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Crafting Sustainable Development Solutions: Frugal Innovations of Grassroots Entrepreneurs

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Received: 16 September 2015; Accepted: 31 December 2015; Published: 7 January 2016
Academic Editor: Vincenzo Torretta

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Abstract: A shift in the entrepreneurial landscape is taking place brought about by grassroots innovators with little formal education and technological knowhow, living and working in penurious environments. This research represents an emerging third wave of literature on Bottom of the Pyramid innovation, where products are offered for and by the underserved. Using primary and secondary data derived from four cases of grassroots entrepreneurs in the Indian Subcontinent, the study explores the phenomenon where resource scarce entrepreneurs craft solutions that are environmental friendly, with low overall ownership costs, and use locally available material. We argue that the grassroots phenomenon can be fruitfully exploited to achieve the new Sustainable Development Goals proposed by the UN as a post-2015 strategy for the future of global governance. These innovations might have a tremendous impact not only in terms of serving unmet and ignored consumer needs, but also longer term impacts through enhanced productivity, sustainability, poverty reduction and inclusion promotion.

Keywords: grassroots entrepreneurs; sustainable development goals; frugal innovation

1. Introduction

It is expected that the development of innovations would play a pivotal role in the Sustainable Development Goals (SDG), which will frame the post 2015 agenda and policies of the UN member states over the next 15 years. As Schumpeter [1] had argued almost a century ago, the entrepreneur-innovator, is the "agent of innovation", and the engine of economic growth in capitalist economies. Over the years, Schumpeter's intuitions have been largely validated by empirical research in the field of industrial innovation [2–4]. Nevertheless, how entrepreneurial innovators operate under conditions of resource constraints in developing countries, and their implications within the complex process of sustainable development is still an under-researched topic [5,6]. Resource scarcity would perforce call for innovation processes that capitalize on a rich interplay of human ingenuity and frugality.

There is an increasing academic interest in how innovation (*i.e.*, new products, processes and services) contributes to "economic development" in the context of developing countries [7]. This interest is polarized around studies of how firms in these contexts catch-up with their competitors in industrialized economies through the international transfer of technology and know-how [8,9], and scholars who focus on the creation of innovation eco-systems designed to foster entrepreneurship [7,10,11]. Yet, others focus on entrepreneurship and innovation as a recipe for *inclusive development*, *i.e.*, the extension of the benefits of market economy to the disadvantaged and socially excluded parts of society [12]. This last research group is specifically interested in the

study of entrepreneurship and innovation as tools for addressing the issues that affect those who live at the "Bottom (or 'the base') of the economic Pyramid" or BOP (*i.e.*, people who live on less than US$2 a day). The burgeoning "BOP" literature has tended to dwell on the role of Multinational Corporations (MNCs) or private-public alliances composed of public bodies and small-medium companies in tapping unexploited markets at the BOP. On the other hand, a small but emerging body of literature is drawing attention to the profound changes brought about by innovations not from large or even small organizations, but undertaken by grassroots innovators. They have little formal education—but often possess a rich heritage of traditional knowledge—and technological knowhow, living and working in penurious environments. According to Smith *et al.* [13], grassroots innovators "seek innovation processes that are socially inclusive towards local communities in terms of the knowledge, processes and outcomes involved". These are *au fait* actors with respect to their *milieu* and their community's specific needs and contexts, which can be hard to grasp by those on the outside. As Kaplinsky [14] has suggested, grassroots innovators and their innovations arising from within the BOP might have a tremendous impact not only in terms of serving unmet and ignored consumer needs, but also longer term impacts through enhanced productivity, sustainability, poverty reduction and promoting entrepreneurship behind the regional borders in which they originally emerge. With the vast majority of the world's population living in poor and developing countries, it is these grassroots actors who would play a crucial role in determining the success of the SDGs.

The understanding of local ingenuity and the endogenous mechanisms of resilience of the so-called "bottom" vis-à-vis epochal challenges such as climate change requires, we argue, a substantial change of the model(s) of development that have dominated the scene since the WWII period, *i.e.*, large scale top-down planning. This is true for both developing and developed countries. A diverse multi-coloured and even contested new set of models based on the inclusion of multiple stakeholders with their specific epistemic positions will be needed to tackle the complexity of the environmental challenges that stand in front of us. This is also the spirit—at least on paper—of the SDGs promoted by the UN as a new strategy to replace the Millennium Goals [15,16]. This renewed global quest, as declared by its proponents, is supposed to ignite new reflections about the very meaning of the development process. It expands the classical original commitment to "fight poverty", to a more systemic vision that spans from the participation of socially excluded groups into the global governance to the "sustainable development" for (and from) the poor. This paper aims at showing how grassroots innovation originated from the South can be instrumental in such a vision. By telling the stories of four grassroots innovators operating in the field of renewable energy and energy-efficient processes, we aspire to show that "the grassroots" can be seen as a fertile and prolific environment to pursue the new SDGs.

The paper is organized as follows: We first introduce the debate about the multiple ways of framing entrepreneurship and innovation at the BOP with a particular attention to the notion of *innovation by the poor*. There we also attempt to contribute to the theoretical understanding of "innovation at the BOP" by distinguishing among three different narratives: poor-as-consumers, poor-as-coproducers and poor-as-innovators. Then, we describe the research design and our adopted methodology: qualitative multi-case study. In the third part, we discuss the findings and their implications for the SDGs' agenda. Finally, we conclude by highlighting the limitations of our research and propose a future research agenda.

2. Theoretical Framework

As Kolk *et al.* [17] have documented, the literature focusing on entrepreneurship and innovation at the BOP has increased steadily over the last decade. This literature intersects with management, organization, entrepreneurship and development studies, forging new terminology such as "frugal innovation" [18], "reverse innovation" [19], "Jugaad innovation" [20], "BOP innovation" [21,22], "Gandhian innovation" [23], "empathetic innovation" [24,25], "long tail and long tailoring innovation" [26], "below-the-radar innovation" [14], and "inclusive innovation" [27]. Despite their

different ways of framing entrepreneurship and innovation, a common theme within these approaches is a combination of insecurity and scarcity, both material and financial, that allegedly (and arguably) affect most of the developing world [28]. This composite literature is mainly driven by three questions.

First, how do entrepreneurs operate (and if so how) in resource-constrained environments (RCE)? This question is usually addressed by *bricolage* literature, which theorizes how entrepreneurs or MNCs overcome scarcity by "*making do with what is at hand*" [29–33].

Second, how do innovation and entrepreneurial practices generated in RCE in the emerging economies affect business-as-usual activities in developed nations considering the globalization of resource scarcity and, in turn, what are the implications for emerging innovation policy? The proponents of this question focus on the potential disruption of entrepreneurship practices coming from the emerging economies, *i.e.*, blowback [34] and reverse [19] innovations and the opportunity to leverage them to overcome the limits of saturated and resource-intensive markets in developed economies [35–38].

Third, how do innovators contribute to various goals such as social inclusion and poverty alleviation? The answers to these question are diverse, multiple and sometime conflicting [39]. Despite such a diversity, two general trends emerge from the literature: (i) a market-oriented approach, generally identified with the so-called "BOP literature", which frames the BOP as a vast underserved market [12,23,27,33,40]; (ii) a Bottom-Up approach that focuses on indigenous forms of entrepreneurship carried out in informal settings by grassroots movements [13,41–43]. The following section illustrates, to the best of our knowledge, the state of the art around this debate.

2.1. The Research Agenda Emerging from the BOP: Who Innovates for Whom?

The market-based approach is often clubbed with the umbrella term "BOP literature". The notion of the BOP was popularized by Prahalad in 2004 in his book "*The fortune at the bottom of the pyramid: eradicating poverty through profits*" [21]. The main argument postulated in Prahalad's work is that the poor are underserved consumers who represent an immense unexploited market excluded from mass consumption because of their very limited purchasing power. BOP firms, usually Multinational Corporations (MNCs) [44], can address the *needs* of the *poor* by providing high-quality and low-cost market solutions [21–23]. The original focus on *poor as consumers* that characterizes the first wave of BOP literature has been the subject of extensive critique. Criticisms include arguments that such framings neglect environmental issues [45], that they present a romanticized view of the poor, and that they "grossly underemphasize the critical role and responsibility of the state in poverty reduction" [46]. They also include critical feminist groups claiming more attention should be given to gender empowerment and equality issues [47–49]. Other scholars claim that a development discourse based on market-based approaches and technology transfer reflects and promotes neoliberal hegemonic thinking in developing countries [50,51]. In response to those criticisms, a more recent wave of BOP studies have reframed the role of the poor from mere *recipients* to *co-creators* of innovation [40,52]. In this view, the successful MNCs at the BOP are those who are able to create *alliances* and partnerships with NGO and civil society representatives. This "second wave" of BOP literature encourages MNCs to penetrate BOP markets through local intermediaries (e.g., NGOs, local firms, community based organizations), that are embedded in the local settings and have a better understanding of the local specificities [52–57].

The BOP literature is theoretically challenged by the ways in which social movements [42], grassroots movements [13,58] and many Non-Governmental Organizations (NGO) [59,60] frame entrepreneurship and innovation. These dissenting voices focus on the endogenous capability of grassroots entrepreneurs to innovate both in developing [13,41,61,62] and developed countries [63–65]. According to Gupta [25], the *poor are not too poor to innovate*. In other words, every community has an innate capacity to come up with effective solutions to solve the problems they face on a daily basis [43]. According to this view, rather than tapping into underserved *consumers*, grassroots innovators aspire to address problems that are essentially and primarily social [60] providing appropriate [43],

socially acceptable [5] and environmentally sustainable [66] solutions. According to Gupta [67] and Fressoli *et al.* [68], including grassroots entrepreneurship and innovation within the range of public policy would not only lead to the delivery of affordable products/services but also to the strengthening of the activity of actors such as Civil Society Organizations (CSO) [69] and NGOs [70], empower local communities [71–75] fill institutional voids [76,77] and promote *more inclusive patterns of development* [78,79].

However, the grassroots phenomenon is not new. Since the seminal work of Schumacher (1973) in the 1970s, this has been at the centre of the debate about the social role and implications of technology. More recent research has shown that grassroots innovation is a common phenomenon worldwide. This literature can be arguably classified into two broad camps. A first body of study focuses on processes, *i.e.*, how does innovation emerge from resource-constrained settings. This perspective is usually identified with the Levy-Strauss notion of *bricolage*, *i.e.*, the capacity to solve problems with what is at hand [30] (see also above). The argument is that under conditions of scarcity, the human mind is stimulated to think "out of the box" [80]. The direct consequence of this is a stream of low-cost, effective and resource-efficient solutions hardly achievable under conditions of resource affluence. The emerging theory of bricolage in management studies is a call to revisit the firm strategy by re-considering innovation as a complex and interactive social process [31]. Bricolage innovation, has been also suggested as an alternative to mainstream innovation to address the problem of the poor [22]. Even more interestingly, the bricolage process in resource-constrained environments is thought to be a potential source of disruptive eco-innovations. These are products and services that are more energy-efficient, use less raw materials and have a reduced impact on the natural environment [34,36,81].

A similar argument, albeit with some nuances, underpins the concept of "frugal innovation" [82]. A number of examples document the attempt to innovate under resource-constrained conditions by MNCs in emerging countries such as India and China [83–85]. In this body of literature, the concept of *bricolage* is usually replaced by the concepts of *frugality or frugal innovation* [86]. According to Bound and Thornton [18] "frugal innovation responds to limitations in resources, whether financial, material or institutional, and turns these constraints into an advantage. Through minimising the use of resources in development, production and delivery, or by leveraging them in new ways, frugal innovation results in dramatically lower-cost products and services" (p. 14). Bricolage and frugality have vernacular equivalents in many languages [20]. In India, for instance, similar phenomena are indicated by the Hindi world "*Jugaad*". The term colloquially means a creative idea or a quick workaround to get through technical, commercial, logistic or legal issues [20,81]. Jugaad, however, has often a negative connotation among innovation scholars due to its extemporaneous nature—usually framed within informal settings—as opposed to the systemic pursuit of value that characterizes mainstream innovation process [86]. Although with different nuances, those concepts share the basic idea that resource scarcity need not be a restriction, but an opportunity to do things more efficiently at lower cost. Similarly, the movement of "appropriate technology" [87] in the 1970s and the communities of grassroots innovators in the North [13] make a case for simple (or frugal) technological solutions to address daily problems of local communities. In conclusion, the call for frugal but effective solutions is shared by top-down centralized institutions such as MNCs operating in resources-scarce contexts, and also by bottom-up—*i.e.*, grassroots—movements who struggle to meet the basic requirements minimizing their financial and human efforts.

A second body of thought on grassroots innovation focuses on the normative, *i.e.*, motivations and values. According to this view, grassroots innovations both in affluent societies and less developed countries, not only differ in their development process in comparison with mainstream innovation, but also in the underpinning values and motivations of those communities from which they emerge [13,63,88]. Emphasis on grassroots innovation is usually placed on exercising control over the innovation process. The innovation activity often includes a sense of social justice, community identity, claims over local resources and the desire to promote a degree of social and economic

self-determination [89]. In a nutshell, the characteristic feature of the grassroots vis-à-vis mainstream market-driven innovation is a call to open up innovation systems and make them accessible to citizens. From this perspective, the environmental motivation of grassroots innovators is a central element in their values system [90]. This has been observed among grassroots innovators in the North [91] as well as in the South [43,66]. Along these lines, not only are "the poor" rediscovered as able to eco-innovate, but are also seen as a potential reservoir of scalable and affordable solutions to pressing environmental problems. As a consequence, public institutions are now following with attention grassroots initiatives, and on rare occasions encouraging them with financial support like for Brazil and Argentina [92]. Recently, eco-friendly grassroots innovations for social inclusion are also on the agendas of international donors such as the World Bank [93] and the OECD [94].

To summarize, from the extant literature we have identified at least three major ways of framing entrepreneurship and innovation in RCE in developing countries (see Table 1). Nevertheless, despite the oversimplified academic narratives recounted above, as some authors have empirically observed [28], the practices in the field remain fundamentally hybrid, multiple and often contested. If the frames promoted by the first and second waves of the BOP literature (*i.e.*, *poor as consumers* and *co-producers*) have been explored in-depth by management and entrepreneurship scholars, empirical work on grassroots innovators however remains scant. Even more surprisingly, given the increasing relevance on the debate about climate change and sustainability, the potential contribution of grassroots innovation to sustainable development has remained at the margins of the mainstream academic debates.

Table 1. Competing framing of entrepreneurship and innovation at the BOP.

Poor Framed As	Focus on	Main Authors
Consumers	Creation of new markets at the BOP	[21–23]
Co-producers	Creation of alliances at the BOP	[27,36,40,52]
Entrepreneurs/innovators	Creation of institutional framework to include grassroots innovation in public policy	[13,25,43]

2.2. The Poor as Eco-Innovators

A fourth crucial question that is thus slowly emerging from this variegated literature is the following. Can the poorest layers of society in the developing world (but also in the developed countries) positively contribute to a reframed paradigm of sustainable development? In short, are the poor too poor to eco-innovate? As Paton & Halme [95] mentioned, "The poor themselves have largely appeared in our drama like movie extras, in the background, while our stories focus on the central business characters." The success of the development goals would depend crucially on the inclusion in the growth agenda the poor, grassroots economic agents who craft solutions that promote sustained and inclusive economic growth.

In the academic circles, there is a tendency to consider sustainability-driven innovation as an exclusive domain of Western, developed countries (the North). However, few emerging economies (e.g., Brazil or China) already consider ecological transition as crucial for their future development [96,97]. The processes underlying the diffusion of the notion of sustainability in the global South are complex and often contested. Nevertheless, the old school of framing environmental degradation as a direct consequence of poverty is slowly shifting towards a more complex and nuanced understanding of the nexus between underdevelopment and environmentalism [98,99]. Some hold that pre-industrial societies, in particular rural and indigenous societies, have proven to be resilient to climate change [100], while others argue that environmental awareness only emerges in complex industrialised societies [101,102]. Few however would deny that the vast majority of humanity living in poorer societies would dramatically influence the future of sustainability. It is crucial to understand the consumption behaviour of this vast body of poor, their approach to sustainability issues and their innovation capability. This suggests that increasingly (and especially in a world in which resource

scarcity will become ubiquitous) disruptive innovation in the future might be of a low-cost "frugal" nature [11]. The challenge then is to understand how this transition would occur (or is occurring), and who the protagonists of these changes are. An intriguing perspective is represented by the possibility to adopt, hybridise with, or scale up the sustainable solutions coming from the South. This can serve as an alternative to the mainstream, business-as-usual narrative from the North. Those aspects have been already discussed and analysed within what are now known as the SDGs that are expected to replace the UN Millennium Goals by 2015 [103]. The debate, initiated under the aegis of the Rio+20 conference [104], aims at expanding the discourse of human development far beyond the concept of poverty, framed as a lack of resources and economic opportunities looking for a wider systemic framework in which social inclusion and environmental conservation are central [15]. Furthermore, the SDGs potentially open up an intriguing debate about the multiple, often contested, pathways to sustainability that can be enriched by including the too often un-heard voices from the grassroots universe paving the road to a more participate model of development interventions. New ways of providing energy, clean water, housing and decent jobs will be needed [105,106] and the original, possible frugal, contribution of the "bottom" can potentially have a disrupting impact in this sense. From this perspective, the notion of sustainability-driven innovation and entrepreneurship appears complex, hybrid and often contested [107,108]. In this view, it is highly probable that transition to greener societies would involve a myriad of different paths, within and across geographical regions and economic sectors [109]. Moreover, to be effective, the transition must be above all fair and equitable. This raises an important question regarding the process, purpose(s) and goals of eco-innovation in developing countries, within the context of the current global economy. Hence, the study of grassroots innovators, we argue is highly relevant within the debate about the SDGs. If the poor are not too poor to eco-innovate, why and how do they eco-innovate? What motivates those actors and what are implications for policy making and business strategy? How can their inventiveness be functional for the achievement of the post-2015 SDGs? Those are the kind of research questions we are going to address in the following sections.

3. Methods

Qualitative approaches such as grounded theory [28], interpretative case studies [55], organizational ethnography [110] among others, are often favoured over quantitative methods to investigate the complexity of informal economies. For this reasons, the research design is a qualitative multiple-case study based on observational data, semi-structured interviews and secondary data of experiences of *grassroots innovators* from the Indian subcontinent. For the case selection we adopted a multi-case approach with an *information-oriented selection strategy* [111]. Unlike random selection, *information-oriented selection* seeks to maximize the utility of information, drawing on a small number of relevant cases. The cases are selected "*on the basis of expectations about their information content*" [111]. Following this approach, we also decided to adopt a strategy of *maximum variation*, which consists in obtaining information from a very diverse set of samples, *i.e.*, different size, location and context. Our initial focus was on grassroots innovators focusing on energy efficiency and/or renewable energy with different backgrounds and working in a diverse typology of settings.

3.1. Case Selection

We conducted our data collection in the Indian subcontinent, which has a huge reservoir of grassroots movements and grassroots innovation [43,112]. For the case selections, we first performed an intensive consultation over a six-month period of media references from India and Bangladesh, which referred to energy-efficient technologies, renewable energy, or in general "eco-innovation" being carried out by the poor with a social impact. From the large number of references found (over 350), we found a consistent cross references of a smaller set of entrepreneurs who were covered by the media, but the source or the inspiration for the coverage was derived from grassroots innovators/inventors identified by the National Innovation Foundation (NIF) of India, an autonomous body of the Department of

Science and Technology. Most of these grassroots entrepreneurs are rural or semi-rural, mostly farmers, mechanics and artisans, almost all of who have little or no formal education. Given that the NIF had conducted interviews with these entrepreneurs, we proceeded to use the publicly available NIF database as one of the secondary data sources [113]. We also explored Bangladesh's vibrant NGOs world, encountering hundreds of interesting examples of frugal innovations. For reasons of context, we decided to hone in on a homogenous group of assembly-type manufacturing innovations, leading us to a total of 52 grassroots innovations. Then, using the principles of maximum variation and information-oriented selection, as well as reasons owing to logistics and finance given the size of Indian Subcontinent, we narrowed the cases down to four. These four pointed to clearer evidence of frugal innovation with strong social impact, yet with concerns regarding the financial sustainability of the ventures. The secondary data were then complemented with primary data collected *in situ* such as semi-structured interviews, observational data, photos and videos (see Table 2). Between November 2012 and February 2015, the authors visited Bangladesh and India on different occasions. The innovators presented in the four cases were interviewed, including direct observations of their innovations and activities.

Table 2. Data collected.

Methods	Data Collected	Concepts Studied and Induced
Case 1: Grameen Shakti (GS) Biogas		
Documentary evidence	Internal reserved and public documents, newspapers articles and websites links	Organizational strategy, communication and legitimation of narratives
Observations	Observations of group meetings, biogasifier installations, promotion activities, instalments collections, repair services (field notes), photos, videos	Norms, values, routines, organizational capabilities, collective practices
Semi-structured interviews with GS engineers and branch managers	10 interviews	Innovation strategy, sources and purpose, organization of production, capability building process
Case 2: A Muruganantham (AM)		
Documentary evidence	NIF documents, news report analysis, public (video) interview analysis	Origins, functioning, historical narrative
Semi-structured interviews with AM	Interview carried over thirteen hours with AM; interview with his senior machine operator	Purpose, experience, motivations, problems, bricolage, energy use, social impact
Observation	Inspection of the machine's functioning	Functioning, energy sources, limitations
Case 3: Mansukhbhai Patel (MP)		
Documentary evidence Semi-structured interviews with MP.	NIF documents, news report analysis, public (video) interview analysis Two interviews	Origins, functioning, historical narrative
Observation	Inspection of the machine's functioning	Purpose, experience, motivations, problems, bricolage, energy use, social impact Functioning, energy sources, ease of use, maintenance, limitations
Case 4: Raj Singh Dahiya (RD)		
Documentary evidence Semi-structured interviews with RD.	NIF documents, news report analysis, public (video) interview analysis Interview with RD Interview with the marketing manager	Origins, functioning, historical narrative Purpose, experience, motivations, problems, bricolage, energy use, social impact
Observation	Inspection of the machine's functioning	Functioning, energy sources, ease of use, maintenance, limitations

3.2. Data Analysis

The audio/video files containing the interviews and the secondary data were classified with a specific code to be used in the text to guarantee traceability of the data. The data collected were subsequently analysed with the aid of NVivo 9 software, which is widely used to analyse heterogeneous, qualitative datasets [114]. In the analysis of the data, we followed a *qualitative Grounded Theory approach*, based on the methods proposed by Gioia *et al.* [115]. The method has proved to be a

fruitful and robust tool for theories validation and theories building, and is increasingly used among management and entrepreneurship scholars [115,116]. The analysis followed two main stages: the creation of a *data structure* and the discussion about the relationships existing between the theoretical dimensions that emerged from such a structure (see figure in Section 5.1). The pivotal step in this approach is the building of a data structure [117]. In order to create the data structure, we started with an initial open data coding, maintaining the integrity of first-order (informant- centric) terms based on our main research objective: *why and how do grassroots innovators eco-innovate?* At a later stage, we included and/or removed in the codes list other categories that were emerging from the data until we reached a manageable number of codes. After this first step we performed a second-order analysis based on the question: *is there some deeper structure in the first-order array?* In this phase, we asked whether the first-order codes suggested concepts that might help me describe and explain the *narrative* of the informants. This step provided us with a list of second-order (theory-centric) themes that were finally assembled into a number (typically 3 or 4) overarching theoretical dimensions. In this way, we built a data structure that has two main functions. The first is to provide a visual synthesis of the analysis we carried out on the original data. The second is to provide the backbone to present a detailed account of this analysis in a *narrative fashion*. The results are shown in Figure 1.

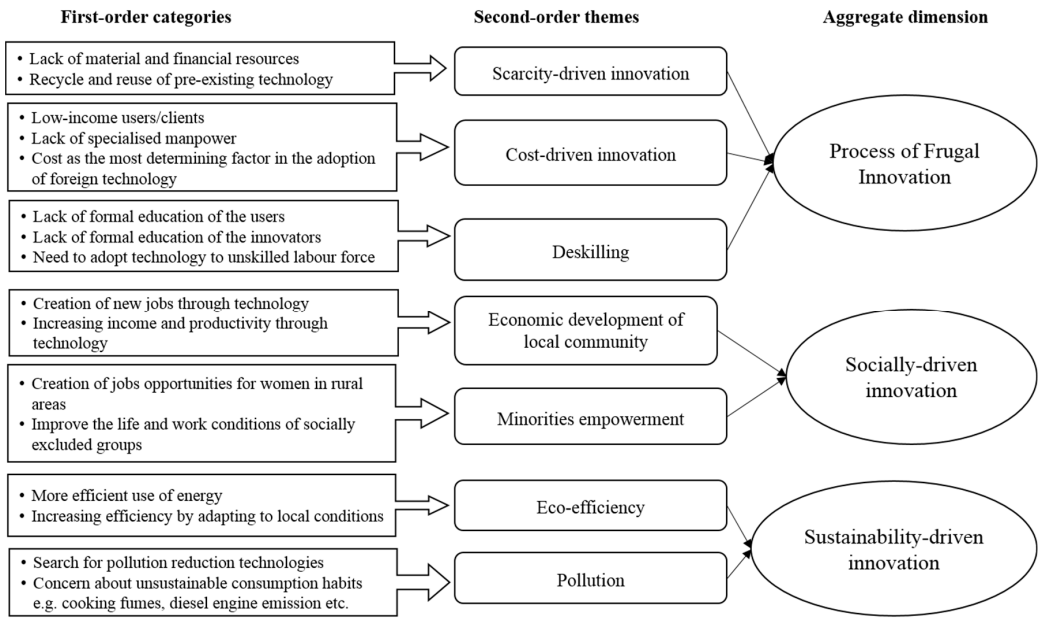

Figure 1. Data structure.

4. Findings

This section briefly introduces the case studies, framing them in the three theoretical dimensions—*Process of Frugal Innovation, Socially-driven Innovation and Sustainability-driven Innovation*—underlying grassroots innovation that have emerged from the analysis of the data.

4.1. Case Studies Description

4.1.1. Case 1: Grameen Shakti (GS) Biogas

Grassroots innovation is usually a phenomenon that emerges from individuals or small communities. The case of Grameen Shakti, however, represents an interesting *hybrid case* in which grassroots innovators are integrated in the activity of a big organization that involves thousands of employees. Grameen Shakti, in fact, is a subsidiary of the well-known Grameen family of organizations grown around the Grameen Bank and founded by the Nobel laureate Muhammad Yunus. Grameen

Shakti works in the field of renewable energy. Its primary mission is to provide clean and affordable energy to the poor living in rural areas of Bangladesh. Despite poor economic performance since its independence, Bangladesh has shown better human development indicators than its powerful neighbour, India [118]. This might be in part explained by the influential and powerful non-profit sector, composed of thousands of civil society and grassroots organizations. For this reason, Bangladesh represents a very interesting place to study the evolution and deployment of grassroots solutions. Since their inception in 1996, Grameen Shakti has installed more than 1,300,000 photovoltaic solar systems, more than 700,000 improved cooking stoves, around 30,000 biogas plants and trained almost 50,000 people [119,120].

By adopting a microcredit approach borrowed from Grameen Bank, Grameen Shakti has impacted on a remarkable number of Bangladeshi and strongly influenced the perception of renewable energy at different levels in the country. Those numbers would suggest that innovation by Grameen Shakti occurs in a centralised and organised manner. The data collected tell a quite different story. The solar home systems commonly installed by the company are the result of a frugal assemblage of pre-existing low-cost technology with locally designed and produced components. Spare parts and technical service are provided by locally available personnel trained for the purpose. The complexity of the electronics is reduced to the minimum to guarantee the effectiveness and rapidity in the maintenance of the systems. However, even more interesting is the way Grameen Shakti has been able to *embed frugal innovators*. The company, is continuously seeking new solutions to bring clean energy to rural Bangladesh using its vast network of branches spread everywhere in the country. Such a network in the rural areas enables the testing and deployment of new solutions very quickly. When the company decided to test biogas as an alternative to kerosene fuel, for instance, they decided to draw on local consultants like Md. Abdul Gofran, an emblematic example of a grassroots innovator who built and tested for months on the top of his roof biogas digesters assembled with locally available material. Eventually, Mr Gofran was able to deliver a different model of bio-digester that can be used to transform organic wastes into biogas, fertiliser or slurry (internal document [121]). Mr Gofran's first contact with Biogas technology occurred in China. China has been experimenting with biogas plants in rural zones since the 1970s [122]. During the same period, the Chinese government encouraged the adoption of household digesters amongst its neighbouring countries. In Mr Gofran's words:

> "I was first introduced the Chinese model in 1992 and it was working very well. I learned from a man who went to China to learn about technology. I started disseminating the technology in Bangladesh and in 1994 I also visited China for training (. . .). I received training for 2 months at a Chinese government-training centre (. . .). Then 2 projects started with my initiative, I experimented for weeks on my roof and in the end 28,000 plants were constructed. In Bangladesh it will continue to progress further". (Mr Gofran personal interview)

After the adoption of Mr Gofran's models, the efficiency of the biogas plants has been increased over time by incremental improvements. The first model had many problems—being expensive, inefficient and with significant gas losses. The plant that Grameen Shakti currently installs is in contrast a highly efficient concrete construction that is able to maintain the gas pressure at a constant level and produces good quality manure. They ended up with a cheaper plant that does not lose gas and guarantees 6 h of cooking a day. Despite its relatively high price (between 25,000 Taka and 35,000 Taka which is between US$300 and US$450), biogas plants are diffusing quickly among small farmers. Mr Gofran's team has also designed a digester in fiberglass that can be easily removed and transported; a very adaptable product for a seasonal farmer living on the *chars*, the alluvial islands that appear and disappear during the rainy season in the delta. The potential for further expansion is promising. The company is constantly promoting its programmes at national level and abroad, especially in the Indian Subcontinent and in Africa through workshops and training courses. National dairy companies like PRAN, for example, have already installed biogas plants in their farms with good results. In our journey, we visited one of the PRAN farms nearby Natore and video-interviewed the

manager. In 2011, the farm purchased a biogas digester to process the waste from their cattle. They managed to build a network of local clients to sell the surplus gas produced by the plant while the slurry produced is sold as fish feed for a local fishery farm. Summing up:

- Frugal innovation: the case suggests that Grameen Shakti biogas technology is essentially cost-driven and shaped by financial and material scarcity. Innovation process occurs *informally*. The products are designed to minimise the necessity of high skilled personnel (de-skilling process).
- Socially-driven innovation: In the intentions of the inventors/innovators, Grameen Shakti products are designed explicitly to address "energy poverty" in rural Bangladesh by leveraging on an environmentalist discourse. The first objective of Grameen Shakti people is then to include socially marginalised groups within the process of sustainable development.
- Sustainability-driven innovation: The discourse of sustainability is central in the Grameen Shakti activity. Solar panels and biodigester are supposed to replace polluting technologies like kerosene lamps and inefficient stoves.

4.1.2. Case 2: Frugal Innovation for Empowerment

The death of Arunachalam Muruganantham's (AM) father forced him to start working for a living from a very early age. Hailing from a very poor family from the southern Indian city of Coimbatore, AM dabbled in many trades before finally setting up a welding workshop. A school dropout at the age of 14, his skills were acquired from *learning by doing*. Soon after he got married in 1998, and one day he was astonished to see his wife was hiding something from him. When he insisted to find out what it was, he discovered it to be an old rag that she used during menstruation. What shocked him even more was to be told, that not only his wife, but most women in his and the surrounding villages used old rags, or sometimes even husk as sanitary pads. This extremely unhygienic practice not only carried great risks of infection, but also often led to cervical cancer. Poor women could not afford to buy the sanitary pads mostly manufactured by MNCs in India.

Determined to find out what was behind the high costs, AM decided to offer a sanitary pad for his wife as a gift, and was very surprised to discover the high price of, what he considered, a product that consisted of nothing more than cotton. He calculated that the pads were being sold at more than 40 times the cost of the raw materials, which he thought was scandalous because an "essential good" for the wellbeing of women should not cost that much.

AM then set about to make a hygienic sanitary pad, and set about to create a simple machine that could be used by anybody with just a little training, to make cheap yet hygienic and quality sanitary pads. Given the strong social stigma associated with sanitary pads, he encountered great difficulty in finding volunteers to test his early prototypes. He would often collect samples of used sanitary napkins by rummaging through the garbage bins, a thing of much social disapprobation. AM's journey was a long and arduous one, involving many experiments. One such early experiment involved AM creating a "uterus" from a football bladder by punching a couple of holes in it, which he then filled with goat's blood. After working on his idea for nearly five years, he was able to finally create a low-cost machine. The scarcity of resources perforce meant the use of bricolage, with the most important parts being assembled and recombined from material at hand.

AM's driving ambition was not only to improve women's health but also create an ecosystem of women entrepreneurs all over rural India. AM's simple machine to make cheap sanitary pads is both democratic and empowering, and can be easily operated. The frugal innovation is gradually revolutionizing menstrual health for rural women in India. His machines cost around Rs 80,000 (approximately 120 USD), and with each machine capable of producing around 1000 pads in a day (in an eight hour shift), each pad could be sold at a profit of around 0.076 USD, which gives a healthy return to the machine owners.

According to a survey by AC Nielsen conducted in 2011 [123], it has been estimated that approximately 70% of all reproductive diseases in India are due to poor menstrual hygiene. Only 12% of women in India use sanitary pads, a statistic that AM clearly wants to change. The grassroots

entrepreneur's motivation is to empower women by turning them into small-scale entrepreneurs, and by deploying a self-sustaining micro-enterprise model. The machine is now enabling increasing numbers of women in rural India (and other developing countries) to create jobs and increase family income. The simplicity and user friendliness of the machine is illustrated by the following quote:

> "The machines are kept deliberately simple and skeletal so that they can be maintained by the women themselves. It looks like the Wright brothers' first flight". (BBC, 2014 reporting on AM's innovation [123])

> "I used my previous experience that I had acquired to create a machine that uses minimal resources, yet and build very cheap sanitary pads as good if not better than the ones by the multinational companies. They are also very simple to use, and even a very young girl with just a bit of training could use". (Mr Arunachalam Muruganantham's personal interview)

The women using the machine work often on a time-sharing basis and sell them directly to the customer, sometimes involving non-monetary transactions such as bartering sanitary pads for vegetables. AM also created a decentralized manufacturing model, where his customers—women entrepreneurs, NGOs, self-help groups, and state governments (under the aegis of the National Rural Health Mission)—could create their own brands. This customization of the brand name and packaging meant that the product could take into account local sensitivities and customs.

It was evident during the course of our meeting that AM was proud of how his machine is empowering not just women, but also having an impact on young girls, who in many parts of rural India, would drop out of school upon reaching menstrual age. AM wants to change that, claiming that his machine:

> " . . . in many parts of rural India is not just liberating women and increasing household income (by making and selling the sanitary pads), but the machine is also empowering girls". (BBC, 2014 reporting on AM's innovation [123])

The diffusion of AM's innovation (and other copycat machines that have sprung up) is creating employment opportunities for rural women not only in India, but he is expanding the model to other developing nations. During the course of our interviews, he was interrupted many times by calls he would receive from overseas buyers, mostly from Africa. There appears to be rising interest from NGOs working in developing countries all over the world to buy his machine, and AM has received worldwide recognition (including appearing in the magazine Time's most influential peoples list).

- Frugal innovation: The machine is simple to build and operate. It requires minimal skills, and requires very little electricity. Production is distributed among small-scale production units, usually based in local communities.
- Socially-driven innovation: AM's motivations, as recorded in our data, are far from being those of a classical profit-driven entrepreneur. The genesis of AM's invention was the will to ameliorate women's health rather than making profits. As a consequence, after reportedly refusing offers of commercialization of the innovation from corporations in India, the scale of its activity remains essentially limited to the creation of self-help groups of women organised in informal cooperatives that share the profits from the sales.
- Sustainability-driven innovation: The central feature of AM's innovation is a sustainable decentralized model of empowerment. AM's technology is a valuable low-carbon alternative to large-scale plants. Furthermore, according to the inventor [124], the machine can be in the future adapted to use other natural fibres like bamboo and banana leafs. There is also an on-going diffusion of his innovation to different parts of the developing world.

4.1.3. Case 3: Frugal Cotton Deshelling

Mansukhbhai Patel (MP) was a farmer and an electrician from rural Gujarat in the western part of India. A tenth grade dropout, ever since a child MP had always been curious and adept at tinkering

with mechanical and electrical appliances. He would spend most of his spare time fiddling with gadgets, evolving into a *bricoleur* at an early age. In the dry climatic conditions of Gujarat, cotton is a very important agricultural product with the livelihood of many farmers depending on obtaining a good crop. A more resistant cotton variety, also called *kala* locally, is greater suited to the dry climate, and grown more extensively in his region. One problem of this variety was, however, is that the fibre is firmly attached to the inner walls of the cotton shell. While for the other hybrid varieties, the cotton balls could be manually picked from the plant; the pods of the indigenous variety could not be opened as easily. As a result, the workers were involved in a tedious and painful post-harvesting manual process of removing cotton from the shell, a work almost exclusively done by women and children. There was a also a fallout in terms of education of the children, since during the harvesting season, the children had to work as day labourers to help out their families, harvesting cotton balls rather than going to school. Studies had also shown that workers who had been exposed to an environment containing cotton dust later suffered from byssinosis, a lung disease [125].

There was also an associated problem of farmers receiving delayed payments for their cotton due to the longer extraction time it took. The harvesting would generally start in January of each year, and extracting would take few more months, only after which would they be able to sell their produce. Thus, the farmers had to wait up to two months to get returns on their investments, obligating many of them to enter into debt. MP mulled about this problem for several months, turning over different ideas in his head:

> "Since I came from a farming family which also grew this type of cotton, I knew what this implied in terms of huge cost and delays involved ... In one of my visits to the village, I had an idea to create a machine to strip rain-fed cotton from shells. Since I had already worked with machines before, and knew a lot about electricity as well, I went about to put my ideas at work". (Mansukhbhai Patel personal interview)

After a couple of years working on different prototypes, MP was finally successful in building a fully mechanized and mobile machine, called the Chetak, in the mid-1980s. Farmers have welcomed his frugal innovation, which has led to high productivity growth and a much steadier and predictable income stream. The Chetak also reportedly cut the cost of cotton farming quite significantly from Rs one per kg to Rs one per 20 kg, a 20-fold increase. Moreover, the by-products from cotton deshelling can be used as a highly valuable bio-combustible. This also adds to the revenue stream of the farmer besides the environmental impact. MP's innovation has further led to an increase in school attendance and released women from a tedious and painful job. He is very proud of this fallout, and as he noted:

> "Because of my machine, children now have the opportunity to go to school ... Women are also now free (from the arduous labour of deshelling)". (Mansukhbhai Patel personal interview)

MP's innovation has been recognized and protected not only in India, but he has also been granted a US patent. With respect to the aggregate dimensions:

- Frugal innovation: the machine mounted on a mobile carrier is rugged and very simply, requiring at most two people, one to operate and another to bag the extracted cotton. Since many of the parts come from existing or familiar farm equipment and machinery, farmers have been quick to relate and adapt to the innovation.
- Socially-driven innovation: MP's main concern was to bring some respite to farmers' families from the hard deshelling work. Rather than replacing the local cotton variety with a foreign commercial one, his priority as an innovator was to improve working conditions as well as preserving the integrity of local farming practices.
- Sustainability-driven innovation: MP claims that the energy being produced using the discarded shells is an important by-product, sometimes as valuable as the cotton itself. Creating value to a hitherto ignored by-product that is also polluting has resulted in an environmental value-add.

4.1.4. Case 4 Agricultural Biomass Gasifier

A compelling narrative of sustainability emerges from the case of Raj Singh Dahiya (RD), who invented a biomass fuelled energy generator. Hailing from a village in the western Indian state of Rajasthan, and unable to go to school, he learnt science by listening to a weekly BBC science program on radio. Coming from a very poor family, RD had to help his family from a very early age, revealing himself to be a keen tinkerer with a strong interest in mechanics. One of the toughest jobs he had to do in his farm was spend nights watering the fields, since water supply was erratic and also the pumps were not reliable due to sporadic electricity. Over the years, he honed his skills in repairing many small machines, however, he realized that building a machine that could generate electricity could provide the greatest boon for his community. Power supply was unreliable, severely hampering farm income and productivity. Given the acute shortage of resources, RD had to bootstrap and make the maximum use of locally available materials. His frugal innovation reflected Lévi-Strauss's view that the bricoleur as one who *interrogates* all the heterogeneous objects of which his treasury is composed to discover what each of them could *signify* and so contribute to the definition of a set which has yet to materialize but which will ultimately differ from the instrumental set only in the internal disposition of its parts. RD's observation to us exemplifies such resourcefulness, as evidenced from our interview notes:

> "I then decided to make an engine that would be able to run using the gas from farm waste. I also wanted that the waste should include anything that could burn, including cow dung, which is easily available. But I did not have any raw material to even make a model". (Raj Singh Dahiya personal interview)

Following a series of experiments, he was finally successful at the turn of the century to build a machine able to convert biomass into gas. The unit draws on "gasification technology" that allows to produce gas from bio-waste. The machine is simple and designed to be built by using easily available material. The gasifier is conical in shape, compact in design and surrounded by a water jacket with the capability to handle multiple fuel sources.

RD's innovation can produce 1 kilowatt power from 1 kilo of bio-waste, with the machine capable of running an engine for an hour. His innovation has had a transformative impact on his community and beyond, with the machine now used to light up houses, run water pumps, saw mills, flour mills, and indeed just about any type of machine. What is also remarkable is the environmental impact of the innovation. RD's gasifier can use as an input any type of biomass waste that is typically found in most Indian villages. Thus, his machine can run on cow dung, sugar cane leftovers and all other types of agricultural waste, as he confirmed to us:

> "Any agricultural bio-waste can be used in my machine—cotton waste; coconut shells; any agricultural waste; rice husk, mustard waste; bamboo". (Raj Singh Dahiya personal interview)

Thus, not only is the machine itself non-polluting, but has also resolved a problem of recycle of agricultural waste in rural communities. Overall, the returns to the farmer turn out to be very significant, especially when compared, for instance, to a "10 kw diesel generator (which) would cost Rs 40,000–80,000. While the cost may be lesser, it requires 4 litres of diesel to run an engine for an hour, a bio-gasifier uses 12.5 kg of farm waste. If you use it for 5 h in a day, you end up spending 20 litres of petrol, while you use only 60 kg of waste from the backyard [126]". Moreover, as RD reported to us:

> "Considering the cost of the machine, fuel-biomass and local labour, this arrangement is estimated to cost less than half the cost per unit power when compared to normal electricity grids costing 4 Rs per unit". (Raj Singh Dahiya personal interview)

With regards to environmental sustainability, RD is not satisfied, however, as he narrated that there is still more energy being produced that can be captured. Trying to resolve this is now his new

challenge. His challenge now is to eliminate the loss of potential energy from the current "wastage" of 2% of biomass that is used as fuel, but does not get burnt.

Besides a lot of media attention, his innovation has been met with a very strong demand, not only from farmers, but even from some schools and universities in India. He has sold a machine even to a client in Germany. Summing up, along the three dimensions, we find:

- Frugal innovation: The machine, as RD claims and verified by experts including those consulted by the NIF, is very simple. RD demonstrated its ease of use, and emphasized that he could teach anyone to use the machine in a matter of minutes. The similarity of the machine, which looks as a cross between a tractor and odd farm equipment, means that farmers can easily relate with the gasifier.
- Socially-driven innovation: RD's primary concern was to deliver to the farmers in his community a reliable source of clean energy provided by a familiar tractor-shaped machine. Despite the local success and the diffusion of the design to other regions, as another example of grassroots innovation, RD's machine was not the result of formally planned R&D activity but rather the response to local social needs.
- Sustainability-driven innovation: Gasifiers technology minimizes pollution in comparison with diesels or gasoline engines and is a very good alternative to the conventional source of energy used in the rural parts of India. Importantly too, all agricultural waste is used as an input, substantially reducing user costs, lowering pollution and encouraging practices of recycling.

5. Discussion

5.1. The Three Dimensions of the Grassroots Sustainability Phenomenon

Our analysis points out to *grassroots innovators* who endeavour to create value across a wide spectrum. In particular, the grassroots phenomenon appears to emerge at the intersection of three theoretical dimensions (Figure 2) that we had earlier discussed in Section 2. The first dimension is a process of "frugal innovation", *i.e.*, the search for simple but effective solutions to deliver affordable products/services. This process is triggered by a bricolage attitude that enables the combination of pre-existing technology (e.g., gasification or biogas technology) with the capacity of the innovators to understand—or to "sense"—the surrounding context. Moreover, as already documented in previous studies, the cases reveal that the acute scarcity of resources did not prevent people from being innovative, but rather promoted scarcity-driven innovation based on inventing or attributing new functions to everyday objects. Nevertheless, the cases appears substantially distant from the makeshift improvisation that characterises the rhetoric of Jugaad in India. As Joshi *et al.* [112,113] had observed, grassroots agents usually pursue value in their innovation by a systematic process of trial and error where little is left for improvisation.

A second broader aggregate dimension emerging from the data is the social commitment that underpins all grassroots activities. The informants are consistently motivated by the urgency to ameliorate the economic condition in their surrounding communities, and an aspiration to empower social minorities such as women, children, small groups of workers, and the like. In the four cases analysed here—as well as in the burgeoning literature on the topic—the social dimension is not an accessory feature but the actual engine of grassroots action. This feature, which seems to characterise the phenomenon across geographical and cultural boundaries [13], reveals that grassroots innovation cannot be easily framed within the boundaries of market-economy that is dominated by profit-seekers individuals. On the contrary, the "social nature" of the grassroots may potentially open up the debate of alternative—possibly more sustainable—forms of organising production and consumption vis-à-vis the business-as-usual paradigm that dominates the economies of the "developed world".

Finally, a third aggregate dimension reveals the intentions of the informants to deliver eco-friendly solutions usually framed in terms of artefacts that provide either direct environmental benefits, or indirectly from minimal energy consumption. On the other hand, from the data collected it

emerges that this approach is far from being planned and formalised in terms of static structures or routines, but rather is similar to what was observed by Belz & Binder [127], in that it was shaped by cultural and local contingencies. In other words, in most of the cases, the sustainability and the economic goals appear to spring naturally from the desire of the innovator to improve the daily life of their communities.

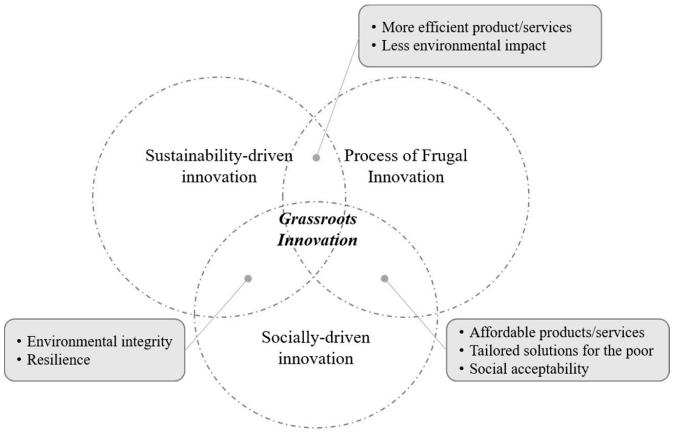

Figure 2. Analysis of the intersection of the aggregate theoretical dimensions.

In short, grassroots innovations aim at reducing production costs, enhance productivity, aspire to increase household income and, above all, are usually *normative-driven*, *i.e.*, they represent the desire to empower users by leveraging, at the same time, a discourse of environmental sustainability. *The grassroots* thus might be easily framed within the boundaries of a *triple bottom line approach, i.e.*, the harmonic combination of economic, social and environmental goals [128]. At the same time, the intersection of these three dimensions provides room for three distinct areas of interaction (see Figure 2):

(i) Frugal innovation driven by a normative framework: The values and motives underpinning grassroots innovation are at the core of innovators' action. Rather than enacting as a *homo economicus*, *i.e.*, seeking utility maximization, the grassroots innovator aspires to solve problems that are inherently social. Under resource-constrained condition, the outcome of those actions in terms of products/services are usually shaped by a process of frugal innovation, *i.e.*, a minimum use of raw material, energy, waste. The intersection of the normative and frugal dimensions produces affordable products/services that usually are tailored to the specific features of their users and are more socially accepted.

(ii) Sustainability-driven innovation guided by a normative framework: The normative framework that shapes the process of frugal innovation also inspires the development of "sustainable solutions", *i.e.*, technologies with low environmental impact. The main scope of this synergy is the will to preserve the (social and environmental) integrity of the community and to reinforce a mechanism of resilience through endogenous and, as a consequence, autonomous solutions.

(iii) Sustainability-driven frugal innovation: The desire to generate solutions designed to minimise the impact on the environment combined with the scarcity of material and financial resources leads to the development of more energy/material efficient solutions. This process occurs by drawing on pre-existing traditional knowledge [25] or by readapting "obsolete" imported technology (e.g., gasification).

In conclusion, the intersections of the three dimension described above have an important common characteristic. The process is always accompanied by the *production of new knowledge* about user needs and behaviour, new ways of using old and new technology and new business strategies. In the process that characterises the genesis, adoption and diffusion of grassroots innovation, new knowledge is produced. In 20 years of activity, Grameen Shakti people not only delivered new technological artefacts

and construction techniques but also accumulated valuable knowledge about the users' habits that have been crucial in the diffusion of the biodigesters. AM's experience encouraged more research on women's hygiene conditions in rural India and stimulated experimentation with alternative natural fibres to manufacture sanitary pads. MP and RD contributed to the field of energy and mechanical engineering with new designs and new applications of pre-existing technology. The new knowledge produced in each of the cases can be potentially exploited to build on the technical and commercial solutions already in place or to inspire other forms of innovation somewhere else, *i.e.*, the next village, region or country (*multidirectionality* of grassroots innovation).

5.2. Relevance of Grassroots Innovators for the SDGs Agenda

Furthermore, the cases analysed fit, to different degrees, into the framework of the SDGs. Table 3 compares the SDGs as proposed in the UN Open Working Group [16] with the cases analysed above. A part from the direct implications of grassroots mobilization—both in the technological and social spheres—for the SDGs, the phenomenon presents several challenges in terms of innovation and development policy. While we have no intention to be exhaustive, we suggest a few such challenges:

(i) As we discussed above, grassroots innovation implies the creation of new knowledge that is usually very different from the knowledge produced in formal laboratories [68,90]. Since its relevance for the global/local sustainability, translating the SDGs agenda into real policy would probably require new institutional tools to understand and exploit "grassroots knowledge" [65]. The practical consequences of this process are uncertain and likely to be contested. The inclusion of grassroots agenda into the mainstream policy at the local/regional level would question the legitimacy of the top-down—often technocratic in nature—essence that still characterises a vast majority of development interventions in the South.

(ii) Grassroots innovation might be a valuable and costless mechanism of adaptation and mitigation to climate change (see also [66,89,129]). How can this potential be exploited? The practical consequences of a functioning synergy between formal Research & Development and grassroots knowledge have been only partially explored and more research is needed to make it operational [68].

(iii) Finally, beyond the individual cases of ingenuity, grassroots movements are a call for local autonomy and self-management [89]. Their aspirations go beyond the development of affordable products for poor people and far beyond the narrow narrative of poor-as-consumers of the BOP literature. Many grassroots movements in the North [64] and in the South [130] aspire to overturn the social structures and power relations. This forms the basis for the major global challenges, e.g., soaring inequality, environmental justice, asymmetric trade agreements, centralised energy systems *etc.* On the other hand, it is not clear how to embed those legitimate claims into the formal institutions that will be in charge of deploying the SDGs. Opening up such a discussion within the wider debate of the SDGs, we argue, would be extremely relevant for the future of sustainability.

5.3. Limitations of the Study

Our research has some limitations, one being that while a *grounded theory approach* proved to be crucial to capture the nuances of discourse and practices of the grassroots ecopreneurs, the context limits the objectivity of data. Moreover, the duration of data collection did not enable us to develop a more longitudinal and richer perspective enabled by temporal data. Studies such as ours, also by their nature, are based on the informants' narrative, field inspections and secondary sources. So far, the inexistence of objective data on actual social and environmental benefits means that is hard to verify some of the benefits. A clear distinction between the claims and the real impacts—economic, social and environmental—is problematic, as is usual in such cases. However, we consider that this kind of analysis and assessment is fundamental to formulate stronger and more robust statements about the real potential of grassroots entrepreneurship in terms of sustainability goals.

Table 3. Case studies fit into the sustainable development goals.

SDG	*1. End Poverty in All Its Forms Everywhere*	*2. End Hunger, Achieve Food Security and Improved Nutrition and Promote Sustainable Agriculture*	*3. Ensure Healthy Lives and Promote Well-Being for All at All Ages*	*4. Ensure Inclusive and Equitable Quality Education and Promote Lifelong Learning Opportunities for All*	*5. Achieve Gender Equality and Empower All Women and Girls*	*6. Ensure Availability and Sustainable Management of Water and Sanitation for All*	*7. Ensure Access to Affordable, Reliable, Sustainable and modern Energy for All*	*8. Promote Sustained, Inclusive and Sustainable Economic Growth, Full and Productive Employment and Decent Work for All*	*9. Build Resilient Infrastructure, Promote Inclusive and Sustainable Industrialization and Foster Innovation*
Case 1: GS	Potential to increase income of farmers	Biogas promotes agro-ecology	Biogas reduces kerosene fumes in households	NA	NA	NA	Improve access to clean energy	Potentially create jobs in renewable energy sector	Present digester design can be further developed into more efficient models
Case 2: AM	Potential to increase income of women organised in SHGs	NA	Improve women health condition	NA	Empower women in rural areas	NA	NA	Promote dignified work for rural women	The case can possible inspire new innovation in natural fibres
Case 3: MP	Potential to increase income of farmers	Improve eco-efficiency of local agriculture	Improve working condition of farmers	Reduce working hours of kids	NA	NA	NA	Improve eco-efficiency of agriculture and produce dignified jobs	Locally built machines for deshelling represent a more efficient alternative to foreign technology
Case 4: RD	Potential to increase income of farmers	Improve eco-efficiency of local agriculture	Improve agriculture waste disposal	NA	NA	NA	Improve access to cleaner energy	Improve eco-efficiency of agriculture	Locally built machines for gasification represent a more efficient alternative to foreign technology

Table 3. *Cont.*

SDG	*10. Reduce Inequality within and among Countries*	*11. Make Cities and Human Settlements Inclusive, Safe, Resilient and Sustainable*	*12. Ensure Sustainable Consumption and Production Patterns*	*13. Take Urgent Action to Combat Climate Change and Its Impacts*	*14. Conserve and Sustainably Use the Oceans, Seas and Marine Resources for Sustainable Development*	*15. Protect, Restore and Promote Sustainable Use of Terrestrial Ecosystems, Sustainably Manage Forests, Combat Desertification, and Halt and Reverse Land Degradation and Halt Biodiversity Loss*	*16. Promote Peaceful and Inclusive Societies for Sustainable Development, Provide Access to Justice for All and Build Effective, Accountable and Inclusive Institutions at All Levels*	*17. Strengthen the Means of Implementation and Revitalize the Global Partnership for Sustainable Development*
Case 1: GS	NA	Biogas is a cleaner alternatives to fossil fuels in rural communities	Recycle of dropping into biogas and manure promotes sustainable consumption	NA	NA	NA	NA	
Case 2: AM	NA	NA	AM's sanitary pad are a local low-carbon alternative to industrial pads	NA	NA	NA	Empower rural women in marginalised communities	NA
Case 3: MP	NA	NA	Improve sustainability of cotton value-chain	NA	NA	NA	NA	NA
Case 4: RD	NA	Improve eco-efficiency of local agriculture by re-using agricultural by-products	Optimise local agriculture by re-using agricultural by-products	NA	NA	NA	NA	NA

5.4. Conclusion and Future Research

This research makes at least three contributions. *First*, our study provides a clear theoretical distinction among three different narratives of innovation at the BOP (*i.e.*, poor-as-consumers, poor-as-co-producers and poor-as-innovators) and documented empirical examinations of the innovation process of grassroots innovations *from and for the poor*. As illustrated earlier, BOP literature has mainly focused on framing the "poor as recipients or co-producers of innovations". This analysis aspires to increase the still scarce extant knowledge about an emerging third wave of BOP studies, *i.e.*, the poor as entrepreneurs/innovators. *Second*, the data presented in this paper suggest that the process of innovation at the grassroots encompasses characteristics that are very similar to those of the *bricoleurs* in the more developed countries associated with a strong social commitment. This, combined with the discourse of environmental conservation and energy-efficient production, makes grassroots innovators a very relevant potential beneficiary and/or participants of initiatives inspired by the SDGs. Finally, we locate the activity of the grassroots innovators within the wider debate of sustainable development. In this paper, we argue that they may contribute to global sustainability for two main reasons: first, their innovation processes are "frugal", *i.e.*, more energy/material efficient; second, they promote horizontal (and probably more democratic) mechanisms of managing technology and delivering products and services. At the same time, it is worth acknowledging that the economic performance of grassroots innovations remains elusive [13]. This is, at least partly, the reason why grassroots movements have been largely neglected by policy makers and academic scholars. As some author has already noticed [65,90], mainstream science and technology policy is often framed almost exclusively within the ideological borders of market economy that favours resource-intensive technologies, centralised production and economic growth over low-carbon and decentralised production of energy and consumption goods. The grassroots phenomenon challenges this paradigm and hardly fits with assessments by financial indicators—and same intellectual arsenal—used to evaluate mainstream innovation. However, exactly for this reason, grassroots movements represent a valuable contribution to the SDGs. According to its proponents, a green transition would urgently require new development models, new technology and new knowledge. Paraphrasing Fressoli [90], this change is unlikely to be carried out by science and technology institutions that are still dominated by a logic and a cognitive framework originated during the 2nd industrial revolution, *i.e.*, a strong dependency on natural resources *extractivism* and large centralised technological systems. By the collaborative creation of new knowledge based on local contingencies, the strategy of open participation and the exploration of technological (but also social) alternatives, grassroots movements might counterbalance a growing "green economy" paradigm that risks being monopolised by big business. The integration of grassroots movements in the decision making process regarding the kinds of sustainable development we as a society want could be a crucial source of diversity to reinvigorate the democratic basis of the debate about transition. The business-as-usual paradigm is today changing towards a green transformation driven by world business elites [131]. Grassroots movements suggest this is not going to be uncontested, and as the cases we illustrated testify, this process is likely to be accompanied by a multiple, anarchic and messier exploration of everyday sustainability solutions. These solutions are crafted at the grassroots level, by actors who are often ignored in the analysis of the protagonists towards sustainability goals. While it is ambitious to think that grassroots ecopreneurs such as the ones analysed in our study would lead a global sustainable transition, it remains important nevertheless to consider their actual and potential contribution. We therefore urge for more research both internationally as well as for a longer time frame, on these silent, global, grassroots actors, so that their motivations, processes and outcomes can be better understood. Policy measures could then be built to incorporate grassroots entrepreneurs when thinking of sustainability.

Acknowledgments: We thank three anonymous reviewers for their comments and suggestions of an earlier version of the paper. Mario Pansera thanks the financial support of Marie Skłodowska-Curie People Action programme of the EU. Soumodip Sarkar gratefully acknowledges financial support received from the Portuguese Science Foundation- FCT and FEDER/COMPETE (grant PEst-C/EGE/UI4007/2013).

Author Contributions: Both the authors contributed equally to do the research and write the paper.

Conflicts of Interest: The authors declare no conflict of interest.

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