The Role of Frugal Innovation in the Global Diffusion of Green Technologies

Abstract:

The paper suggests that the debate on sustainable development and sustainable innovation could profit from the concept of frugal innovation, because both concepts acknowledge the limitations of a resource constraint world. The complex relationship between frugal innovation and sustainable innovation is explored in conceptual terms and results in criteria, which denote potential overlaps between both concepts. Furthermore, the paper analyses world trade data with green technologies to demonstrate the increasing relevance of South-South and North-South trade and to derive implications for frugal innovation. Moreover, case studies of frugal and sustainable innovations are analysed in order to highlight their requirements and implications. Maybe the most important conclusion stemming from the considerations in this article is, that the integration of frugal and sustainable innovation principles can breathe new life into the discussion about sustainable innovation and sustainable development in general.

Keywords: frugal innovation, sustainable innovation, eco-innovation, sustainable development, pro-poor innovation

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1 Introduction

For today's companies, innovation is often a highly resource intensive activity, involving large public and private investments to create high specification products and services for an elite group of customers with an already high ecological footprint. In contrast, frugal innovation is inclusive. Through creativity at every stage of the innovation process, it aims to generate more value from fewer resource inputs while at the same time reaching out to a customer base with so far relatively low levels of consumption and, consequently, a small ecological footprint.

In the past decade there have been several changes, which have induced the emergence of new, frugally oriented models of innovation for development (Radjou/Prabhu, 2016, Heeks et al. 2014):

- increasing awareness of poor consumers as an accessible mass market,
- increasing involvement of private sector in innovation for the poor,
- growing technological capabilities - and hence absorptive capacity - within developing countries, and

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- the advent of new platform technologies particularly in the field of information and communication that form the basis for more accessible business models.

The paper suggests that the ongoing debate on sustainable development and sustainable innovation could profit from the notion of frugal innovation as proposed in a separate strand of literature. While other authors have found that both approaches could be both mutually reinforcing and conflicting (Le Bas, 2016; Brem and Wolfram, 2014), their relationships and the terms of potential synergies between them have so far neither been very deeply explored in conceptual terms nor resulted in a clear demarcation of the overlaps between both concepts.

Against this background, this paper aims to establish a notion of "sustainable frugal innovation" and to outline to what extent this could contribute to resolving emerging tensions between economic, social and ecological sustainability that are undoubtedly emerging at low to mid-income markets for green solutions.

To acknowledge the purported overlap between both concepts it is in a first step important to acknowledge that - while cost-effectiveness matters - (Tiwari/Herstatt, 2012) frugal innovation is, by ambition, aimed at solutions which are "more than just cheap" (Bound/Thornton, 2012).

In the context of this paper, it is therefore helpful to define and understand frugal innovation based on its original social impetus (Gupta, 1997; Gupta, 2008;). Different from classic innovation efforts, frugal innovation is defined not only by its outcome but also by its (potential) socioeconomic impact. While making solutions available to a broader range of the population takes priority, a large share of the literature acknowledges that frugal innovators should take into account all relevant local framework conditions not least as in developing economies, environmental may very directly become social issues as well (Seyfang and Smith, 2007; Agarwal and Brem, 2012). In this paper, we will therefore argue that the frugal innovation approach has a potential to reconcile the three dimension of sustainability (ecological, social and economic) and to avoid that the low- to mid-price market for green products becomes saturated by solutions that do not live up to basic principles of environmental sustainability.

In order to substantiate this claim theoretically as well as empirically, the paper is organised as follows: Section 2 elaborates on the link between frugal and sustainable innovation in conceptual terms. Section 3 analyses international trade with green technologies and derives implications for frugal innovation. In section 4, case studies are discussed in order to enhance our understanding of requirements, characteristics, and

implications of frugal and sustainable innovation. Section 5 summarises the findings and concludes.

2 Conceptual Link between Frugal and Sustainable Innovation

In the shortest possible terms, frugal innovation can be defined as the attempt to deliver solutions that actually work and develop positive impact under conditions of scarcity rather than fail fast due to a lack of robustness, over-specification, complex maintenance or simply never come to be deployed as their price exceeds what is locally affordable (European Commission, 2016; Radjou/Prabhu, 2015; Bound/Thornton, 2012). In a slightly more detailed way, the "frugal approach" can be defined at three levels:

- At the level of the *innovation process* where scarcity is leveraged as source of creativity, existing technology is deployed in new manners to fix new challenges and local contexts are used as an inspiration to develop solutions from a new perspective (Radjou/Prabhu, 2015; Ray/Ray, 2010; Zhu/Shi, 2010; Radjou, 2009; Gupta, 1997).
- At the level of the *resulting solution*, where products are simpler, more robust, tailored to new requirements (not uncommonly basic needs in different areas of daily life) and locally embedded through suitable services (European Commission, 2016; Radjou/Prabhu, 2015; Roland Berger, 2014; Prahalad/Meshelkar, 2010).
- At the *level of socio-economic impact*, where they have potential to increase the affordability of solutions to specific problems (Gupta, 1997; Kroll/Gabriel, this issue), and provide a potential to generalise the new solutions that developed in response to local needs (Seyfang and Smith, 2007) and render them systemically transformative (Christensen et al., 2006; Radjou, 2012; Zhou/Tong, 2013).

In contrast, sustainable innovation is rooted in the broader concept of sustainable development. Basically, the concept of sustainable development addresses ecological problems in conjunction with socio-economic issues resulting from poverty and inequality (Hopwood *et al.*, 2005). The most prominent definition of sustainable development is provided in the report of the Brundtland Commission, which defines sustainable development as meeting "the needs of the present without compromising the ability of future generations to meet their needs (WCED, 1987, 43)."

Based on this definition, sustainable innovation can be defined as innovation that improves performance in the ecological, economic and social dimension of sustainability (Carrillo-Hermosilla *et al.*, 2010; Boons *et al.*, 2013). As Boons et al. (2013) point out, the concept of sustainable innovation will have different meanings in different country contexts, because sustainability challenges differ widely, e. g. between developed and developing countries. Closely related to the concept of sustainable innovation and frequently used interchangeably is the notion of environmental innovation or eco-innovation. Eco-Innovation is defined as "a new or significantly improved product (good or service), process, organisational method or marketing method that creates environmental benefits compared to alternatives (Horbach et al. 2011, 8)."

The relationship between frugal innovation and sustainable innovation is not a self-evident one. As sustainable innovation aims to internalise the social and environmental costs, which result from market failure (Rennings, 2000), the resulting products or services are likely to be more complex and expensive than those originating from conventional innovation. Consequently, the emergence and diffusion of sustainable innovations frequently hinges on supportive government policies (Jaffe *et al.*, 2005). Hence, the concept of sustainable innovation can deviate quite considerably from the requirements of frugal innovation.

However, there are other aspects of the frugal approach, which strongly resonate with efforts aiming at and successfully achieving sustainability (Le Bas, 2016). This can be demonstrated by taking recourse to basic definitions of frugal innovation as providing "more for more for less" (Radjou and Prabhu, 2015) "under resource constraints" (Ray and Ray, 2010), illustrating an ambition to not only reach a broader segment of potential buyers at lower prices ("more for less"), but also somehow to provide "more" to these greater circle of users at terms that sustainably increase the quality of their daily lives. From a sustainability perspective, this outreach to a broader circle of users can be crucially important because significant environmental or social improvements can only arise when innovations diffuse widely. Currently, this widespread diffusion is often considerably slowed down by the price premium of sustainable solutions. Hence, the integration of frugal design principles in the process of sustainable innovation could help to overcome such barriers (see section 4 for illustrative examples). Moreover, many frugal innovation processes are by definition aimed at greater longevity (Bound and Thornton, 2012), robustness (Roland Berger, 2014), low maintenance needs (European Commission, 2016) and embeddedness in local service ecosystems (Kumar and Puranam, 2012).

Thus both paradigms share the notion of a resource constraint world, which makes it necessary to use available financial and natural resources as efficient as possible. However, matters are more complex. For example, the definition of frugal innovation provided by Tiwari and Herstatt (2014) postulates that frugal innovation can be characterised as "new or significantly improved products (both goods and services), processes, or marketing and organizational methods that *seek to minimize the use of material and financial resources* in the complete value chain (development, manufacturing, distribution, consumption, and disposal) with the objective of significantly reducing the total cost of ownership and/or usage while fulfilling or even exceeding certain pre-defined criteria of acceptable quality standards (italics added by authors)." Hence, the primary objective of frugal innovation is not to reduce environmental impacts (Le Bas 2016), but to reduce total costs of ownership or usage by minimizing material and financial resource inputs. However, research in the field of Industrial Ecology has pointed out, that a reduced material input along the value chain does not necessarily lead to positive effects on the environment (Bunker, 1996), because materials vary considerably with regard to their environmental impact and a simple consideration of material efficiency in terms of mass is insufficient from an environmental perspective (Voet *et al.*, 2004). Furthermore, there can be conflicts between material efficiency and recyclability (Kempkes *et al.*, 2017).

At the same time, aspects such as product durability, reparability, and recyclability constitute comparatively unambiguous overlaps between both concepts. The same may apply to aspects related to energy consumption associated with production and consumption, such as the use of renewable energy sources and enhanced energy efficiency.

Undoubtedly, there can be tensions between the often at first hand socially inspired motivation of frugal innovation and the comprehensive standards of ecological sustainability, if only because frugal innovation will, if successful, necessarily increase overall consumption. As frugal innovations target mass markets at the bottom of the pyramid, moreover, they introduce new solutions into so far uncharted environments in which their widespread diffusion could entail unknown environmental risks and rebound effects, even if the ecological footprint is only marginally larger compared to the status quo. To become broadly accessible, finally, some frugal innovation processes will - despite all ingenuity - have to take recourse to deploy under environmental consideration second best technologies, materials or delivery models (European Commission, 2016).

In practice, the boundaries between frugal solutions and those that are simply cheap while compromising on ecological footprint and quality can thus become fluid and not in all cases easy to determine. From a normative perspective, however, the desirability and productivity of the frugal approach lies precisely in the ambition to not make such compromises (European Commission, 2016; Gupta, 2008; Seyfang and Smith, 2007). One expression of this is the repeated mention of longer lifetime rather than unit price as a means to achieve greater affordability (Bound/Thornton, 2012). As long as suitable leasing or rental models are in place to enable their use as a service, frugal products themselves do not have to be very cheap per unit and compromise on material and technology (European Commission, 2016). Moreover, although specific solutions may not be perfect according to ambitious environmental standards, they may still be relatively better than existing solutions or alternative products, which might be introduced to that market segment without any particular concern of environmental issues.

In summary, the frugal approach alone may not provide a quick fix solution, but certainly a guideline and inspiration for innovators and policy makers willing to mitigate the environmental impact of the impending uptake of consumption in low- to mid term economies that we will be facing anyway, one way or the other. It puts forward the proposition that social and ecological sustainability can be reconciled based on equally, if not more profitable business models. To achieve this, future sustainable frugal innovations should meet the following criteria:

- are cheap enough to be accessible for broader parts of the global population, but keep negative environmental rebound effects in check;
- are robust, high quality and low-maintenance to ensure a long lifespan;
- use materials that can be re- or at least downcycled;
- use no or less toxic materials;
- make use of renewable energy sources and/or increase energy efficiency during production and use;
- do not affect the general living habits of users or spur other behaviors in a manner that is ecologically detrimental

3 Global Trade in Green Technologies and Implications for Frugal Innovation

The global demand for green technologies has been growing significantly and forecasts predict that an above average growth will continue in the future (Roland Berger 2015). In order to match regional requirements, foreign technologies have to be adapted. Designing a technology, however, does not only require technological capabilities, but also the ability to adapt the export good to the context of the country of destination (Hoskisson et al. 2013). If the country of destination is characterized by resource constraints, a company from a resource scarce environment might enjoy an adversity advantage, because it is better equipped with the necessary capabilities to develop a product, which succeeds in a resource constrained environment (Cuerva-Cazurra and Genc 2008; Peng 2012; Boehe et al. 2016). Thus, exporting oriented emerging economies might be better suited to export technologies to markets in middle- and low income countries than the exporters from high-income countries.

In order to analyse the global diffusion of green technologies empirically, we retrieved data from the UN-Comtrade database. The specification of green technologies is based on previous work (Walz and Marscheider-Weidemann 2011; Walz and Köhler 2014) and covers the following technological fields: (1) energy efficiency, (2) environmentally friendly energy supply, (3) material efficiency and waste management, (4) water technologies, (5) green mobility, and (6) technologies to reduce air pollution. Our raw data consists of export and import flows, which specify for each exporting country the destination on a country-by-country basis.

Building on the World Bank's country classification[1], we calculated exports between and within three country groups, i.e. low income countries, emerging economies/middle income countries, and high income countries. Thus, we distinguished nine different trade flows:

- Exports from low income countries to other low income countries (L-L-exports), to emerging economies/middle income countries (L-M-exports), and to high income countries (L-H-exports);
- Exports from emerging economies/middle income countries to low income countries (M-L-exports), to other middle income countries (M-M-exports), and to high income countries (M-H-exports);

[1] However, in order to focus on the changing role of emerging economies in exports and imports of green technologies, we allocated Singapore and South Korea, which are listed as high income countries in the World Bank classification, together with the other middle income countries under one country group which we named "emerging economies/middle income countries".

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- Exports from high income countries to low income countries (H-L-exports), middle income countries (H-M-exports), and other high income countries (H-H-exports.

Table 1 shows the results of this analysis. The market shares of exports from high income countries remain constant or even fall. In contrast, there is substantial dynamic in the development of trade between low income and emerging economies/middle-income countries. We find that low income countries absorb only less than one percent of all green technology imports. This underlines the problem of a substantial gap between environmental needs and availability of green technologies in these countries. The import shares of emerging economies/middle-income countries have been rising continuously from below 20 % in 2003 to about 35 % in 2014. Thus, the import share of high income countries have been diminishing. The market dynamics is also the lowest in high income countries, with imports staying at a lower reached in 2008. In contrast, the import dynamics has been much stronger in emerging economies/middle income and - however on a low absolute basis - in low income countries.

Year	L-L	L-M	L-H	M-L	M-M	M-H	H-L	H-M	H-H
2003	0.01%	0.02%	0.01%	0.49%	5.30%	12.96%	0.41%	20.99%	59.80%
2004	0.01%	0.02%	0.02%	0.50%	5.87%	13.63%	0.36%	21.96%	57.63%
2005	0.02%	0.02%	0.02%	0.51%	6.64%	14.75%	0.40%	22.24%	55.40%
2006	0.02%	0.03%	0.02%	0.62%	7.28%	15.75%	0.34%	22.14%	53.81%
2007	0.02%	0.03%	0.02%	0.57%	7.99%	16.33%	0.35%	22.36%	52.33%
2008	0.02%	0.03%	0.02%	0.64%	9.60%	16.82%	0.36%	23.08%	49.42%
2009	0.03%	0.03%	0.03%	0.95%	10.30%	16.83%	0.45%	24.46%	46.92%
2010	0.03%	0.03%	0.03%	1.11%	11.98%	18.68%	0.43%	24.45%	43.25%
2011	0.02%	0.03%	0.03%	1.19%	12.78%	19.20%	0.50%	23.95%	42.30%
2012	0.02%	0.03%	0.03%	1.10%	13.59%	19.48%	0.40%	23.90%	41.47%
2013	0.03%	0.04%	0.04%	1.15%	13.51%	18.99%	0.39%	23.92%	41.92%
2014	0.02%	0.02%	0.02%	1.17%	13.23%	19.99%	0.40%	21.47%	43.67%

Table 1: Shares of green technology exports in world's exports

Given the small overall importance of exports from low-income countries, we merged them with the emerging economies/middle-income countries into one category, i.e. countries of the South. Thus, we reduce the complexity to four market segments: South-South trade, South-North-trade, North-South trade, and North-North trade.

Figure 1 shows that most of the growth of exports is to markets in the South. Especially the exporters from the South benefitted from this increase: A detailed country-to-country analysis shows that the share of exports from South to South has been increasing substantially and is

making up about 15 % of world exports. This share is particular high among technologies to enhance material efficiency (30.5 %) and energy efficiency (22.7 %). The share of South-North trade has been also increasing, especially between 2003 and 2008. In contrast, the share of North-South trade has remained constant after 2008, and the share of North-North trade has been reduced substantially. A country specific analysis shows that in particular China has been playing an important role: It has been absorbing green technology imports from the North on the one hand, but has been also highly successful in becoming a major exporter holding about 12 % of world export shares. In particular, China has also been successful in becoming the major supplier of green technologies to other countries of the South.

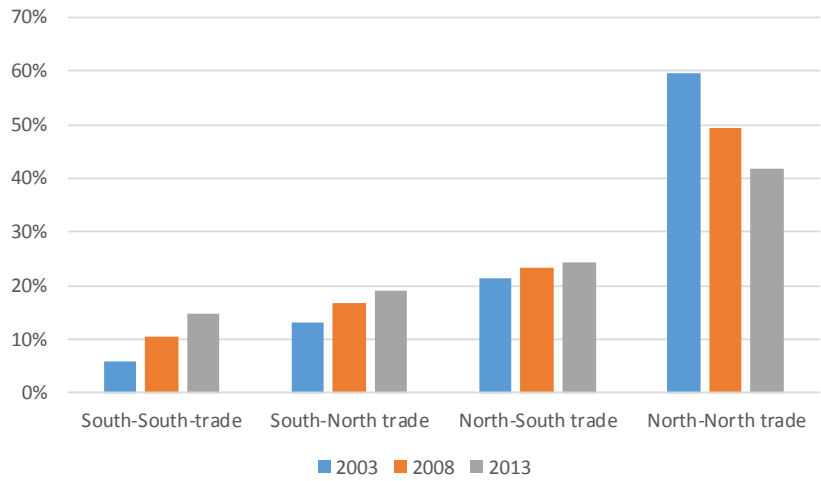

Figure1: Development of shares of market segments as percentage of world exports in green technologies

Green technologies are a good for which a high income elasticity is assumed (Neumayer, 1998). Thus, low-income countries, in particular, but also middle-income countries, have a lower willingness to pay for green technologies. Hence, in order to increase demand under these conditions, the solutions have to be reduced to their basic functionalities. This reiterates the concept of frugal innovations twofold. First, frugal innovations emerging in developing countries can be an alternative to importing expensive environmental technologies. Second, developers of frugal innovations in other countries might have an additional outlet for their innovations in exporting them to developing countries. In particular, the second option fits into the logic of green market development: Green technology markets increasingly grow in countries with low and medium income. Technology exports from countries of the South to the South

show the highest dynamics among the market segment. A deliberate strategy of using frugal innovation as part of a strategy to target the growing markets of the South would fit into this logic.

4. Exploratory Analysis of Practical Experiences with Frugal and Sustainable Innovation

This section analyses four practical experiences with frugal and sustainable innovation by means of a morphological box. A morphological box (Zwicky, 1969) is used as an analytical tool to carve out important parameters and configurations of sustainable and frugal innovations. As the number of cases discussed here is very limited, the analysis has an exploratory character. The first two parameters of the morphological box ask, whether the innovation takes place in the context of a developed or developing country and which type of innovator is involved, e. g. a not-for-profit organisation, a small for-profit organisation, a large for-profit organisation, or a university/research laboratory. The third and fourth parameter cover key aspects of frugality (concentration on core functionality, affordability, and robustness) and the type of innovation (product, service, or product-service-system). Furthermore, the fifth and sixth parameter assess the degree of innovation (radical, incremental) and the nature of the resulting environmental benefits (enhanced efficiency of materials or energy use, use of renewable energy or materials, reduction of waste or emissions, environmental stewardship, and encouragement of sufficiency).

In the following, the morphological analysis is applied to four cases of frugal and sustainable innovation, i. e. Soleckshaw, StreetScooter, Selco, and M-Kopa, which have been identified from the academic literature on frugal innovation. Soleckshaw and StreetScooter are sustainable and frugal solutions in the area of urban mobility, whereas Selco and M-Kopa provide off-grid solutions for energy access in rural areas. The Streetscooter is the only example from a developed country context.

The Soleckshaw is a solar-electric rickshaw, which was developed in India as a technological solution to overcome the social plight of rickshaw pullers and the problem of air pollution in India's cities. Rickshaw pullers in India suffer from negative health effects caused by pulling two to three times their weight and by exposure to air pollution and malnutrition. These health risks frequently lead to bronchial infections, including tuberculosis, after three to four years of work (Chandran and Brahmachari, 2015). Furthermore, rising concerns over air pollution in Indian cities and climate change have encouraged the search for green transport solutions (Prasad *et*

al., 2013). The development of the Soleckshaw was encouraged by the Director General of the Indian Council of Scientific and Industrial Research (CSIR) and technological development took place at the CSIR's Central Mechanical Engineering Research Institute (CMERI) in Durgapur. The CSIR's objective for the Soleckshaw was to create an affordable, sustainable and pollution-free technology, which would improve the lives of millions of Indian rickshaw pullers. Although the Soleckshaw has been described as a simple combination of existing technologies, the concept in its entirety can be described as a radical innovation (Chandran and Brahmachari, 2015). During the developmental stage, the integration of feedback from prospective users and field tests with rickshaw pullers have resulted in substantial improvements of the original design (Prasad *et al.*, 2013; Chandran and Brahmachari, 2015). The CSIR has adopted a non-exclusive licensing approach for this invention and in this way has transferred the original design to a couple of private companies for production (Kumar, 2010). Compared to conventional rickshaws, the Soleckshaw requires less effort because the electric motor supports the driver, in particular at uphill roads. Thus, the driver can run for longer distances and earn more money (Prasad *et al.*, 2013). According to Kumar (2011), a conventional rickshaw puller on average generates a monthly income of 170 US$, whereas the Soleckshaw rises this income to 330 US$. The Soleckshaw's electric motor is powered by a battery, which can be charged at a solar PV charging station. The environmental benefit over conventional fossil-fuel driven vehicles is that there are no polluting emissions and that a renewable energy source is used instead of exhaustible fossil fuels. Given the fact that approximately 10 million rickshaws exist in India alone (Chandran and Brahmachari, 2015), the environmental and social benefits of a widespread diffusion of the Soleckshaw would be large. As of 2015, Chandran and Brahmachari (2015) estimate that in India about half a million electric rickshaws are in use.

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Parameters	Configuration					
Context	**Developing Country**			Developed Country		
Type of Innovator	Not-for-profit Organisation	Small For-profit Business		Large For-profit Business		**University/ Research Laboratory**
Key Aspects of Frugality	**Core Functionality**		**Affordability**		**Robustness**	
Type of Innovation	**Product**		Product-Service-System		Service	
Degree of Innovation	**Radical**			Incremental		
Environmental Benefit	Material Efficiency	Energy Efficiency	**Use of Renewable Energy or Materials**	**Reduction of Waste and Emissions**	Environmental Stewardship	Encourage Sufficiency

Figure 2: Morphological Box Soleckshaw

The StreetScooter is an electric delivery car for downtown areas, which was initially developed by the laboratory for machine tools at the RWTH Aachen in Germany. Since 2010, the StreetScooter is produced by a university spin-off, which, in 2014, was acquired by the Deutsche Post, a large German postal and courier service company (Kampker *et al.*, 2017). From the beginning, the design of the StreetScooter was based on principles of frugal innovation, affordability in particular, because until now, electric cars are much more expensive than conventional cars, which considerably restricts their widespread diffusion (Clausen, 2017). The StreetScooter was developed in close cooperation with the Deutsche Post and about 100 of its delivery agents, which has resulted in considerable improvements of the original design (Clausen, 2017). The underlying production technology relies on most recent technological hardware production principles. For example, the rapid development of the first prototype was facilitated by 3D printing of components as well as by regular and quick design checks in a Virtual Reality environment. Beginning in 2011, a network of 80 suppliers from the automotive sector was created, which started to produce a small series of 20 vehicles in 2013 (Kampker *et al.*, 2017). The production network is based on the concept of a learning factory and industry 4.0 technologies (Kampker *et al.*, 2015). At the end of 2017, 5000 StreetScooter vehicles have been put onto the street (Wimmelbücker, 2017). The StreetScooter can be characterised as a radical innovation not only because it disrupts the market for conventional delivery cars, but also because it deviates from the conventional production approach in the automotive sector. Although the environmental effects of electric cars are difficult to evaluate in general terms, it can be concluded, that local emissions are avoided and that electric cars offer the potential to use power from renewable energy sources, which would

drastically reduce environmental impact during the car's useful life (Dallinger, 2011)

Parameters	Configuration					
Context	Developing Country			Developed Country		
Type of Innovator	Not-for-profit Organisation	Small For-profit Business		Large For-profit Business	University/ Research Laboratory	
Key Aspects of Frugality	Core Functionality		Affordability		Robustness	
Type of Innovation	Product		Product-Service-System		Service	
Degree of Innovation	Radical			Incremental		
Environmental Benefit	Material Efficiency	Energy Efficiency	Use of Renewable Energy or Materials	Reduction of Waste and Emissions	Environmental Stewardship	Encourage Sufficiency

Figure 3: Morphological Box StreetScooter

Selco is a small for-profit business in India, founded in 1995 by Harish Hande and Neville Williams. Selco offers products and services for people that lack adequate access to energy. In India, about three-quarters of the population live in rural areas, thereof more than 60 % are without access to the electricity grid (Mitkowski *et al.*, 2016). As the connection of poor rural households to the grid turns out to be a slow and very capital-intensive process, Selco's business model follows an alternative path to energy development, which uses decentralised small PV systems for households and small businesses. Selco offers tailored PV systems and lighting solutions on a lease-to-own scheme to make them affordable even for the poorest households. Moreover, the company customises off-the-shelf technologies for the specific needs of households and occupations, These products are created in Selco's development center based on locally available, low-cost materials. To ensure that these products are affordable, Selco partners with several institutions from the financial sector, which offer special financial mechanisms for the poor (Mitkowski *et al.*, 2016). Because Selco manages to overcome barriers to energy development in rural India by combining tailored technological solutions with appropriate financial services, the degree of innovation can be judged as radical. According to the company's website, in October 2014 Selco had reached 200.000 people and 5.000 institutions. Besides these social benefits, environmental benefits arise from the substitution of kerosene lamps with more energy efficient lightings powered by electricity from solar energy.

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M-Kopa is another small for-profit enterprise that offers similar products and services to Selco, albeit in another regional context and with a different business model. M-Kopa was founded in 2011 and operates in Kenya and other neighbouring countries. Similar to the situation in rural India, only 15 % of the population in Kenya is connected to the electricity grid. However, almost all Kenyans have access to mobile phones and M-Kopa takes advantage of this fact by using M-Pesa, a very popular mobile money plattform in Kenya, to finance the sale of solar lighting systems. Such systems consists of a PV panel, three ceiling lights, a radio and a charging outlet for mobile phones. The payments are made in small instalments on a pay-as-you-use basis through M-Pesa (Shell Foundation, 2014). According to M-Kopa, in May 2017 the company had connected 500.000 homes and adds 500 new customers every day (M-Kopa, 2017). Just like Selco, the frugal business model of M-Kopa can be characterised as a radical innovation, which entails many social and environmental benefits.

Parameters	Configuration					
Context	**Developing Country**			Developed Country		
Type of Innovator	Not-for-profit Organisation	**Small For-profit Business**		Large For-profit Business	University/ Research Laboratory	
Key Aspects of Frugality	**Core Functionality**		**Affordability**		**Robustness**	
Type of Innovation	Product		**Product-Service-System**		Service	
Degree of Innovation	**Radical**			Incremental		
Environmental Benefit	Material Efficiency	**Energy Efficiency**	**Use of Renewable Energy or Materials**	Reduction of Waste and Emissions	Environmental Stewardship	Encourage Sufficiency

Figure 4: Morphological Box Selco and M-Kopa

In conclusion, the results support the argument, that the concept of frugal innovation is meaningful for developed and developing countries. As the StreetScooter example demonstrates, this argument is particularly valid for frugal and sustainable innovations, because the widespread diffusion of sustainable innovations in developed countries is frequently hampered by the lacking willingness and ability of consumers to pay for the additional environmental benefit. Thus, a stronger focus on frugal design and production principles could help to overcome such barriers. A further insight gained from the analysis is, that, in all four cases, the original intention behind the innovation was to achieve environmental and social benefits in conjunction as well as to attain a widespread diffusion. Another

communality of the four cases is, that the degree of innovation can be described as radical and that inventors work either for small-for profit businesses or research facilities. The innovations discussed here are product innovations, but in the case of Selco and M-Kopa tailored financial services were identified as being crucial for a successful diffusion because a frugal design of the product is only a necessary, but not a sufficient condition to reach the poorest parts of the population in India and East Africa.

5. Conclusions

The paper adds to the existing conceptual literature on both frugal and sustainable innovation in three main ways.

First, the relationship between frugal and sustainable innovation was explored in conceptual terms and found to be not straightforward. While there are overlaps and a common conceptual premise, some outcomes of frugal innovation might in practice even be detrimental to sustainability. Inevitably, successful frugal innovation will lead to a widespread diffusion of additional products in Bottom of the Pyramid (BoP) markets and to an increased aggregate footprint of these segments of the population.

Secondly, the paper substantiates earlier suggestions that a need for frugal and sustainable innovation lies both in developed and developing economies (European Commission, 2016; Kroll/Gabriel, this issue). As the analysis of international trade with green technologies shows, international trade is increasingly taking place between North and South and between South and South, whereas the relevance of North-North trade is decreasing. Countries from the global South seem to enjoy an adversity advantage in the trade with other Southern countries. Apparently an uptake of consumption is already underway in low- to mid-income countries anyway. Arguably, the central question remaining thus is whether it will be satisfied by cheap, low quality mass produce or with solutions that reconcile social and ecological sustainability.

Thirdly, the case studies on frugal and sustainable innovation support the argument by stressing that the double intention of achieving both social and environmental benefits is in practice key to many frugal and inclusive innovations. Not least, as environmental conditions tend to develop a much more direct impact on the daily lives of people in developing countries. Furthermore, the cases underline that even if frugal design principles result in a low cost solutions, these might in terms of unit cost often remain unattainable to the poorest parts of the population. Typically, this does then not prompt further compromises in material and quality.

Instead, complementary financial services tailored to the needs of the poor are a crucial part of frugal and sustainable innovation.

Against this background, this paper argues that the take up of frugal principles in sustainable innovation and vice versa can lead to outcomes that can improve or mitigate the environmental outcome of an evolving trend that we are already facing. Paying attention to certain criteria during the design of new products and services could result in solutions that are at the same time frugal and sustainable. In the authors view, the integration of frugal and sustainable innovation principles in a new concept of "sustainable frugal innovation" could reinvigorate the discussion about sustainable innovation as a holistic approach to achieve sustainable development and, at the same time, add purpose and direction to frugal efforts beyond the situational fixing of localised social issues.

So far, even in developed countries many sustainable innovations are stuck in niche markets, are too expensive to be widely adopted and cannot develop the impact originally intended. To some extent, this might be due to the fact, that the complexity of the sustainable innovation approach is unduly reduced by putting too much emphasis on the ecological dimension without considering central preconditions for adoption that are rooted in the social, societal and economic domains. In this situation, the criteria for "frugal sustainable innovation" as developed in this paper could provide valuable guidance and add value to the future academic discussion as well as to innovators and policy maker.

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