

## **FIFTY SHADES OF GREEN – WHAT PALES THE FINAL COLOUR OF GREEN SOLUTIONS?\***

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The purpose of the paper is to explain the widely-observed phenomenon that the benefits of some apparently environmentally friendly solutions are much smaller than predicted. The applied research method is a systematic review of papers belonging to the ‘business and environment’ and ‘environmental science and technology’ literatures. Qualitative and interpretive research is used to support our propositions. Five key concepts accounting for the pitfalls associated with *environmental sustainability-oriented (ESO) interventions* have been identified and illustrated with real-life examples. Overlooked (1) interconnections among resources and environmental impacts, e.g. trade-offs, reveal that (2) system boundaries are often ill-defined, which can easily result in (3) problem shifting from one aspect of corporate environmental performance to another or from one stage in the life cycle to another. Additionally, false (4) assumptions and a strong (5) contextuality of best practices also overshadow the outcomes of ESO interventions. The relation among these general concepts is analysed and a graphic representation is provided.

**Keywords:** environmental sustainability, systems thinking, unintended consequences, problem shifting, trade-offs

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## 1. INTRODUCTION

Over the past decades, the measurement, reporting and the continuous improvement of *corporate environmental performance* (CEP) has grown in importance. CEP, defined as the outcome of efforts aimed at economising with resources and reducing the environmental harm associated with corporate activities in a life cycle perspective, has become not only an essential component of corporate communication and reputation building but also an important determinant of competitive advantage (Ambec – Lanoie 2008; Hart 1995; Porter – Van der Linde 1995).

Trying to accumulate ‘sustainability capital’ (Figge – Hahn 2005) and to ‘go green’, at least in terms of improving eco-efficiency and complying with ever stricter regulations, manufacturing companies devote considerable resources into it. Notwithstanding accelerating technological progress in a variety of fields that has enhanced the technical feasibility of CEP improvement (e.g. Burritt – Christ 2016; Duflo et al. 2012), and a rapidly growing number of environmental methods and tools (Byggeth – Hochschorner 2006), companies’ investments in environmentally friendly solutions often deliver below expectations.

Although the reasons are manifold, the most frequently mentioned one is that corporate environmental sustainability management has become extraordinarily complex both technologically and contextually. The improvement of CEP requires systems thinking (Williams et al. 2017), a high level of absorptive (Cohen – Levinthal 1990) and adaptive capability (Váncza et al. 2011) and also capability to integrate and manage multidisciplinary knowledge (Gold et al. 2001; Ketata et al. 2015).<sup>1</sup>

These requirements and in particular, the broad scope of the concept of environmental sustainability represent formidable challenges ahead of CEP improvement. Adverse side-effects may surface and materialise with a considerable time lag, and the ultimate impact of several apparently environmentally friendly programmes/solutions often remains smaller than predicted.

<sup>1</sup> Consider the specific example of nanomaterials widely applied in manufacturing: a par excellence example that requires the integration of multidisciplinary knowledge. Klaine et al. (2012: 8) suggest that “it is no longer sufficient for toxicologists to work with chemists and biochemists” to explore the potential toxic features of the materials to be processed. Research “teams must include, among others, material scientists who understand the synthesis, structure, and innate properties of each material; physicists who characterize nanomaterial behaviour; and specialist areas of life sciences to understand how biomolecules can coat or modify nanomaterial surfaces.”

Over and above the well-known environmental rebound effect,<sup>2</sup> a wide variety of hidden ecological burdens and unexpected side-effects may prevent the expected environmental footprint reductions from materialising. Performance improvement may remain confined to a sub-system or to one specific stage of the life cycle, while the adverse side-effects of environmental sustainability-oriented (ESO) interventions may become apparent in other parts of the system or in other stages of the life cycle.

Against this background, the purpose of this paper is to develop conceptual arguments and organise them into a generic framework that could explain the disappointing results of ESO interventions, by analysing the adverse side-effects and other associated problems. We argue that the systemic nature of environmental sustainability generates effective barriers to CEP improvement. Dynamic interactions within the system bring about unintended consequences or adverse side-effects, which may (partly) offset the benefits of ESO interventions. Accordingly, our research question can be formulated as follows:

*What is the reason of the widely-observed phenomenon that many apparently environmentally friendly solutions fail to bring about the expected environmental benefits, or at least, the benefits remain much smaller than predicted?*

This research question clearly delimits the topics covered. This study is intended to explain why some *purposeful* and *well-intentioned* ESO initiatives deliver below expectations. Hence, the issues of greenwashing (Delmas – Burbano 2011; Kallio 2007) – whether firms are engaging in it for business reasons (i.e. driven by society's and investors' expectations, market demand or competitive pressure) or for political legitimacy (Banerjee 2008) – are outside the scope of this paper, irrespective of the fact that the difficulty to identify (the extent of) greenwashing (Ramus – Montiel 2005) is often an important explanatory factor of inferior-to-expected performance improvement. Similarly, illusory expectations about finan-

<sup>2</sup> Environmental rebound effect refers to the phenomenon that improvements in eco-efficiency would often trigger an increase in the demand for the given products or services. Considered from the perspective of the overall environmental impact, this offsets the gains in efficiency (e.g. Greening et al. 2000). For example, Davis et al. (2014) report the results of a large-scale appliance replacement programme in Mexico that subsidised households' replacing their old refrigerators and air-conditioners with energy-efficient models. These authors found that refrigerator replacement reduced electricity consumption considerably less than what had been predicted by ex-ante engineering analyses of the World Bank. Moreover, in the case of air-conditioners, replacement *increased* electricity consumption. The authors concluded that changes in appliance utilisation have (more than) offset the energy efficiency-driven reductions in electricity consumption.

cial benefits, i.e. about return on ESO investments are not addressed in this paper, as it is confined to inferior-to-expectation improvement in CEP.

Our analysis draws on the theory of complex systems (see Williams et al. 2017 employing this perspective with regard to sustainability management), and on the thesis of decision-makers' bounded rationality (Simon 1957), pointing to executives' (and policy-makers') limitations in taking optimal decisions in complex situations.<sup>3</sup> Another influential premise our analysis draws on, is the life cycle assessment (LCA) approach used for estimating products' environmental impact from cradle to grave, i.e. from raw materials extraction to final disposal (Pennington et al. 2004).

The research method of this paper is a review of the business and environment literatures combined with insights from the environmental science and technology literatures. This combination, together with the restructuring of the explored literatures, allows for new conceptualisations and it also makes possible to illustrate our arguments with real-life examples. We apply exploratory and interpretive research and develop propositions about the possible reasons why many ESO interventions in technology, production, energy management and business, in general, fail to come up to expectations.

To the author's knowledge, this paper represents the first attempt to review and synthesise the pitfalls associated with a number of ESO solutions. Transcending the anecdotal approach of listing real-world examples derived from the literature, we organise the reviewed cases into explanatory concepts that may be relevant for both policy-makers and practitioners.

The remainder of this paper proceeds as follows. First, we present details about the applied data gathering and data analysis method. Then, we turn to the results. We present a descriptive, thematic analysis and then we introduce and analyse the categories and concepts that emerged as an outcome of our data collection exercise. We conclude by summarising our arguments and discussing some managerial and policy implications.

## 2. DATA GATHERING AND DATA ANALYSIS

We started our data gathering exercise by looking for articles discussing corporate environmental sustainability management in general, and the difficulties

<sup>3</sup> Notice that bounded rationality can also be turned into advantage: limited capabilities of perception and reasoning could drive decision-makers towards a cooperative attitude, which, in turn, pays back in improved overall performance. The author is indebted to an anonymous reviewer for calling her attention to this point.

practitioners would encounter when implementing ESO initiatives, in particular. We focussed on studies concerned with (a) the systemic features of corporate environmental sustainability, (b) challenges in the measurement and definitions of greenness and, in particular, (c) the pitfalls in ESO interventions, encountered by practitioners, e.g. sustainability officers and other executives.

Since the research question we examine is very specific, and most of the studies that present peculiar problems related to the implementation of sustainability measures fall outside the business and environment literature (they can be found rather in the environmental science and technology literatures), we decided to apply a snowball technique (Fink 2012) instead of starting with a broad sample of articles and narrowing the sample in successive rounds. In this vein, in accordance with the principle of purposeful sampling described by Patton (1990), we first surveyed 12 high-impact review articles discussing the above-listed issues.<sup>4</sup> The selection of these studies was based on the author's prior knowledge and research in the field of eco-innovations and corporate sustainability management.

The first round of data gathering yielded valuable insights about key general concepts related to the subject of our research. Moreover, it permitted us to identify additional references to papers that are discussing:

- unconsidered environmental overheads;
  - unintended consequences and adverse indirect effects of ESO interventions;
- and
- illusory beliefs related to the environmentally benign character of specific solutions.

In the second stage, we checked the content of the papers referred in the 12 original studies that are discussing these issues. If they were, indeed, relevant, we expanded the sample of the surveyed papers also by scrutinising the articles citing the ones picked in the second round of sampling.<sup>5</sup> This exercise was repeated in successive rounds, resulting in the identification of additional relevant studies among the articles cited in or citing the newly included ones. If deemed necessary, snowball sampling was complemented with focussed searches for studies that highlight particular sub-topics or clarify technical questions that emerged over the course of the analysis. Our snowball technique yielded 35 additional papers that were analysed using a method of constant comparison. This method,

<sup>4</sup> Huesemann 2001; Pennington et al. 2004; Hochschorner 2006; Lopez 2007; Aragón-Correa et al. 2010; Hart – Dowell 2011; Searcy 2012; Montiel – Delgado-Ceballos 2014; Adams et al. 2016; WEC 2016; Haffar – Searcy 2017; Williams et al. 2017.

<sup>5</sup> This latter exercise was limited to the 20 highest-cited studies, as ordered by Google Scholar's software. Another limitation we applied to avoid inflating the sample is that we imposed a maximum of two articles to include that discuss the same subject.

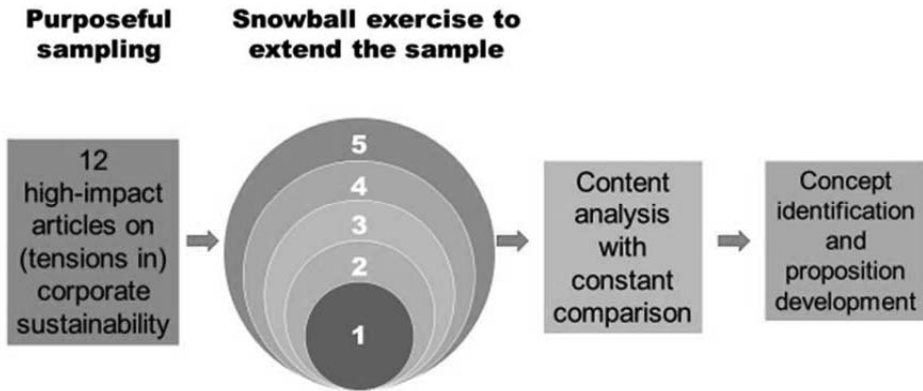


Figure 1. The applied method of data gathering and analysis

1 = Abstract analysis of papers cited in the 12 original studies, that were described as concerned with the unintended consequences and the adverse indirect effects of ESO interventions. Identification of the relevant papers and content analysis.

2 = Abstract analysis of the 20 highest-impact papers citing the ones selected in the previous round. Content analysis of the ones that were considered relevant.

3, 4, 5 = Repetition of the previous exercise.

described in Glaser (1965), implies a simultaneous collection and analysis of the qualitative data. Data analysis, in this case, refers to contrasting the findings of studies included in later stages with the framework that was emerging in the previous rounds of data analysis, so as to reinforce or refine the emerging conceptual framework.

Our data gathering strategy, summarised in *Figure 1*, yielded altogether 47 relevant papers, representing a combination of ‘business and environment’ and ‘environmental science and technology’ literatures.

A limitation of this methodology is that the final sample is far from being exhaustive. Data analysis was limited to a relatively small and skewed sample of relevant studies, in which relatively recent papers are over-represented. Nevertheless, we strongly believe that the quality and the depth of the sampled articles can compensate for the modest size of the sample, as the selected articles are, indeed, up to the point and insightful.

Our *data analysis* involved three steps, starting with a content analysis of the qualitative insights presented in the surveyed papers (first-order analysis) to discover deeper structures, and identify key patterns and similarities. In an effort to develop a conceptual framework, a second-order analysis was performed, as suggested by Strauss and Corbin (2008), and the data were organised into general concepts. Finally, the relation among the general concepts was analysed (Doz 2011) and a graphic representation was provided.

### 3. RESULTS

#### Descriptive thematic analysis

One of the best-known examples of adverse side-effects of ESO solutions is that of catalytic converters (CC) reducing the toxicity of emissions from internal combustion engines. But CC production is by far the largest user of precious metals (Bossi – Gediga 2017), the extraction and refining of which is highly energy-intensive and polluting. Moreover, the functioning of CC increases fuel consumption and thus, carbon dioxide emissions.

The surveyed papers abound in similar examples of adverse indirect effects of seemingly environmentally friendly solutions or ESO interventions. In this section we summarise some examples:

- a) *Remanufacturing*, i.e. restoring used products to a 'like-new' functional state by disassembling, cleaning and rebuilding it, and also replacing defective components to ensure that remanufactured products meet or exceed the standards of newly manufactured ones (Sundin – Brass 2005), is considered a practice of benign environmental impact, since it reduces both waste and resource consumption. However, studies calculating the relative environmental impact of remanufacturing, compared to new product manufacturing, warn that there are some channels, through which this solution represents often-unconsidered burden to the environment. In particular, the environmental impact of activities related to reverse logistics, to the cleaning of the used components (removing contaminants, such as oil and grease), and to re-painting and packaging the remanufactured product needs to be considered (Liu et al. 2014; Bazan et al. 2015).
- b) Similarly, *recycling* is also considered environmentally friendly, at least, compared to product disposal. Recycling is, however, highly energy-intensive and involves heavy consumption of water. The recycling process often generates polluting smokes and effluent (Aragón-Correa – Rubio-Lopez 2007). Improper recycling and waste management methods may be seriously harmful for the environment.<sup>6</sup>
- c) Transition to electric mobility (to *battery-powered electric vehicles*) is considered a key enabler of reducing global greenhouse gas emissions. However, the average carbon content of the electricity used for charging the batteries

<sup>6</sup> For example, Sepúlveda et al. (2010) report about the concentration of toxic material (e.g. heavy metal in soil) in the neighbourhood of waste electrical and electronic equipment recycling plants in China and India, and Tsydenova – Bengtsson (2011) highlight the chemical hazards related to e-waste management.

of electric vehicles is currently higher than that of high-efficiency gasoline-powered vehicles (Graff Zivin et al. 2014), since charging is usually done at night and coal-fired-electricity is used (Tamayao et al. 2015).

- d) Although shifting to *renewable energy* resources is high on the agenda of policy-makers, this shift is accompanied by multiple adverse environmental side-effects. For example, in the case of:
- solar technology: although the operation of the technology does not generate any carbon-dioxide, the extraction, the processing and the disposal of the necessary materials are accompanied by relatively high greenhouse gas emissions (Nugent – Sovacool 2014). Further, the technology requires rare earth elements, the extraction, separation, processing and use of which also entail pollution and involve complex environmental concerns (McLellan et al. 2013);<sup>7</sup>
  - wind power: adverse ecological side-effects can be observed, such as noise, impact on wildlife, e.g. on marine ecosystem (Mann – Teilmann 2013; Premalatha et al. 2014);
  - biomass: adverse effects include excessive water consumption, water pollution, soil degradation and pollution related to the conversion of biomass into energy (Abbasi – Abbasi 2000; Yang et al. 2012);
- e) Interventions aiming at *improving material efficiency* often trigger side-effects, which diminish the benefits gained from eco-efficiency improvement. For example, the reduction of yield losses is a good technique of increasing material efficiency; however, it cuts the availability of scrap for recycling (Allwood et al. 2013). Material efficiency improvement through product life extension is a particularly interesting example of unconsidered side-effects. Allwood et al. (2013) showed that maintaining energy using durable goods in use will, at the end of the day, involve excess energy use. As technology improvement usually materialises in increased energy efficiency of newer generation products, late product replacement may also retard these beneficial environmental impacts.
- f) The use of *nanomaterials* in industrial applications is expected to have a variety of direct and indirect environmental benefits. Direct benefits stem from the application of nanotechnology in energy conversion (of renewable energy resources) and storage (Hussein 2015; Liu et al. 2010), while indirect benefits derive from the improved functionality of products containing nanotechnology-based high-performance materials. Improved functionality increases prod-

<sup>7</sup> The cited authors note that similar problems can be observed with other clean (energy) technologies that also require rare earth elements. Examples include wind power technologies, fuel cells, and batteries for energy storage.



uct lifespan, and/or improves its resource/energy efficiency. Nanotechnology-based solutions are also applied in environmental remediation technologies, e.g. in water filtration and purification. However, occupational health related safety concerns and other adverse effects can partly offset the beneficial environmental effects of nanotechnology applications.<sup>8</sup> Moreover, as reported in some studies (Hischier – Walser 2012; Pallas et al. 2018), the cumulative energy demand for nanomaterial production is orders for magnitude higher than that of the conventional material.

- g) Although *additive manufacturing* is expected to bring about major reductions in the environmental footprint of production, e.g. through (1) increased resource efficiency (elimination of waste in production and consumption), (2) reconfigured supply chains (localised production, significant reduction of transport-intensity), (3) a move towards circular economy (nearly perfect recyclability of metal powder), there are several and often unconsidered factors that may moderate the ultimate impact of the technology (Ford – Despeisse 2016). First, the energy consumption of additive manufacturing (of the production of input material and of the processing itself) may significantly exceed that of the conventional manufacturing techniques. Second, the toxicity of the material used for additive manufacturing is higher than that of conventional material inputs. Further, the recyclability of products (in particular of the multi-material ones) produced using an additive manufacturing technique is questionable.

In sum, the surveyed papers provided clear evidence of the complexity of environmental sustainability, of the uncertainties surrounding its measurement and management, and of the prevalence of unconsidered adverse side-effects. The papers emphasised that a broad spectrum of environmental impacts needs to be considered and addressed by interventions, instead of taking a single-dimensional view of environmental performance assessment. The papers also showed that a non-negligible part of environmental activities, themselves, imply environmental damages.

### Emerging concepts

Trying to go beyond the described phenomena and identify deeper dimensions, we organised the qualitative data into aggregate concepts. Our second order analysis (Strauss – Corbin 2008) of the descriptions presented in the previous

<sup>8</sup> For example, according to Gómez-Pastora et al. (2014), the toxicity of these materials or the risk stemming from their interaction with natural elements and transforming them into a more hazardous form require further investigations.

sub-section suggests five, partly interconnected and complementary general concepts that, together, elucidate some key reasons, why green interventions would often deliver below expectations. Accordingly, overlooked (1) interconnections among resources and environmental impacts, e.g. trade-offs, reveal that (2) system boundaries are often ill-defined, which can easily result in (3) problem shifting: from one aspect of corporate environmental performance to another or from one stage in the life cycle to another. Further, false (4) assumptions and a strong (5) contextuality of best practices also overshadow the outcomes of ESO interventions. This section discusses these concepts in turn, and illustrates them with real-life examples from the surveyed literatures.

*Interconnections and/or trade-offs:* The first general concept we identified is interconnection among resources, forms of waste and aspects of CEP. The interconnection of resources, such as water and energy or renewable energy resources and traditional resources, is a commonplace in environmental science and technology literatures (McMahon – Price 2011; Allwood et al. 2013; Van den Bergh et al. 2015), but it is often overlooked by corporate environmental management practitioners.

The interconnection between water and energy is obvious if we consider that water is necessary for extracting and processing fuels or for cooling power plant equipment. Conversely, treating wastewater, pumping groundwater, transporting water, desalinating water, or replacing water in manufacturing process (e.g. cooling with air) are highly energy-intensive (McMahon – Price 2011). Other interconnections can be identified in the high average energy-intensity of some apparently environmentally friendly solutions, such as recycling, carbon capture and additive manufacturing.

In addition to *resources*, various forms of *waste* are also interconnected, e.g. material waste and excess energy consumption. If excessive in-process inventory (buffer) is kept, this type of material waste may increase throughput eliminating/reducing unplanned equipment downtime. In this way, the excess buffer reduces excess energy-consumption of machinery in idle state. More work in progress will, however, increase the likelihood of depreciation (damage, oxidation, spoilage) of (unfinished) goods in storage (multiplication of material waste) and/or require excessive internal transport, which in turn is associated with excess energy-consumption (Colledani et al. 2014). Another example of interconnected forms of waste is the necessity to weigh using (auxiliary material waste) against rapid tool wear excessive lubricants or cutting fluid (Sheehan et al. 2016).

These interconnections suggest two lessons. First, various aspects of CEP *jointly* determine corporate environmental performance: a discrete management of specific impacts will fail to deliver the expected results. Second, interconnec-

tions cannot be restricted to complementarity and synergy among aspects defining CEP: seemingly disparate environmental issues often *trade off against each other*. Trade-offs refer to the situation when improvement in one aspect of environmental performance comes at the expense of another (Hahn et al. 2010). For example, such trade-offs can be observed, among individual efficiency categories (material efficiency and energy efficiency).

In summary, frequent trade-off situations, driven by the interconnection among resources, among forms of waste and among environmental impacts, limit the benefits that can be derived from the ESO interventions. Minimisation of one form of waste may increase another type of waste. Interventions aiming at reducing/eliminating a specific environmental impact category may have adverse side-effects: they may trigger other harmful-for-the-environment impacts.

*System boundaries*: The second emerging concept within our qualitative database is that of ‘system boundaries’: their excessively narrow definition, or the consideration of one single dimension of the system is behind many illusory beliefs concerning the overall (beneficial) impact of ESO solutions/interventions (Korhonen 2005). For example, the environmentally friendly character of solar technology is straightforward if its use-phase is considered in isolation. However, if other stages in the product life cycle are included in the assessment, such as raw material extraction, production, or disposal, the ‘green shade’ of this solution will already be less brilliant.

Another example is the case of waste to energy systems (surveyed by Astrup et. al. 2015). Waste-to-energy solutions are considered eco-friendly if carried out using advanced technology. However, if evaluations consider not only the effectiveness of the waste-to-energy conversion methods, but calculate also the impacts of (a) the associated air pollution, (b) residue management (after the thermal treatment process) and (c) the capital goods used in the waste-to-energy processes, this ‘broadening of system boundaries’ taints the environmentally friendly character of the given solution.

Finally, consider item (c) from the list of illustrative examples in the previous subsection. If greenhouse gas emissions are accounted for only in the use-phase of the vehicles, electric vehicles are rightly labelled as zero-emission, environmentally friendly solutions. If, however, the electricity generation mix (and the share of coal) used for battery charging is also taken into account, overall environmental benefits are far from unambiguous (Holland et al. 2016). Further, the high energy costs of battery manufacture and recycling also need to be included in the overall assessment (see e.g. Larcher – Tarascon 2015).

Ill-defined system boundaries assessing the environmental impact of specific solutions may also propose a dimmer picture than the reality. For example,

focusing on the *production stage* of nanotechnology-enabled products, LCAs demonstrate a high cumulative energy demand (of nanomaterial production). Conversely focusing on the use-phase, LCAs can rightly emphasize the large energy-saving potential of nanomaterial-based products (see survey by Hirschier – Walsen 2012).

The correct definition of system boundaries is a major issue also in the case of industrial symbiosis solutions. One of the major weaknesses of the industrial symbiosis concept<sup>9</sup>, for example, is that this approach may be burdened with adverse incentives. Scholars and policy-makers hail this concept as a key contributor to ecologically sustainable development of industry. However, when the key performance indicators concern the exchange of waste streams, this moves the focus away from a more traditional pollution prevention principle, where waste should rather be prevented and wasteful production processes should be substituted. In Korhonen's (2005) wording this is a '*system versus its components*' controversy. Accordingly, the impact of the whole system will, indeed, be reduced through industrial symbiosis, but the impact of the individual components of the system is not considered. Focusing solely on the interactions among the constituents of the system (on utilisation of each other's waste material and waste energy flows) will provide 'perverse' incentives to economic actors, namely that individual firms should maintain or even increase their waste production to supply collaborating partners with raw materials. This may "perpetuate a wasteful production rather than motivate development of cleaner processes." (Duflou et al. 2012: 603).

*Problem shifting*: The next concept, *problem shifting*, links the previous two general constructs. Environmental problem shifting occurs if interventions focusing on one aspect of sustainability or one stage in the product life cycle, result in the worsening of another aspect (e.g. in trade-off situations) or to problems emerging in another life-cycle stage.

Problem shifting is closely associated with system boundaries. If these are defined excessively narrowly, for example, if ESO interventions focus exclusively on greenhouse gas emissions, this runs the risk of overlooking equally relevant environmental impacts or – even worse – of shifting the problem to other, interconnected environmental impacts, as outlined in the case of renewable energy resources in the previous sub-section.

Problems can be displaced not only from one environmental impact to another but also from one component of the system (sub-system) to another, if system

<sup>9</sup> A simplified description of this concept is that waste from one industrial process or company can serve as raw material for another. The cooperating actors use each other's material and energy flows, and reduce thereby the impact of industry on the environment (Chertow 2000).

boundaries are defined too narrowly. For example, interventions aiming at eco-optimisation or resource-efficiency maximisation are implemented at a specific level within the manufacturing system: at device (machine) level, or at the level of the production cell, the production line, the facility, the global corporation, or the global value chain. Obviously, interventions aiming at the optimisation of resource consumption at machine or at production-line level (i.e. at process level), may not be optimal at facility level (system level), and vice versa (Dufloy et al. 2012). For example, optimisation of energy consumption at machine level implies its switching to a state of reduced power demand (or switching it off) while waiting for parts. However, this may compromise system throughput, and thus, reduce resource efficiency at system level. Besides problem displacement to a higher hierarchical level, this is, at the same time, a classic trade-off situation. Another typical problem-displacement case is resource optimisation at business unit level, by way of displacing specific production processes (with the related resource consumption and embedded emissions) to pollution havens.<sup>10</sup>

*Assumptions:* The fourth general concept we identified is the role of *assumptions*. The idea in brief is that the implementation of ESO interventions or the labelling of certain solutions as environmentally friendly is always moderated by assumptions. However, in most of the real-life contexts, these assumptions simply do not hold. For example, most of the items in the list presented in the previous sub-section have the *hidden assumption* that *environmentally friendly practices have no adverse environmental consequences*, which, as argued previously, is not the case.

Consider, for example, item (a) described in the previous sub-section, i.e. the assumptions related to remanufacturing decisions. Sustainability gains from remanufacturing stem from saving resources (material and energy) and implementing circular economy principles. One of the implicit assumptions here is that it is relatively easy to disassemble the product. Obviously, the sustainability impact of remanufacturing is substantially reduced if the product had not been designed for remanufacturing (Ferguson – Souza 2010). Additional remanufacturing-related, more or less implicit assumptions include that:

- a well-functioning reverse logistics network is available and transportation does not add significantly to total energy costs;
- the recovered products are all suitable to be remanufactured (in reality, part of them needs to be disposed, because of irreparable damages or extreme wear);

<sup>10</sup> Note that evidence is mixed with respect to offshoring pollution, i.e. optimising local environmental quality in rich countries. A review of arguments for and against this hypothesis is beyond the limits of this paper. (See e.g. López et al. 2013; Malik – Lan 2016.)

- the recovery of the products can be repeated infinitely (in reality, access to products and components often poses huge problems for remanufacturers, and materials often degrade in the process of remanufacturing);
- the obsolescence rate of the given product is low (which is not always the case);<sup>11</sup> and
- the energy consumption of and the CO<sub>2</sub> emissions and waste generation related to the remanufacturing process are negligible (Bazan et al. 2015).

These assumptions are often too strong to be realistic. Gutowski et al. (2011) surveyed 25 case studies for 8 different product categories to find out whether remanufacturing can, indeed, save energy. The results were, at best, mixed, with 8 straightforward positive cases out of 25.

Considering item (g), the beneficial environmental impact of additive manufacturing depends on the speed of the diffusion of this manufacturing technique, and on the extent it really changes the global structure of production (and brings about localised or decentralised production).

*Contextuality:* ESO interventions often involve the imitation of best practice solutions implemented elsewhere. Success is, however, usually constrained by *contextual factors* – the fifth aggregate concept that emerged as a result of the second-order analysis of our qualitative data. Some of the cases listed in the previous sub-section illustrate the importance of contextual factors. For example, in the case of remanufacturing or recycling, the methods applied for cleaning the parts to be remanufactured and the development level of the technology applied for recycling influence the overall benefits (see footnote 6). Or, take the example of shifting to electric vehicles. The magnitude of the derived benefits depends on the cleanness of the electric grid (on the share of coal in the energy mix and in the marginal emissions from an increased demand for electric power to charge electric vehicles).

As for the magnitude of the benefits stemming from shifting to renewable energy resources, there are huge contextual differences in wind power and solar power technologies (Nugent – Sovacool 2014) originating in differences in the material used, in the energy-intensity and energy composition of wind/solar power manufacturing processes<sup>12</sup>, differences in the size and capacity of wind/

<sup>11</sup> If technological progress aiming to improve the use-phase energy consumption of new products is above a certain speed, recycling would be a better option than remanufacturing, since new energy efficient vintages would make the remanufactured but relatively more energy consuming models obsolete.

<sup>12</sup> Quoting Guezuraga et al. (2012), Nugent – Sovacool (2014: 238) remarked that the manufacturing of the same wind power plant technology in Germany would result in less than half of the total emissions compared to what such a process would entail in China.

solar power plants, in the physical and natural conditions of the sites where these plants operate, in the frequency and quality of maintenance, and so forth.

Another example is the non-negligible differences in LCA results of ICT products. Comparisons of different LCA results reveal that contextual factors, e.g. the patterns of use (total use of the product, intensity of use and product lifespan), the average vintage (this influences unit electricity consumption), the number of users, the location (e.g. local electricity mix), the technological level of local manufacturing and of end-of-life treatment can significantly modify the outcome of LCAs (Arushanyan et al. 2014; Suckling – Lee 2015).

Again, studies assessing the performance of solid waste management systems display large disparities in terms of the associated benefits. The variability of the results can be explained, among others, with different composition of waste, different efficiency of technology use, or different local energy supply mix, i.e. with *contextual factors* (Laurent et al. 2014).

Following the presentation of the five general concepts that emerged from the second-order analysis of our qualitative data, we now turn to the relations among these concepts.

As suggested previously, these five general concepts are complementary and interrelated. Taken together, they reflect the systemic nature of corporate environmental sustainability. Systems can be modelled using *assumptions* concerning their attributes and *boundaries*. System functioning is influenced by its external and internal environment, i.e. by *contextual factors*. One of the key characteris-

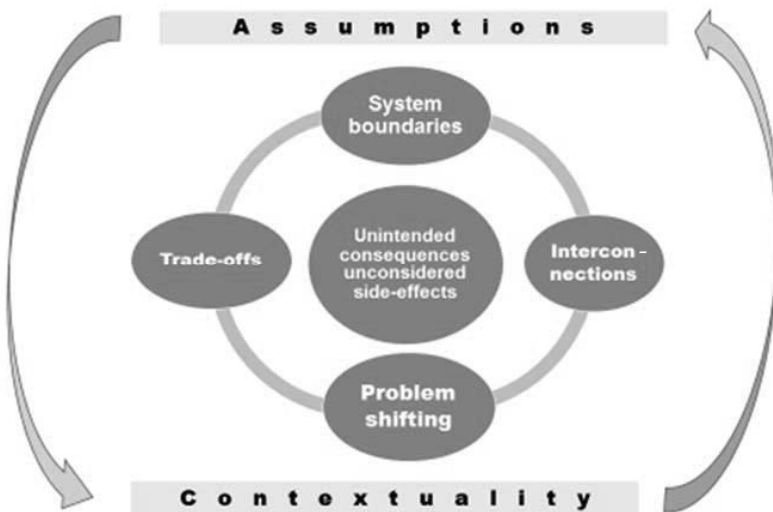


Figure 2. Factors accounting for the inferior-to-expected effectiveness of ESO interventions

tics of the internal environment is the *interconnection* between the constituents of the system: this accounts for the emergence of *trade-offs* or of synergy effects in the case of external interventions in the functioning of the system.

The dynamic interrelationship of the five concepts is illustrated in *Figure 2*, which demonstrates that these factors *jointly* account for the inferior-to-expected effectiveness of ESO interventions.

#### 4. CONCLUSIONS AND IMPLICATIONS

The purpose of this article was to explain, why the benefits of ESO interventions usually remain smaller than expected. In a process of a systematic literature review, we identified five complementary and interrelated factors that jointly account for the inferior-to-expected effectiveness of ESO interventions. We found that interconnected resources, forms of waste and environmental impacts that trade off against each other, are among the key explanatory factors of inferior-to-expected results. This phenomenon highlights the importance of a correct definition of system boundaries when devising ESO interventions, so as to avoid problem shifting from one impact category to another or from one stage in the product life cycle to another. Further, our review of the literature indicates that false assumptions and a strong contextuality of best practices also overshadow the outcomes of ESO interventions. These five factors are all rooted in the systemic nature of corporate environmental sustainability.

This paper generates a number of implications for practitioners including environmental (and other functional) officers and top senior corporate executives. A key lesson is that the (size of the) benign outcome of investments into ESO solutions is not self-evident: contextual factors and interdependencies among the constituents of the broad system may moderate the quality and the quantity of the results of interventions. Corporate executives need to bear in mind that the impact of ESO interventions is often constrained by unintended side-effects. When devising ESO programmes and interventions, the interconnection between various environmental impact categories needs to be understood, and potential trade-offs taken into account.<sup>13</sup>

<sup>13</sup> As a matter of fact, having experimented with the 'business case for sustainability' (Porter – Van der Linde 1995) for decades, corporate executives must be well aware of the fact that both the returns on and the results (in terms of improvements in CEP) of investments in going green will probably remain inferior to expectations. Communicating optimistic expectations is, however, a necessary part of the corporate reputation-building exercise.



When considering to launch a particular ESO programme or to implement an ESO intervention, a systematic thought experiment needs to be performed. The expected and the possible impacts of the planned programme/intervention need to be taken into account at multiple levels, by broadening the initially considered boundaries of the system.

Adopting a systems perspective also implies considering the assumptions related to the planned programme/intervention: making implicit assumptions explicit in the course of the thought experiment. Next, the excessively strong assumptions need to be gradually relieved. Finally, the thought experiment also needs to address the context of the planned programme/intervention and compare it with the similar actions implemented elsewhere. This helps to identify the specific contextual factors that may moderate (constrain) the outcome of an identical programme/intervention. Obviously, thought experiments do not necessarily improve the effectiveness of sustainability-oriented corporate interventions, but they definitely contribute to avoiding illusory expectations. Moreover, they might direct executives' attention to eventual trade-offs, moderating factors and/or to selected systemic interconnections, allowing these aspects to be also addressed.

## 5. REFERENCES

- Abbasi, S. A. – Abbasi, N. (2000): The Likely Adverse Environmental Impacts of Renewable Energy Sources. *Applied Energy*, 65(1): 121–144.
- Adams, R. – Jeanrenaud, S. – Bessant, J. – Denyer, D. – Overy, P. (2016): Sustainability-Oriented Innovation: A Systematic Review. *International Journal of Management Reviews*, 18(2): 180–205.
- Allwood, J. M. – Ashby, M. F. – Gutowski, T. G. – Worrell, E. (2013): Material Efficiency: Providing Material Services with Less Material Production. *Philosophical Transactions of the Royal Society A*, 371(1986): 1–15.
- Altuzarra, A. (2016): Convergence R&D Intensity across European Countries. *Acta Oeconomica*, 66(2): 351–374.
- Ambec, S. – Lanoie, P. (2008): Does it Pay to be Green? A Systematic Overview. *The Academy of Management Perspectives*, 22(4): 45–62.
- Aragón-Correa, J. A. – Rubio-Lopez, E. A. (2007): Proactive Corporate Environmental Strategies: Myths and Misunderstandings. *Long Range Planning*, 40(3): 357–381.
- Arushanyan, Y. – Ekener-Petersen, E. – Finnveden, G. (2014): Lessons Learned – Review of LCAs for ICT Products and Services. *Computers in Industry*, 65(2): 211–234.
- Astrup, T. F. – Tonini, D. – Turconi, R. – Boldrin, A. (2015): Life Cycle Assessment of Thermal Waste-to-Energy Technologies: Review and Recommendations. *Waste Management*, 37: 104–115.
- Banerjee, S. B. (2008). Corporate Social Responsibility: The Good, the Bad and the Ugly. *Critical Sociology*, 34(1): 51–79.

- Bazan, E. – Jaber, M. Y. – El Saadany, A. M. (2015): Carbon Emissions and Energy Effects on Manufacturing–Remanufacturing Inventory Models. *Computers & Industrial Engineering*, 88: 307–316.
- Bossi, T. – Gediga, J. (2017): The Environmental Profile of Platinum Group Metals. *Johnson Matthey Technology Review*, 61(2): 111–121.
- Burritt, R. – Christ, K. (2016): Industry 4.0 and Environmental Accounting: A New Revolution? *Asian Journal of Sustainability and Social Responsibility*, 1(1): 23–38.
- Byggeth, S. – Hochschorner, E. (2006): Handling Trade-Offs in Ecodesign Tools for Sustainable Product Development and Procurement. *Journal of Cleaner Production*, 14(15): 1420–1430.
- Carrillo-Hermosilla, J. – Könnölä, T. (2010): Diversity of Eco-Innovations: Reflections from Selected Case Studies. *Journal of Cleaner Production*, 18(10): 1073–1083.
- Chertow, M. R. (2000): Industrial Symbiosis: Literature and Taxonomy. *Annual Review of Energy and the Environment*, 25(1): 313–337.
- Cohen, W. M. – Levinthal, D. A. (1990): Absorptive Capacity: A New Perspective on Learning and Innovation. *Administrative Science Quarterly*: 128–152.
- Colledani, M. – Tolio, T. – Fischer, A. – Iung, B. – Lanza, G. – Schmitt, R. – Váncza, J. (2014): Design and Management of Manufacturing Systems for Production Quality. *CIRP Annals-Manufacturing Technology*, 63(2): 773–796.
- Davis, L. W. – Fuchs, A. – Gertler, P. (2014): Cash for Coolers: Evaluating a Large-Scale Appliance Replacement Program in Mexico. *American Economic Journal: Economic Policy*, 6(4): 207–238.
- Delmas, M. A. – Burbano, V. C. (2011): The Drivers of Greenwashing. *California Management Review*, 54(1): 64–87.
- Doz, Y. (2011): Qualitative Research for International Business. *Journal of International Business Studies*, 42(5): 582–590.
- Dufflou, J. R. – Sutherland, J. W. – Dornfeld, D. – Herrmann, C. – Jeswiet, J. – Hauschild, M. – Kara, S. – Kellens, K. (2012): Towards Energy and Resource Efficient Manufacturing: A Processes and Systems Approach. *CIRP Annals-Manufacturing Technology*, 61(2): 587–609.
- Ferguson, M. E. – Souza, G. C. (eds.) (2010): *Closed-Loop Supply Chains: New Developments to Improve the Sustainability of Business Practices*. Boca Raton, FL: CRC Press.
- Figge, F. – Hahn, T. (2005): The Cost of Sustainability Capital and the Creation of Sustainable Value by Companies. *Journal of Industrial Ecology*, 9(4): 47–58.
- Fink, A. (2012): *How to Conduct Surveys: A Step-by-Step Guide*. Los Angeles CA: Sage Publications.
- Finnveden, G. – Hauschild, M. Z. – Ekvall, T. – Guinée, J. – Heijungs, R. – Hellweg, S. – Koehler, A. – Pennington, D. – Suh, S. (2009): Recent Developments in Life Cycle Assessment. *Journal of Environmental Management*, 91(1): 1–21.
- Ford, S. – Despeisse, M. (2016): Additive Manufacturing and Sustainability: An Exploratory Study of the Advantages and Challenges. *Journal of Cleaner Production*, 137: 1573–1587.
- Glaser, B. G. (1965): The Constant Comparative Method of Qualitative Analysis. *Social Problems*, 12(4): 436–445.
- Gold, A. H. – Malhotra, A. – Segars, A. H. (2001): Knowledge Management: An Organizational Capabilities Perspective. *Journal of Management Information Systems*, 18(1): 185–214.
- Gómez-Pastora, J. – Bringas, E. – Ortiz, I. (2014): Recent Progress and Future Challenges on the Use of High Performance Magnetic Nano-Adsorbents in Environmental Applications. *Chemical Engineering Journal*, 256: 187–204.
- Graff Zivin, J. S. – Kotchen, M. J. – Mansur, E. T. (2014): Spatial and Temporal Heterogeneity of Marginal Emissions: Implications for Electric Cars and Other Electricity-Shifting Policies. *Journal of Economic Behavior & Organization*, 107: 248–268.

- Greening, L. A. – Greene, D. L. – Difiglio, C. (2000): Energy Efficiency and Consumption – The Rebound Effect – A Survey. *Energy Policy*, 28(6): 389–401.
- Guezuraga, B. – Zauner, R. – Pölz, W. (2012): Life Cycle Assessment of Two Different 2 MW Class Wind Turbines. *Renewable Energy*, 37(1): 37–44.
- Haffar, M. – Searcy, C. (2017): Classification of Trade-Offs Encountered in the Practice of Corporate Sustainability. *Journal of Business Ethics*, 140(3): 495–522.
- Hahn, T. – Figge, F. – Pinkse, J. – Preuss, L. (2010): Trade-Offs in Corporate Sustainability: You Can't Have Your Cake and Eat It. *Business Strategy and the Environment*, 19(4): 217–229.
- Hart, S. L. (1995): A Natural-Resource-Based View of the Firm. *Academy of Management Review*, 20(4): 986–1014.
- Hart, S. L. – Dowell, G. (2011): A Natural-Resource-Based View of the Firm: Fifteen Years After. *Journal of Management*, 37(5): 1464–1479.
- Hischier, R. – Walser, T. (2012): Life Cycle Assessment of Engineered Nanomaterials: State of the Art and Strategies to Overcome Existing Gaps. *Science of the Total Environment*, 425: 271–282.
- Holland, S. P. – Mansur, E. T. – Muller, N. Z. – Yates, A. J. (2016): Are There Environmental Benefits From Driving Electric Vehicles? The Importance of Local Factors. *American Economic Review*, 106(12): 3700–3729.
- Huesemann, M. H. (2001): Can Pollution Problems be Effectively Solved by Environmental Science and Technology? An Analysis of Critical Limitations. *Ecological Economics*, 37(2): 271–287.
- Hussein, A. K. (2015): Applications of Nanotechnology in Renewable Energies – A Comprehensive Overview and Understanding. *Renewable and Sustainable Energy Reviews*, 42: 460–476.
- Kallio, T. J. (2007): Taboos in Corporate Social Responsibility Discourse. *Journal of Business Ethics*, 74(2): 165–175.
- Ketata, I. – Sofka, W. – Grimpe, C. (2015): The Role of Internal Capabilities and Firms' Environment for Sustainable Innovation: Evidence for Germany. *R&D Management*, 45(1): 60–75.
- Klaine, S. J. – Koelmans, A. A. – Horne, N. – Carley, S. – Handy, R. D. – Kapustka, L. – Nowack, B. – von der Kammer, F. (2012): Paradigms to Assess the Environmental Impact of Manufactured Nanomaterials. *Environmental Toxicology and Chemistry*, 31(1): 3–14.
- Korhonen, J. (2005): Industrial Ecology for Sustainable Development: Six Controversies in Theory Building. *Environmental Values*, 14(1): 83–112.
- Larcher, D. – Tarascon, J. M. (2015): Towards Greener and More Sustainable Batteries for Electrical Energy Storage. *Nature Chemistry*, 7(1): 19–29.
- Laurent, A. – Bakas, I. – Clavreul, J. – Bernstad, A. – Niero, M. – Gentil, E. – Hauschild, M. Z. – Christensen, T. H. (2014): Review of LCA Studies of Solid Waste Management Systems–Part I: Lessons Learned and Perspectives. *Waste Management*, 34(3): 573–588.
- Liu, C. – Li, F. – Ma, L. P. – Cheng, H. M. (2010): Advanced Materials for Energy Storage. *Advanced Materials*, 22(8): 28–62.
- Liu, W. W. – Zhang, B. – Li, Y. Z. – He, Y. M. – Zhang, H. C. (2014): An Environmentally Friendly Approach for Contaminants Removal Using Supercritical CO<sub>2</sub> for Remanufacturing Industry. *Applied Surface Science*, 292: 142–148.
- López, L. A. – Arce, G. – Zafrilla, J. E. (2013): Parcelling Virtual Carbon in the Pollution Haven Hypothesis. *Energy Economics*, 39: 177–186.
- Malik, A. – Lan, J. (2016): The Role of Outsourcing in Driving Global Carbon Emissions. *Economic Systems Research*, 28(2): 168–182.
- Mann, J. – Teilmann, J. (2013): Environmental Impact of Wind Energy. *Environmental Research Letters*, Vol. 8, 035001, <http://iopscience.iop.org/article/10.1088/1748-9326/8/3/035001/pdf>.

- McLellan, B. C. – Corder, G. D. – Ali, S. H. (2013): Sustainability of Rare Earths – An Overview of the State of Knowledge. *Minerals*, 3(3): 304–317.
- McMahon, J. E. – Price, S. K. (2011): Water and Energy Interactions. *Annual Review of Environment and Resources*, 36: 163–191.
- Montiel, I. – Delgado-Ceballos, J. (2014): Defining and Measuring Corporate Sustainability: Are We There Yet? *Organization & Environment*, 27(2): 113–139.
- Nugent, D. – Sovacool, B. K. (2014): Assessing the Lifecycle Greenhouse Gas Emissions from Solar PV and Wind Energy: A Critical Meta-Survey. *Energy Policy*, 65: 229–244.
- Pallas, G. – Peijnenburg, W. J. – Guinée, J. B. – Heijungs, R. – Vijver, M. G. (2018): Green and Clean: Reviewing the Justification of Claims for Nanomaterials from a Sustainability Point of View. *Sustainability*, 10(3): 689.
- Patton, M. Q. (1990): *Qualitative Evaluation and Research Methods*. Newbury Park, CA: SAGE Publications.
- Pennington, D. W. – Potting, J. – Finnveden, G. – Lindeijer, E. – Jolliet, O. – Rydberg, T. – Rebitzer, G. (2004): Life Cycle Assessment Part 2: Current Impact Assessment Practice. *Environment International*, 30(5): 721–739.
- Pires, J. C. M. – Martins, F. G. – Alvim-Ferraz, M. C. M. – Simões, M. (2011): Recent Developments on Carbon Capture and Storage: An Overview. *Chemical Engineering Research and Design*, 89(9): 1446–1460.
- Porter, M. E. – Van der Linde, C. (1995): Toward a New Conception of the Environment-Competitiveness Relationship. *The Journal of Economic Perspectives*, 9(4): 97–118.
- Premalatha, M. – Abbasi, T. – Abbasi, S. A. (2014): Wind Energy: Increasing Deployment, Rising Environmental Concerns. *Renewable and Sustainable Energy Reviews*, 31: 270–288.
- Ramus, C. A. – Montiel, I. (2005). When are Corporate Environmental Policies a Form of Greenwashing? *Business & Society*, 44(4): 377–414.
- Searcy, C. (2012): Corporate Sustainability Performance Measurement Systems: A Review and Research Agenda. *Journal of Business Ethics*, 107(3): 239–253.
- Sepúlveda, A. – Schluep, M. – Renaud, F. G. – Streicher, M. – Kuehr, R. – Hagelüken, C. – Gerecke, A. C. (2010): A Review of the Environmental Fate and Effects of Hazardous Substances Released from Electrical and Electronic Equipments during Recycling: Examples from China and India. *Environmental Impact Assessment Review*, 30(1): 28–41.
- Sheehan, E. – Braun, A. T. – Kuhlmann, T. – Sauer, A. (2016): Improving Material Efficiency for Ultra-Efficient Factories in Closed-Loop Value Networks. *Procedia CIRP*, 40: 455–462.
- Simon, H. A. (1957): *Models of Man*. New York: Wiley&Sons.
- Strauss, A. – Corbin, J. (2008): *Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory* (3rd ed.). Thousand Oaks, CA: Sage Publications.
- Suckling, J. – Lee, J. (2015): Redefining Scope: The True Environmental Impact of Smartphones? *The International Journal of Life Cycle Assessment*, 20(8): 1181–1196.
- Sundin, E. – Bras, B. (2005): Making Functional Sales Environmentally and Economically Beneficial through Product Remanufacturing. *Journal of Cleaner Production*, 13(9): 913–925.
- Tamayao, M. A. M. – Michalek, J. J. – Hendrickson, C. – Azevedo, I. M. (2015): Regional Variability and Uncertainty of Electric Vehicle Life Cycle CO<sub>2</sub> Emissions Across the United States. *Environmental Science & Technology*, 49(14): 8844–8855.
- Tsydenova, O. – Bengtsson, M. (2011): Chemical Hazards Associated with Treatment of Waste Electrical and Electronic Equipment. *Waste Management*, 31(1): 45–58.
- Váncza, J. – Monostori, L. – Lutters, D. – Kumara, S. R. – Tseng, M. – Valckenaers, P. – Van Brusel, H. (2011): Cooperative and Responsive Manufacturing Enterprises. *CIRP Annals-Manufacturing Technology*, 60(2): 797–820.

- van den Bergh, J. – Folke, C. – Polasky, S. – Scheffer, M. – Steffen, W. (2015): What if Solar Energy Becomes Really Cheap? A Thought Experiment on Environmental Problem Shifting. *Current Opinion in Environmental Sustainability*, 14: 170–179.
- WEC (2016): *World Energy Resources 2016*. London: World Energy Council.
- Williams, A. – Kennedy, S. – Philipp, F. – Whiteman, G. (2017): Systems Thinking: A Review of Sustainability Management Research. *Journal of Cleaner Production*, 148: 866–881.
- Yang, Y. – Bae, J. – Kim, J. – Suh, S. (2012): Replacing Gasoline with Corn Ethanol Results in Significant Environmental Problem-Shifting. *Environmental Science & Technology*, 46(7): 3671–3678.