacturing processes and equipment. The integrated methods were applied to an injection moulding company. Using a bill-of-energy approach, a decision-support system was developed. Energy information and estimates can be more easily developed for manufacturing processes through this unique structure.

Furthering the idea of machining energy savings, Liu *et al.* (in this volume) developed and tested a novel method for predicting the energy consumption of machining processes. A broad-based decision-support modelling system was developed within this context as joint considerations of energy resource usage and economic valuations played a win-win role in the design of machining processes.

Zhu *et al.* (in this volume) developed and tested an intelligent energy management scheme, to support the decision-making processes for selecting the right mix of energy to achieve the best conversion processes and technologies to be used in a manufacturing system context. Using an automotive OEM assembly plant field study, they validated the scheme. They demonstrated the conflicting nature of the two cost models proposed. They highlighted the importance of objective decision-making tools, driven by specific performance criteria, in managing the energy and the overall sustainability of production environments.

Energy consumption in machine tooling was the focus of the final related papers on manufacturing systems and energy usage. Where others were for planning, design, and management, O'Driscoll *et al.* (in this volume) studied the use of non-intrusive intelligent energy sensor, which can monitor and control the operational status of a machine tool during operation. They concluded that the information available at the machine tools electrical service level was useful for identifying individual component activations in addition to helping to improve the overall operational status. Getting timely information on the status of a machine tool during machining can help to reduce the energetic impacts of machining and therefore, can help in improving the overall energy efficiency of manufacturing.

Machining systems play a large role in energy usage, but material handling and moving systems also play an important role in energy resources usage. Luo *et al.* (in this volume) addressed energy saving by developing and testing an approach to achieve cost-optimal operation of belt conveyors, a material movement system, in a coal-fired power plant. The economics of these situations clearly showed that substantial energy operational costs (up to 40%) are embedded within the conveyor belt systems (Hager and Hintz, 1993). Two control approaches with energy cost reductions as the objectives, were able to achieve optimal energy cost operations of conveyor belt systems. Forecasting disturbances and execution disturbance contexts were evaluated. These were examples of contextual factors that can influence managerial decisions related to energy and economics. The utility of the methodology was evidenced by some of the nuanced scenarios identified in the field study.

From a broader extra-organizational perspective, Neshat and Amin-Naseri (in this volume) addressed the problem of planning electricity generation in a price competitive market that forced suppliers to minimize operational and environmental costs. Suppliers focused on efficient production facilities as a means of reducing electricity losses and fossil dependency and greenhouse gas (GHG) emissions to compete in a market with lower prices. The Iranian electricity market was studied to illustrate the applicability of the proposed model. Hybrid methodologies provided better economical and environmental performance than a single game methodology, thereby underscoring the need for additional realistic modelling efforts to more clearly understand the environment-economy relationships.

Related power plant energy research was introduced by Munisamy and Arabi (in this volume). In this paper a productivity index to evaluate 48 Iranian thermal power plant's changes in productivity in three different categories - steam, gas, and combined cycle- over an eight-year power industry restructuring. A major conclusion was that organizational and policy learning helped thermal power plants improve during the restructuring period. In this case the restructuring was not necessarily a technological but a policy solution, expanding the picture of how industries can improve on economic-environmental characteristics with careful planning.

The industry level of analysis also considered municipal solid waste sites. Arafat *et al.* (in this volume) evaluated and compared different municipal solid waste treatment methods from an energy recovery potential, CO_2 footprint and from environmental performance viewpoints. Their comparison focused on how different technologies and approaches in these landfills contributed to energy formation. The environmental benefits were based upon taking advantage of solid wastes and improved management.

The issue of environment and economy can also be looked at from a macroeconomic level. The studies in the SV range from internal organizational operational efforts, to supply chain, and industrial relationships. It became clear that additionally analyses must be performed at national and international levels. Rashidi *et al.* (in this volume) worked at this level as they investigated the eco-efficiency of countries in the Organization for Economic Co-operation and Development (OECD). The eco-efficiency was assessed based upon energy inputs, undesirable outputs, and non-discretionary factors. They found a direct and positive relationship between potential of energy saving and potential of undesirable output abatement. The variations in countries within the time span were also discussed. One conclusion was that countries producing high quantities of undesirable outputs do not operate eco-efficiently and therefore, have substantial room for improvement in energy usage. Alternatively, countries consuming less energy may operate eco-efficiently and may have a lower potential to reduce undesirable outputs.

Greenhouse gas (GHG) emission aspects

Greenhouse gas (GHG) emissions, as a contributor to global climate change, constitute an important aspect of the environmental and economic relationship. (Sevigné-Itoiz *et al.* (in this volume) developed and tested a procedure to perform comprehensive assessments of GHG emissions as a consequence of increasing the amount of material collected for recycling. They applied the procedure in the paper and cardboard recycling system in Spain and found that the GHG results varied between -36 kg CO2 eq. and -317 kg CO2 eq. per ton of waste paper collected, depending on the quantity of waste paper exported and the source of marginal pulp considered. In addition, the cumulative energy demand showed similar trends as for GHG emissions. Relating recycling and solid waste to GHG emissions is an important environmental trade-offs. The overall benefits of recycling can be captured not only in solid waste management and economics, but also in resource depletion, energy usage, and GHG emissions.

This integrated and broader perspective was further documented in paper by Lambrecht and Thißen (in this volume), where tons of CO_2e emitted coupled with waste generation in a production process were investigated. They found that the emissions of CO_2e represented the environmental dimension. Their approach used a systematic approach for defining sustainability objectives based on material flow networks. Material flow based optimisation for scenarios and trade-offs between economic and environmental performance were also investigated. The utility of their model was exemplified by finding the environmental and economic optima of a waste air treatment system.

Lam and Lai (in this volume) developed and tested an integrative method to assist shipping companies in meeting customer requirements and improving their shipping operations for environmental performance. A case study of an international tanker shipping company is used to demonstrate the application of this approach to enhance eco-efficiency. Using case-based evidence from shipping companies in China, Norway and Singapore, they demonstrated that their proposed approach was a useful tool for shipping companies when designing measures and deploying environmental requirements desired by shippers. The ultimate goal was to help achieve environmental sustainability in shipping operations.

Liu *et al.* (in this volume) researched how to embed environmental factors coupled with traditional cost aspects into the production planning of a new manufacturing system. Developed by Sony and named as a *seru* production system. It was considered to be an extension of just-in-time (JIT) and was defined as Double E (ecology and economy) in Japan because of its performance on economic and environmental aspects. They verified the effectiveness of the proposed algorithm for minimizing the makespan and the total carbon dioxide emissions for processing all product types by a *seru* production system. The achievements of this paper can serve as a guide to implement sustainable manufacturing for manufacturing enterprises having *seru* production systems; and can also enrich the related theory to management of production systems.

Fikar and Hirsch (in this volume) addressed the problem of delivering nursing home services in urban areas. In particular they analysed different strategies to pool vehicles for transporting nurses to patients, route and schedule the service of nurses with different qualification levels to patients including pickups after completion of their services. The Austrian Red Cross, a major home health care (HHC) provider in Austria, was used as a case study. They achieved more than 85% vehicle usage reductions in comparison with if the vehicles were used by a single nurse. They also found some reductions in carbon footprint due to nurses walking some of the way to and from their patients' homes. Further increases in efficiency of these types of providers were stimulated by stricter environmental regulations and by the desire to decrease companies' ecological footprints. The joint scheduling modelling and behaviour model showed how new designs and changes in practices can add to flexibly finding alternative solutions to improve economic-environmental balances.

Remanufacturing and waste reduction, eco-efficiency

There were several authors who addressed the environment-economic perspectives of sustainability from a waste minimization and closed-loop (remanufacturing, recycling) perspective. Abdulrahman *et al.* (in this volume) analysed the key factors that determine whether the remanufacturing strategy should be deployed in-house or outsourced. They conducted a study of two leading Chinese auto-parts companies. In the example decision, the two Chinese manufacturers preferred remanufacturing in-house, but they still faced challenges relating to their technical and managerial capabilities. The remanufacturing environment was critical to closing-the-loop internal and external to organizations across product families. Aras et al. (in this volume) addressed the problem of designing a reverse logistics network for the collection and recovery of discarded personal computers, inkjet and laser jet printers in 15 major cities of Turkey during the period 2013-2018. The proposed approach help decision makers to determine the locations and capacities of recycling facilities that will handle the returned products. They concluded that the best locations for opening recycling facilities are the largest three cities of Turkey, i.e., Ankara, Istanbul, and Izmir.

Yilmaz *et al.* (in this volume) proposed an approach to evaluate several best available techniques (BAT) for recovery and reuse in the iron casting industry. The preferable strategies towards cleaner production in iron foundries were documented by using a combination of achieved benefits, environmental impacts and cost of implementation. On-site recovery and external reuse of waste sand were found to be effective for decreasing overall environmental impacts of castings. This closed-loop example further exemplified how thinking environmentally can also benefit organizations economically.

Expanding the scope to explicitly consider the remanufacturing loop closure to a supply chain, Qiang (in this volume) focused on competition among OEMs. The production quantity and level of remanufacturability were investigated to determine the impact on product cost for both new and remanufactured products. Although proactive design for product remanufacturability will decrease market share of the new product for reactive competitor remanufacturability design, the former is more profitable due to the capture of additional market shares of the refurbished product. It was also found that if all consumers have a higher willingness-to-pay for the refurbished product, being proactive is less attractive. However, this is not the case when manufacturers face asymmetrical demand markets.

The aluminium industry recycling process was investigated by Paraskevas *et al.* (in this volume). The objective of minimizing material losses due to the loss of the original functional quality of the material, dissipation of scarce resources and the need for dilution of the resulting metal impurities with primary materials, exemplifies some of the complexities, which, on the surface, seem like straightforward situations. This investigation found that both materials technology and process improvements play important roles in improving overall environmental efficiency of the aluminium recycling system.

Eco-design considerations for a broader system can help to address the balance of various sustainability dimensions. Moreira *et al.* (in this volume) investigated the eco-design of textile products to be used the green aircraft completion (GAC) sector. GAC represents one of the final stages of aircraft production, focusing on a plane's interior decoration. A large North American company was used as the case study. The broad framework developed in this paper enabled GAC organizations to develop systems involving the final consumer, suppliers and the local communities. The goal was to not only decrease their carbon footprint but also to advance the case organization's corporate social responsibility.

Another example of the textile industry, which is well known for its environmental and social impacts (Brigden *et al.*, 2012), is included in the paper by Sproedt *et al.* (in this volume). They propose a methodology to identify and measure the eco-efficiency drivers within a production system at the shop-floor level. The joint methodology using LCA and optimization, introduced helped to achieve eco-efficiency gains. The consideration of the broader implications and various tools helped them to address some of the complexities managers face in these situations.

Miscellaneous Concerns and Relationships.

For this section, SV papers that are not easily placed in specific sections are overviewed. One of the least investigated environmental and natural resources in the clean production literature is one of our most humanly important resources, water. On this issue the use of recycled water from different sources for irrigating sporting facilities and its impact on the salinity of the soil was investigated by Rahman *et al.* (in this volume). They concluded that when recycled water was used for irrigating urban landscapes, the reduction of salt in the wastewater stream from clothes washing machines would be beneficial in helping to manage soil salinity from recycled water use for irrigating urban landscapes. The proposed decision-making tool can be used to potentially analyse various householders' habits and other management options for controlling the risk of soil salinization, implying broader policy and regulatory management of the water resources.

In a slight change of pace, focusing on technology development, Kundu *et al.* (in this volume) developed a method to identify the optimal factors (parameters) for a microwave heating process for preparing activated carbon from agricultural waste palm kernel shells. The proposed method is faster and uses less energy than conventional techniques, thus providing a real advantage to activated carbon producers.

Justification and evaluation of various environmental management systems is a decision facing organizations, Guerrero-Baena *et al.* (in this volume) developed a methodology to assess and select their implementation in for-profit firms. A group of Spanish olive oil firms with a proactive environmental management orientation was used to empirically validate this approach. They learned that intellectual capital related elements are rated higher than financial capital elements by decision-makers. The methodology presented could be extended to other types of evaluations, such as projects where intangible benefits are a significant part. The many dimensions of these types of decisions were exemplified and underscore the managerial complexity of the decision-making environment.

Under the sustainability lenses, Janeiro and Patel (in this volume) introduced weak and strong sustainability paradigms to analyze the underlying rationale for the prioritization of all the sustainability indicators used to assess technology adoption. They argued in support of the strong sustainability paradigm, which is based on physical science preservation of natural resources and that cannot be 'substituted' by a combination of socio-economic benefits. Under a novel planetary boundaries theory, they proposed the use of environmental thresholds as a way forward in prioritising environmental impact.

Chandran *et al.* (in this volume) studied the complexities in developing and deployment of a decision-support system to monitor wildlife crime occurring in different countries. They used the Wildlife Enforcement Monitoring System (WEMS) and Q-sort method to work out how different groups of stakeholders make decisions using a belief classification matrix. This type of study focused on a different and less investigated sustainability topic, which of the maintenance of biodiversity, and specifically on endangered species. This form of study can urgently needs significantly more research because animal populations are under more stress in their ever increasingly encroached upon environs.

Rosa and Beloborodko (in this volume) investigated the quality of industrial symbiosis with a focus on environmental and economically win-win benefits. This example showed that not all situations are necessarily tradeoffs. Illustrations of the benefits of applying this method were quantified for systems in the brewery industry and in the wood processing industry in Latvia. They showed that only a few of the considered self-organized industrial synergies were beneficial regarding all three - environmental quality, economic quality and geographic proximity - evaluation categories. They concluded that these three aspects create a three-layer filter for development of qualitative industrial synergies and the quality of each category should be considered before the planning stage of such collaborations.

3.2. Methods and tools for supporting decision-making

Assessing environmental, economic and social impacts of decisions and practices can be completed using quantitative assessment and decision-making methodologies. In the previous section each paper was overviewed on sustainability and managerial contexts, an overview on tools and methods used in the SV papers are summarized in this section. For this SV fourteen of the 38 papers developed and tested optimization models, see Figure 1. Six papers used simulation and heuristic approaches. Eight used multi-criteria decision analytical approaches, four used descriptive life cycle assessment based models, whereas soft O.R. based techniques were used in six of the papers. Aspects of each paper methodology are now reviewed along these five general methodological categories.

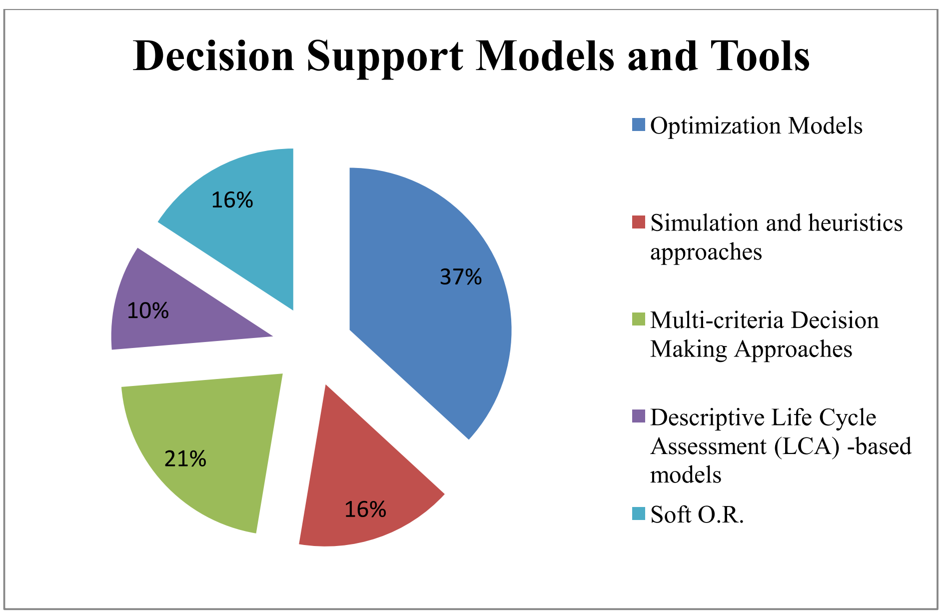

Figure 1 - Distribution of decision support models and tools used to address sustainability problems in this SV.

3.2.1. Optimization Models

Three separate papers in this SV used multi-objective optimization models as decision-making tools. Mota *et al.* (in this volume) developed a mixed-integer linear multi-objective optimization model for designing a four-echelon closed loop supply chain that accounts for environmental, economic and social factors. The Ɛ-constraint method was chosen to solve the mathematical model. Similarly, using multi-objective optimization models, Liu et al. (in this volume) proposed a bi-objective mixed-integer mathematical programming model for the production planning *seru* manufacturing system that minimized the makespan and the carbon dioxide emissions caused by energy consumption for processing of all product types. They developed a metaheuristic for solving the optimization model. To also balance economic and environmental issues, another multi-objective optimization model was developed by Paraskevas *et al.* (in this volume) using Goal Programming and life cycle analysis to maximize the scrap usage and minimize dilution and product quality losses during the metallurgical recycling phase in the secondary aluminium production. The variety of problems, techniques, and solution methodologies for multiple objective optimizations, show the overall potential for expanding work in this area. The characteristics of the models and formulations can provide greater insight into general modelling and solution techniques as well. The structures of these models can be very useful for complex decision environments, similar to sustainability concerns.

Three papers combined single objective optimization models with other tools to address the variety of cleaner production problems. Zhu *et al.* (in this volume) introduced a model predictive control scheme using hybrid, discrete and continuous, simulation and linear programming to address the planning of energy consumption at multiple plant levels. The model predictive control scheme was also used by Luo *et al.* (in this volume) using an embedded non-linear optimization problem to find the optimal total electricity cost for operation of belt conveyors. The integration of techniques is also exemplified by Lambrecht and Thißen (in this volume) who proposed the combination of material and energy flow analysis with a mathematical programming model. They evaluated a manufacturing system from all perspectives of sustainability, and in particular, environmental and economic dimensions. In these examples the integration of tools, whether they are analytical tools or environmentally focused tools, shows the flexibility of analytical solution methodologies. Multi-methodological approaches are very promising since they can synergistically be introduced to address gaps by single methodological approaches. A major issue is that the complexities of integrative techniques take longer to explain and understand to managers who would be responsible for applying or interpreting the results.

Organizational competition and strategic sustainability issues are also addressed analytically in three papers. The authors adopt different approaches to deal with these strategic and creatively identified inter-organizational issues. Warranty of products as social responsibility is addressed by Wei *et al.* (in this volume). A two-stage game theoretic perspective was used to explore optimal strategies on price and warranty periods for two complementary products in a two-echelon supply chain with three independent, risk-neutral, and profit-maximizing chain members. This relatively complex environment, for a game theory application included one common retailer and two manufacturers. In a very different domain, a game theoretic-based approach was used by Neshat and Amin-Naseri (in this volume) to solve an energy capacity expansion planning problem including operational investment and environmental costs. The approach also combined a two-sided multi-agent based model and mixed integer programming. Remanufacturability in a supply chain context was addressed by Qiang (in this volume). He proposed a variational inequality approach to solve the remanufacturability problem that arises when manufacturers, as decentralized decision-makers, compete for market shares in a two-period closed-loop supply chain (CLSC) network with multiple demand markets. These strategically focused models showed that a higher level of decision- making could be supported by analytical modelling approaches. A limitation of these approaches is that the models can become increasingly complex, relatively quickly. Also, to make sure the models are mathematically tractable, assumptions are needed to bind the decision-making environments. But, these can be concerns with any modelling approach. The guidance in the general longer-term strategic decisions can also be used to help relate to lower level, operational models.

Examples of multiple levels of analyses, with traditional and newer approaches can be found in the final five optimization models. In the humanitarian logistics arena, Camacho-Vallejo *et al.* (in this volume) developed bi-level mathematical programming model to optimize the distribution of international aid after a disaster has happened in the energy saving domain. This is somewhat tactical in focus, but tactical in a humanitarian environment may also be strategically important. In a reverse logistics domain, Aras et al. (in this volume) developed a multi-period capacitated facility location-allocation model to determine the locations and capacities of recycling facilities to handle end-of-life returned products. The proposed model minimizes the total cost of opening facilities, operating them, and transporting the discarded products from their collection points to the facilities. Seddighi and Ahmadi-Javid(in this volume) proposed a mixed-integer linear programming model to address a multi-period generation expansion planning problem in Iran. Socio-environmental factors and disruption risk aspects were simultaneously handled by the risk-averse approach proposed by the researchers. The last two papers focus on operational and inventory based models, some of the oldest analytical techniques in operations and production. Liu et al. (in this volume) developed a mathematical model to forecast the total energy consumption of the main driving system of a machine tool. In the inventory management domain, Jawad *et al.* (in this volume) proposed the application of an extended exergy accounting approach to determine the economic order quantity (EOQ). In these latter models, all the inventory costs (ordering, purchasing and holding) were converted into equivalent exergetic values, or unit equivalents of exergy of labor, capital and environment. Once again, there was evidence of how traditional operations and production models can be integrated effectively with environmental science and policy tools, methods, and theories.

3.2.2. Simulation and heuristics approaches

Many times optimal solutions are not easily determined or are so bounded that practical issues are difficult to address. The use of simulation and heuristics can provide the depth and breadth necessary to either complement or address issues that cannot be well addressed in optimization modelling. The breadth of the tools in this domain are even greater than optimization models due to the lack of a need to obtain the best solution, but very good solutions in various scenarios. Many of these tools embed statistical and stochastic tools rather than deterministic solution approaches. The randomness of practical situations makes stochastic modelling an appropriate direction for these modelling efforts. A similar argument can be made for fuzzy approaches.

Authors of six papers used simulations and heuristics approaches to solve a variety of sustainability oriented practical problems. In a home health care context, Fikar and Hirsch (in this volume) developed a two-stage metaheuristic method for solving a type of many-to-many multi-trip dial-a-ride problem. In this problem context decision makers need to define a daily plan for home health care service providers operating multiple vehicles to deliver nurses to clients' homes and to pick them up after a certain service is provided. Expanding upon the social dimensions is a corporate social responsibility context. In this paper Poplawska *et al.* (in this volume) proposed a new two-stage framework based on fuzzy logic, and visual analytics, to assess stakeholders' salience by indicating the exact degree of membership to a particular interest group.

In the water resource management domain, Rahman *et al.* (in this volume) proposed a Bayesian belief network approach for managing salinity issues associated with the use of recycled water. This unique closed-loop investigation, focussed upon different domestic sources for urban irrigation, especially sporting oval irrigation was investigated. In the energy saving context of manufacturing of activated carbon**,** Kundu *et al.* (in this volume) proposed a robust Taguchi method to identify the operating conditions for four factors (parameters) using the microwave heating method to prepare activated carbon using palm kernel shells, a locally available agricultural waste, as raw material. A variety of integrated algorithms and statistical tools embedded in a nonintrusive intelligent energy sensor_were developed by O'Driscoll et al. (in this volume). The goal was to quantify the energy consumption and operational status of a machine tool during machining. The integrative nature of these tools, similar to the previously summarized optimization models, was evident.

Another characteristic for these models, evident also in the previous optimization tools, was to link environmentally oriented methodologies and tools. Sproedt *et al.* (in this volume) exemplified this integration when they proposed a decision-support system based on a novel discrete-event simulation approach integrated with a life cycle analysis method to analyse and evaluate the complex economic and environmental performance interrelations in production systems. In this case the ultimate goal was to improve the eco-efficiency of their systems.

3.2.3. Multi-criteria Decision Making Approaches

Given the many dimensions and tradeoffs associated with social, environmental and economic in sustainability decision-making problems, the use of multiple criteria decision-making tools seems like a natural fit. Multiple criteria decision making tools are valuable in balancing sustainability dimensions that sometimes are also in conflict (Bai and Sarkis, 2010; Chai et al., 2013). Some of optimization models presented above could also be classified in this category (Ehrgott, 2005; Figueira et al., 2010), but many multiple criteria models are perceptual and optimization is not necessarily a goal.

Eight papers from this SV focus on the development and application of multiple criteria decision-making. Four of them rely on analytical hierarchy-based models that focus on discrete alternatives and utilize aggregations of compensatory weighting systems. Evaluating three alternatives for addressing the remanufacturing automotive sector in China appears in the Abdulrahman *et al.* (in this volume) paper. In this paper analytic hierarchy process (AHP) is used for evaluating and selecting the right remanufacturing strategy for two Chinese auto parts firms. Three basic remanufacturing strategic alternatives: in-house, outsourcing and/or not to engage in remanufacturing.

The analytic network process (ANP), a multi-criteria method considered a more general form of AHP, was utilized by Guerrero-Baena *et al.* (in this volume). This paper seeks to assist companies in the process of evaluating and selecting an environmental management system in for-profit firms. But, analytical hierarchy tools can be effectively integrated with other tools. For example, ANP and Quality Function Deployment (QFD) was a proposed integrated methodology introduced by Lam and Lai (in this volume) to determine the environmental management requirements of their customers (shippers) and to design and implement actions to achieve operational environmental sustainability.

The complexity of integrative relationships amongst these multiple methodologies was evident in the paper that integrated AHP, LCA, Social LCA, and a multi-criteria decision analysis method (PROMETHEE). This complex set of relationships was developed and applied effectively by Zhang and Haapala (in this volume). They assessed the economic, environmental, and social impacts at the work cell level in a manufacturing system. In this case, the PROMETHEE ranking method was used for ranking alternatives, which allowed decision-makers to evaluate the scores for different discrete alternatives.

Discrete alternative multiple criteria decision making has included a productivity analysis tool known as data envelopment analysis (DEA) (Sarkis, 2000). Three papers in this SV rely on DEA, some traditionally as a tool for multi-objective performance analysis. In an environmental performance analysis concern, Rashidi *et al.* (in this volume) analysed the environmental efficiency of countries in the Organization for Economic Cooperation. DEA has many variations, in this case two non-radial models were used to evaluate the eco-efficiency in the presence of both energy and non-energy inputs and desirable and undesirable outputs. Similarly, at this level of analysis for DEA was applied in analysing the Iranian electricity industry by Munisamy and Arabi (in this volume). They proposed a new slacks-based DEA measure to compute the meta-frontier Malmquist Luenberger productivity index. In particular, they used the DEA-based method to evaluate the change in the productivity of 48 Iranian thermal power plants in three different categories - steam, gas, and combined cycle- over an eight-year period of restructuring in the power industry. Finalizing this line of decision-making tools, in a supply chain context, Tajbakhsh and Hassini (in this volume) proposed a DEA-based model to evaluate the environmental, economic and social efficiency of a supply chain comprised of multiple partners, multiple stages, and intermediaries that have different weights and new inputs. Authors employed duality theory to model an additive efficiency measure and thus avoid dealing with nonlinear DEA models. These three examples showed the flexibility of DEA applications and tools. Hundreds, if not thousands, of variations with DEA exist. Interestingly, no papers integrating DEA with other tools were included in this SV, but many opportunities exist for this integrative approach to DEA.

Finally, one paper used multi-criteria decision-making tools to address the remanufacturing automotive parts problem. Golinska *et al.* (in this volume) developed a grey decision-making tool for classifying the current state of "sustainability" of remanufacturing operations for small and medium enterprises. They identify and prioritize the operations, which needed improvement actions using a set of fifteen sustainability indicators that consider economic, environmental and social perspectives. The Grey decision-making system was used to classify the companies in one of three categories (red, yellow and green), which corresponded with the different levels of sustainable operational excellence practices.

3.2.4. Descriptive Life Cycle Assessment (LCA) -based models

LCA is one of the more traditional tools used for environmental management of products and processes. It may be viewed as a form of descriptive analysis to decision making. Descriptive models are concerned with why and how a phenomenon happen in a particular domain (Bell et al., 1988). These types of model were utilized to describe current or past system performance. Typically, LCA has not been used to infer what should happen in the future nor to prescribe a possible action and its potential consequences, although theoretically, such applications of LCA have been championed. LCA-based models are popular with an increasing number of research papers using LCA integrated with other models and tools, as evidenced by some of the papers discussed in the previous sections. In this section the focus is on LCA models as the foundational models.

3.2.4.1. Individual LCA-based approaches

Two papers used LCA-based approaches to address different concerns. The first one, by Arafat *et al.* (in this volume), is on the Municipal Solid Waste problem. They applied a LCA-based approach to analyse the environmental performance of five processes used to treat municipal solid waste (MSW). Incineration, gasification, anaerobic digestion, bio-landfills, and composting process were investigated in terms of environmental impacts and energy production. Six MSW streams were considered; food, yard, plastic, paper, wood and textile wastes. The energy model, life cycle and environmental impact assessments were conducted on the base of waste treatment processes as they applied to individual waste streams. Their tool helps decision-makers to select their particular type of MSW treatment according to economic and environmental impacts. A focus on the metal industry by Yilmaz *et al.* (in this volume) proposed the same approach to evaluate the environmental performance and cross-media effects of eleven best available technologies (BATs) applicable to the metal industry. The iron casting process was the specific emphasis. They found that, among the techniques evaluated, on-site recovery and external reuse of waste sand were capable of decreasing overall environmental impact of casting by 60 - 90% revenues and savings for the manufacturers, which led to the possibility of step-wise improvements.
These decision-support examples using LCA is critical for future acceptance and integration of this tool set. Unlike more traditional OR tools, the use of LCA is not something that is easily accessible to industrial engineers and operations managers since

many are not exposed to them in their education. Having case examples such as these provides ample opportunities for helping to educate professionals and students.

3.2.4.2. Integrated LCA-based approaches

Two papers used integrated LCA-based approaches. The waste electrical and electronic equipment reverse logistics problem by Souza *et al.* (in this volume) proposed the use of a cognitive causal maps method to elucidate the stakeholders' sustainability perspectives. These maps were integrated with a life cycle sustainability assessment methodology. This methodology is an aggregation of three LCA-based methodologies: LCA, Life Cycle Costing (LCC) and Social LCA (Jørgensen et al., 2013). In this paper, the authors used cognitive causal maps as a methodology to define and select impact categories by stakeholders' consultation. The paper and cardboard recycling system problem in Spain was addressed by Sevigné-Itoiz *et al.* (in this volume). They proposed material flow analysis integrated with consequential LCA to properly assess the total GHG emitted by the collection of material for recycling. Material flow analysis is used to evaluate the interaction between material flows, economy and the environment and is also possible to observe variability over time and determine possible changes in trends in raw materials and waste markets. This integration of tools has occurred in almost every modelling set and is due to the complexities involved in sustainable decision-making.

3.2.5. Soft O.R.-based techniques

Many sustainability concerns are "wicked problems" or "messes" that are typically beyond the reach of the traditional, mathematical modelling methods of (O.R.) thus the advent of soft O.R. techniques. These methodologies are structured and rigorous but non-mathematical. They are useful frameworks to solve ill-defined problems, and have been particularly useful to lead with groups of stakeholders which highlights the idea of multiple perspectives and conflicting interests (Rosenhead, 1996). The work by Souza *et al.* (in this volume) described earlier in this paper, could be categorized, but it was mainly focussed on the integration of one soft O.R. method with LCA.

Five papers used Soft O.R. techniques in a diversity of domains. To address a waste management concern in Latvia, Rosa and Beloborodko (in this volume) proposed a structured quantitative method to evaluate the quality of industry synergy and the collaboration opportunities to reduce waste in the brewery and wood processing industry. They developed a rating scale to evaluate the quality of each exchange flow accordingly to three main categories of industrial symbiosis: (1) geographic proximity between the involved companies and (2) environmental and (3) economic benefits provided by the exchange. In a green aircraft completion setting and seeking to reduce the aviation industry‘s carbon footprint, Moreira et al. (in this volume) proposed a conceptual product development framework, which integrated eco-design tools and approaches into the traditional product development process to generate a novel and environmentally-friendly product development process in the textile industry, suppliers providers to the aviation industry.

For improving energy efficiency in a manufacturing setting, it is important to identify the set of individual steps required to produce finished goods. Each step transforms raw material and add values to the work-piece, as it becomes a finished product. Madan et al. (in this volume) developed a science-based methodology and implement a user-friendly decision support system to estimate, evaluate, and improve the energy performance of unit-manufacturing processes, in particular for the injection moulding process. The process-oriented methodology utilizes the soft O.R. perspective.

Three related works with the objective of attempting to add quantifiable information to make decisions in sustainability, utilized various soft O.R. approaches. The first one is the work by Martin (in this volume) who explored methods to incorporate values in sustainability decision-making. A Q method-based framework was used to elicit different ways of thinking about wildlife, Chandran *et al.* (in this volume). They proposed using the technique to identify how conservation actors can manage the adoption of a trans-boundary decision-support system to monitor wildlife crime.

Finally, Janeiro and Patel (in this volume) addressed the prioritization of sustainable indicators. They analysed the underlying rationale for an integrated sustainability assessment and discussed different alternative paradigms of sustainability, with the focus on the concepts of weak and strong sustainability, which defines a spectrum of views on the possibility to replace environmental capital with human-made capital.

Each of these tools has been used to help make sense and organize thoughts and processes to address very different sustainability concerns. The soft methodologies do not rely on the quantitative aspects, but more on the process of eliciting difficult to quantify insights into a structural form for sense-making. But, like the other techniques described in every section, their integration with other methodologies and approaches is a good potential direction so future research, development, and application.

4. Conclusions

The papers in this SV covered a variety of methodologies and dimensions in relation to sustainability. The increasing importance of the social and ethical dimensions was more evident. These additional dimensions and their importance have led to efforts in making the focus more integrative, holistic, multidisciplinary and interdisciplinary. In doing so, we hope the articles of this SV will contribute toward more sustainable societies and organizations.

The following trends are envisaged for future research in this area:

- The increased usage of soft-OR techniques to identify the diversity of the stakeholders and to construct and use appropriate sustainability indicators;

- Integration of descriptive, predictive and prescriptive models and solution methods because of the necessity imposed by the complexity of sustainability problems, which must be addressed in the short and long-term.

- Multi-criteria decision-making models are intrinsically appropriate for sustainability problems and are being increasingly used. In this respect, social perspectives are being investigated further. But this continues to be a rich research field for soft O.R. techniques as well for the development and adaptation of integrative solution approaches in general.

- Focusing on networks can also provide ways to help to achieve sustainable societies, by more effectively taking economic, environmental and social perspectives and networks into consideration by building upon the natural synergies among a great variety of institutions (and people).

These trends are only general findings from the observations and analyses of the papers in this SV. Each paper, in its own way, provided insights into future research whether it was the content and focus of sustainability topics, or methodological and modelling focused. The breadth of the studies provided examples of how various tools can be applied across industries, levels of analysis, and varieties of stakeholders. The tools, both standalone and integrated, each has advantages. Reading this SV alone can provide readers ideas for a lifetime of future research. We hope that you find the papers as interesting and insightful from both practical and research perspectives as we found them to be. It is this marriage of theory and practice that can help us develop and to live in truly sustainable societies.

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References

Abdulrahman, M.D.-A., Subramanian, N., Liu, C., Shu, C.,. Viability of remanufacturing practice: a strategic decision making framework for Chinese auto-parts companies. J. Clean. Prod. in this volume.

Ahi, P., Searcy, C., 2013. A comparative literature analysis of definitions for green and sustainable supply chain management. J. Clean. Prod. 52, 329–341.

Altay, N., Green, W.G., 2006. OR/MS research in disaster operations management. Eur. J. Oper. Res. 175, 475–493.

Ansett, A., 2007. Mind the gap: a journey to sustainable supply chains. Employ Response Rights J. 19, 295–303.

Arafat, H.A., Jijakli, K., Ahsan, A., n.d. Environmental performance and energy recovery potential of five processes for municipal solid waste treatment. J. Clean. Prod. in this volume.

Aras, N., Korugan, A., Büyüközkan, G., Şerifoğlu, F.S., Erol, İ., Velioğlu, M.N., 2015. Locating recycling facilities for IT-based electronic waste in Turkey. J. Clean. Prod. in this volume.

Bai, C., Sarkis, J., 2010. Green supplier development: analytical evaluation using rough set theory. J. Clean. Prod. 18, 1200–1210.

Bell, D.E., Raiffa, H., Tversky, A., 1988. Descriptive, Normative, and Prescriptive Interactions in Decision Making. In: Bell, D.E., Raiffa, H., Tversky, A. (Eds.), Decision Making: Descriptive, Normative, and Prescriptive Interactions. Cambridge University Press, Boston, Mass., p. 636.

Brandenburg, M., Govindan, K., Sarkis, J., Seuring, S., 2014. Quantitative models for sustainable supply chain management: Developments and directions. Eur. J. Oper. Res. 233, 299–312.

Brigden, K., Casper, K., Cobbing, M., Crawford, T., Dawe, A., Erwood, S., Haiama, N., Harjono, M., Hojsik, M., Kai, Z., Kong, A., Miao, Z., Sadownichik, T., Tianjie, M., Vilimaviciute, I., 2012. Toxic Threads: Putting Pollution on Parade How textile hiding their toxic trail. Amsterdam.

Camacho-Vallejo, J.-F., González-Rodríguez, E., Almaguer, F.-J., González-Ramírez, R.G., 2014. A bi-level optimization model for aid distribution after the occurrence of a disaster. J. Clean. Prod. in this volume.

Carter, C.R., Rogers, D.S., 2008. A framework of sustainable supply chain management: moving toward new theory. Int. J. Phys. Distrib. Logist. Manag. 38, 360–387.

Chai, J., Liu, J.N.K., Ngai, E.W.T., 2013. Application of decision-making techniques in supplier selection: A systematic review of literature. Expert Syst. Appl. 40, 3872–3885.

Chandran, R., Hoppe, R., de Vries, W.T., Georgiadou, Y., 2015. Conflicting policy beliefs and informational complexities in designing a transboundary enforcement monitoring system. J. Clean. Prod. in this volume.

Ehrgott, M., 2005. Multicriteria optimization, Second. ed, Medical physics. Springer Berlin / Heidelberg, Heidelberg.

Figueira, J., Greco, S., Ehrogott, M., 2010. Multiple criteria decision analysis: state of the art surveys. Kluwer Academic Publishers, Boston, Massachusetts.

Fikar, C., Hirsch, P., 2014. A matheuristic for routing real-world home service transport systems facilitating walking. J. Clean. Prod. in this volume.

Golinska, P., Kosacka, M., Mierzwiak, R., Werner-Lewandowska, K., 2014. Grey Decision Making as a tool for the classification of the sustainability level of remanufacturing companies. J. Clean. Prod. in this volume.

Guerrero-Baena, M.D., Gómez-Limón, J.A., Fruet, J.V., 2014. A multicriteria method for environmental management system selection: an intellectual capital approach. J. Clean. Prod. in this volume.

Gunasekaran, A., Spalanzani, A., 2012. Sustainability of manufacturing and services: Investigations for research and applications. Int. J. Prod. Econ. 140, 35–47.

Hager, M., Hintz, A., 1993. The energy-saving design of belts for long conveyor systems. Bulk Solids Handl. 13, 749–758.
Janeiro, L., Patel, M.K., 2014. Choosing sustainable technologies. Implications of the underlying sustainability paradigm in the decision-making process. J. Clean. Prod. in this volume.
Jawad, H., Jaber, M.Y., Bonney, M., 2014. The Economic Order Quantity model revisited: an Extended Exergy Accounting approach. J. Clean. Prod. in this volume.
Klemeš, J.J., Varbanov, P.S., Huisingh, D., 2012. Recent cleaner production advances in process monitoring and optimisation. J. Clean. Prod. 34, 1–8.
Kundu, A., Sen Gupta, B., Hashim, M.A., Redzwan, G., 2014. Taguchi optimization approach for production of activated carbon from phosphoric acid impregnated palm kernel shell by microwave heating. J. Clean. Prod. in this volume.
Lam, J.S.L., Lai, K., 2014. Developing environmental sustainability by ANP-QFD approach: the case of shipping operations. J. Clean. Prod. in this volume.
Lambrecht, H., Thißen, N., 2014. Enhancing sustainable production by the combined use of material flow analysis and mathematical programming. J. Clean. Prod. in this volume.
Liu, C., Dang, F., Li, W., Lian, J., Evans, S., Yin, Y., 2014. Production planning of multi-stage multi-option seru production systems with sustainable measures. J. Clean. Prod. in this volume.
Liu, F., Xie, J., Liu, S., 2014. A method for predicting the energy consumption of the main driving system of a machine tool in a machining process. J. Clean. Prod. in this volume.
Luo, J., Huang, W., Zhang, S., 2014. Energy cost optimal operation of belt conveyors using model predictive control methodology. J. Clean. Prod. in this volume.
Madan, J., Mani, M., Lee, J.H., Lyons, K.W., 2014. Energy performance evaluation and improvement of unit-manufacturing processes: injection molding case study. J. Clean. Prod. in this volume.
Marrewijk, M. Van, 2003. Concepts and definitions of CSR and corporate sustainability: between agency and communion. J. Bus. Ethics 44, 95–105.
Martin, L., 2015. Incorporating Values into Sustainability Decision-Making. J. Clean. Prod. in this volume.
Moreira, N., de Santa-Eulalia, L.A., Aït-Kadi, D., Wood–Harper, T., Wang, Y., 2014. A conceptual framework to develop green textiles in the aeronautic completion industry: a case study in a large manufacturing company. J. Clean. Prod. in this volume.
Mota, B., Gomes, M.I., Carvalho, A., Barbosa-Povoa, A.P., 2014. Towards supply chain sustainability: economic, environmental and social design and planning. J. Clean. Prod. in this volume.
Munisamy, S., Arabi, B., 2015. Eco-efficiency change in power plants: using a slacks-based measure for the meta-frontier Malmquist–Luenberger productivity index. J. Clean. Prod. in this volume.
Neshat, N., Amin-Naseri, M.R., 2014. Cleaner power generation through market-driven generation expansion planning: an agent-based hybrid framework of game theory and Particle Swarm Optimization. J. Clean. Prod.
O'Driscoll, E., Kelly, K., O'Donnell, G.E., 2015. Intelligent energy based status identification as a platform for improvement of machine tool efficiency and effectiveness. J. Clean. Prod. in this volume.
Paraskevas, D., Kellens, K., Dewulf, W., Duflou, J.R., 2014. Environmental modelling of aluminium recycling: a Life Cycle Assessment tool for sustainable metal management. J. Clean. Prod. in this volume.
Poplawska, J., Labib, A., Reed, D.M., Ishizaka, A., 2014. Stakeholder profile definition and salience measurement with fuzzy logic and visual analytics applied to corporate social responsibility case study. J. Clean. Prod. in this volume.
Qiang, Q. (Patrick), 2014. The closed-loop supply chain network with competition and design for remanufactureability. J. Clean. Prod. in this volume.

Rahman, M.M., Hagare, D., Maheshwari, B., 2014. Framework to assess sources controlling soil salinity resulting from irrigation using recycled water: an application of Bayesian Belief Network. J. Clean. Prod. in this volume.

Rashidi, K., Shabani, A., Farzipoor Saen, R., 2014. Using data envelopment analysis for estimating energy saving and undesirable output abatement: a case study in the Organization for Economic Co-Operation and Development (OECD) countries. J. Clean. Prod. in this volume.

Rosa, M., Beloborodko, A., 2014. A decision support method for development of industrial synergies: case studies of Latvian brewery and wood-processing industries. J. Clean. Prod.

Rosenhead, J., 1996. What's the problem? An introduction to problem structuring methods. Interfaces (Providence). 26, 117–131.

Sarkis, J., 2000. A comparative analysis of DEA as a discrete alternative multiple criteria decision tool. Eur. J. Oper. Res. 123, 543–557.

Seddighi, A.H., Ahmadi-Javid, A., 2015. A Sustainable Risk-Averse Approach to Power Generation Planning with Disruption Risk and Social Responsibility Considerations. J. Clean. Prod. in this volume.

Sevigné-Itoiz, E., Gasol, C.M., Rieradevall, J., Gabarrell, X., 2014. Methodology of supporting decision-making of waste management with material flow analysis (MFA) and consequential life cycle assessment (CLCA): case study of waste paper recycling. J. Clean. Prod.

Souza, R.G., Rosenhead, J., Salhofer, S.P., Valle, R.A.B., Lins, M.P.E., 2014. Definition of sustainability impact categories based on stakeholder perspectives. J. Clean. Prod.

Sproedt, A., Plehn, J., Schönsleben, P., Herrmann, C., 2015. A simulation-based decision support for eco-efficiency improvements in production systems. J. Clean. Prod.

Székely, F., Knirsch, M., 2005. Responsible leadership and corporate social responsibility: Metrics for sustainable performance. Eur. Manag. J. 23, 628–647.

Tajbakhsh, A., Hassini, E., 2014. A data envelopment analysis approach to evaluate sustainability in supply chain networks. J. Clean. Prod.

Tang, C.S., Zhou, S., 2012. Research advances in environmentally and socially sustainable operations. Eur. J. Oper. Res. 223, 585–594.

UNEP-IRP, 2011. Decoupling natural resource use and environmental impacts from economic growth.

Wei, J., Zhao, J., Li, Y., 2014. Price and warranty period decisions for complementary products with horizontal firms' cooperation/noncooperation strategies. J. Clean. Prod.

Wilkinson, A., Hill, M., Gollan, P., 2001. The sustainability debate. Int. J. Oper. Prod. Manag. 21, 1492–1502.

Yilmaz, O., Anctil, A., Karanfil, T., 2014. LCA as a decision support tool for evaluation of best available techniques (BATs) for cleaner production of iron casting. J. Clean. Prod.

Zhang, H., Haapala, K.R., 2014. Integrating sustainable manufacturing assessment into decision making for a production work cell. J. Clean. Prod.

Zhu, Q., Lujia, F., Mayyas, A., Omar, M.A., Al-Hammadi, Y., Al Saleh, S., 2014. Production energy optimization using low dynamic programming, a decision support tool for sustainable manufacturing. J. Clean. Prod. in this volume.